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REVIEW ARTICLE

The nexus between indicators for sustainable transportation: a systematic literature review

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Abstract
The relationship between indicators for sustainable transportation is a pressing issue that has argued the attention of policymakers, engineers, and academics. The transportation sector plays a crucial role in economic growth, while also having significant environmental consequences. This systematic literature review offers a comprehensive overview of the different research methodologies utilized to estimate the interrelationships between the transport sector, environmental degradation, and economic growth. Our study analyzed 977 citations sourced from Web of Science and SCOPUS, spanning the years 2010 to June 2022. The PRISMA methodology was employed for organizing and identifying articles. After a thorough evaluation, 52 published articles from 25 international journals were selected for further examination. Our findings show that researchers have used a variety of modeling approaches to shed light on this complex issue, with multivariate co-integration techniques, decomposition analysis, and the generalized method of moments being among the most widely used methods in recent years. This review provides perspectives to policymakers and decision-makers, enabling them to create effective energy and environmental strategies for a long-term, sustainable transportation future.

Keywords Economic growth · Environmental degradation · Indicators for sustainable transportation · Sustainable transportation · Systematic literature review

Abbreviations

ARDL	Autoregressive distributed lag
EC	Energy consumption
EKC	Environmental Kuznets Curve
FMOLS	Fully modified ordinary least square
FP	Fuel price
FT	Freight transport
GDP	Gross domestic product
GHG	Greenhouse gases
GMM	Generalized method of moments
LMDI	Logarithmic mean divisia index
MENA	Middle East and north Africa
RI	Road infrastructure
SLR	Systematic literature review
TCO2	Transport carbon dioxide emissions
TEC	Transport energy consumption
TVA	Transport value added
OECD	Organization for economic co-operation and development
VAR	Vector autoregressive
VECM	Vector error correction model

Introduction

The relationship between transportation and economic growth is a crucial topic that has received substantial attention in recent economic literature. Transportation is vital for the development of all sectors of the economy because it facilitates the mobility of people and goods (Wang and Wang 2019). Several empirical studies highlight the positive impact of the transportation sector on economic growth and its essential role in facilitating economic activity.

Yeaple and Golub (2007), Liddle (2009), Marazzo et al. (2010), Chi and Baek (2013), Pradhan and Bagchi (2013),

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Gao et al. (2015), Hakim and Merkert (2016), Anam et al. (2016), Maparu and Mazumder (2017), Moschovou (2017), Ibrahiem (2018), Park et al. (2019), and Mudronja et al. (2020) demonstrate that the transportation sector has a beneficial impact on economic activity and contributes to the advancement of nations. Additionally, these studies also show that private businesses make decisions to cluster or disperse based on the relationship between transportation costs and increasing returns to scale, which affects regional economic growth. According to Hausmann (2001), international transportation infrastructure plays a crucial role in promoting the openness of international trade and driving the economic development of nations. The author notes that landlocked countries face limited access to global markets, which severely constrains their economic growth.

Unfortunately, the transportation sector consumes a substantial amount of non-renewable energy. The transportation sector primarily relies on the utilization of fossil fuels such as oil and gas, which release considerable quantities of greenhouse gases (GHGs) and contribute significantly to the acceleration of climate change (Timilsina and Shrestha 2009; Saboori et al. 2014; Cetin 2016a; Luo et al. 2017; Han et al. 2018; Andrés and Padilla 2018; Teixeira and Sodré 2018; Solaymani 2019; Zhu and Gao 2019; Li and Solaymani 2021; Scheelhaase et al. 2021; Chen et al. 2022; Yao et al. 2023).

The negative effects of environmental deterioration are becoming more and more apparent in the form of pollutants that are found in the ambient air. The combustion of fossil fuels generates a wide variety of air pollutants, including carbon dioxide (CO_2) and nitrogen dioxide (NO_2), which exacerbate the impact of GHGs and contribute to the acceleration of global warming. These CO_2 emissions resulting from the combustion of fossil fuels, which are caused by a wide range of economic activities, constitute a significant factor in the acceleration of global warming. The increased number of vehicles on roads raises the demand for energy, which in turn stimulates economic growth. Nevertheless, the intensive use of fossil fuels leads to substantial GHG emissions.

It is crucial to consider the broader impacts of pollutants on the environment and human health when discussing transportation-related CO2 emissions. Heavy metals, as a significant class of pollutants, pose a severe threat to ecosystems and living organisms. Certain heavy metals can be extremely detrimental to human health and other forms of life (Cevik Degerli and Cetin 2023; Sharma et al. 2023). Numerous scholarly investigations have been conducted to examine the deleterious impacts of heavy metals and their levels in various environmental conditions (Bozdogan Sert et al. 2019; Cetin et al. 2020; Ucun Ozel et al. 2020; Pekkan et al. 2021; Cesur et al. 2021; Cetin et al. 2022a, 2022b, 2022c; Cesur et al. 2022; Cicek et al. 2022; Cetin and Jawed 2022; Bilge Ozturk et al. 2022; Cicek et al. 2023; Cevik Degerli and Cetin 2023; Cetin and Abo Aisha 2023). The presence of heavy metals can be indirectly linked to vehicle emissions and pollution.

These pollutants have adverse impacts on the sustainability of a state's overall progress and pose a potential threat to the planet (Shahbaz et al. 2018). Global carbon emissions have more than doubled since 1973, rising from 15 billion tons to 32 billion tons in 2015. Energy-related CO_2 emissions worldwide increased from 32,294 million tons in 2015 to 33,143 million tons in 2018 (Energy 2019). The proliferation of vehicles on roads is a contributing factor to the increase in emissions, with an estimated 1.2 billion automobiles worldwide consuming approximately 13.5 billion barrels of petroleum fuels each year.

Projections suggested that worldwide CO_2 emissions will increase by 50% in 2030 and 80% in 2050, driven by the growing demand for energy and the increasing number of automobiles on roads (Statistics 2017). Consequently, it is essential to adopt more stringent environmental regulations and policies to decouple the strong connection between transportation intensity and CO2 emissions (Ben Abdallah et al. 2013; Cetin 2015; Solaymani et al. 2015; Cetin 2016b; Soto et al. 2018).

Promotion of clean energy use and limiting pollutant emissions are necessary to encourage environmental protection. Accordingly, the correlation between the transportation sector, economic development, and environmental quality has been the subject of academic debate and study across many countries for a long time. The dynamic connection based on the economic activity, environment, and transport sector nexus was the subject of conflicting and paradoxical goals among policymakers.

In order to comprehensively understand the topic of sustainability in the transportation sector, it was found that a suitable approach for this investigation would be the systematic literature review (SLR), due to its capacity to ensure the inclusion of all pertinent literature within a particular research domain. Moreover, this methodology is a precise, systematic, comprehensive, reliable, and rigorous approach for analyzing, evaluating, and reporting results from a chosen body of literature (Senivongse et al. 2017; Martín-Navarro et al. 2018). It was employed for the purpose of investigating various sustainability concerns pertaining to transportation.

By using this methodology, this paper gives an overview of the econometric methods applied in examining the nexus between CO2 emissions, economic activity, and the transportation sector, from both specific- and multi-country studies. Therefore, the findings of this study can be considered effective in examining the associations among the analyzed variables, encouraging discussion about the implementation of suitable measures to mitigate CO2 emissions.

The selection of the SLR was based on its extensive scholarly acceptance in the fields of management, medicine, social sciences, and engineering. It has been utilized in various studies including the following: Centobelli et al. (2017), Hegetschweiler et al. (2017), Cheng et al. (2018), Boulton et al. (2018), Gardon et al. (2020), Lavissière et al. (2020), Aloui et al. (2021), Kim et al. (2021), Emodi et al. (2022), Syaifullah et al. (2022), Ravensbergen et al. (2022), and Bao et al. (2023). The benefits of a systematic review are argued to improve the reflection of reality and reduce bias (Mulrow 1994).

In our study, we make several contributions to the field of sustainable transportation indicators. Firstly, we conduct a SLR that encompasses a wide range of sources, including peer-reviewed articles. This approach ensures the comprehensiveness and rigor of our study by considering diverse perspectives and insights from the existing body of literature. Secondly, our study addresses a gap in the literature by focusing specifically on the interrelationships between different indicators for sustainable transportation. By examining the relationships among various indicators, we contribute to a more holistic understanding of their collective impact on sustainability. This analysis provides valuable insights into the complex interactions between various dimensions of sustainable transportation. Lastly, our study offers practical implications for policymakers, researchers, and practitioners involved in sustainable transportation planning and decision-making.

The rest of this work is structured as follows. The linkage between transportation, CO_2 emissions, and economic growth is presented in the second section. The third section discusses the review methodology. The fourth section provides a descriptive analysis of the chosen articles. The fifth section discusses the main econometric models observed in existing work. The sixth section presents sustainable transport policies. The final section highlights the conclusions and policy implications.

Literature review

Nexus between transport sector and economic growth

In recent years, intense competition in the business world has driven the adoption of modern production methods such as lean production and just in time. The use of these methods can enhance a company's competitiveness. As a result, investors recognize the importance of transport punctuality and regularity as crucial factor for business success. A large body of research in the literature has examined a strong causal link between transportation and economic growth (Mraihi 2012; Pradhan and Bagchi 2013; Beyzatlar et al. 2014; Lee and Yoo 2016; Shi et al. 2016; Mohmand et al. 2017; Sun and Cui 2018; Tong and Yu 2018; Shafique et al. 2020; Zhu et al. 2021; Dai et al. 2023; Liu et al. 2023).

Yeaple and Golub (2007) used a three-stage least squares estimation to evaluate the impact of road infrastructure on total factor productivity in 18 nations and 10 manufacturing industries. Their research focused on the period between 1979 and 1997. The results of this study indicated that road infrastructure has a substantial effect on productivity across multiple industries.

In the case of India, Pradhan (2010) investigated the relationship between energy use, economic activity, and transport infrastructure from 1970 to 2007. The outcomes showed a unidirectional causality relationship running from transportation infrastructure to economic activity. Additionally, Pradhan and Bagchi (2013) employed the vector error correction model (VECM) to analyze the impact of transportation infrastructure on economic development in India from 1970 to 2010. They found bidirectional causality between road transport and capital formation, as well as between economic development and road transport. Additionally, they discovered a unidirectional causality from rail transportation to gross domestic product (GDP).

For the case of Iran, Bahrami (2012) used the Toda and Yamamoto methods to examine the nexus between economic growth and investment in the transportation sector from 1963 to 2009. They discovered a unidirectional causality running from transportation investment to economic growth. In the USA, Sharif et al. (2019) identified a strong correlation between transportation services and economic prosperity. Meersman and Nazemzadeh (2017) used error correction models, aggregate growth modeling, and causality tests to analyze the effect of transport infrastructure on economic development in Belgium from 1970 to 2012. Their findings suggest that investments in highways, railways, the overall investment rate, and the level of economic openness positively influence economic growth in both the short and long term. Port investments were found to have the potential to enhance economic growth, but only in the long term.

For the case of the EU-28 countries, Gherghina et al. (2018) determined that all kinds of transportation infrastructure have a positive impact on economic development, except railway transport. Pradhan (2019) used a VECM to discuss the nexus between economic activity and transportation infrastructure in the G-20 countries from 1961 to 2016. They found that transportation infrastructure contributes to economic activity.

For the case of China, Guo et al. (2011) used vector autoregression (VAR) approaches to study the relationship between traffic facilities (railway and highway mileage) and GDP for the period 1964–2004. The outcomes show that the selected variables are cointegrated, with both negative and positive contributions of highway and railway investments to GDP respectively. Yu et al. (2012) investigate the impact of transportation infrastructure investment and economic growth in China. The data was collected from 28 provinces and municipalities over the period of 1978–2008. The outcomes highlighted a positive correlation between transportation investment and economic growth, with the central regions of China exhibiting the highest economic outputs. Tong and Yu (2018) studied the correlation between freight transport (FT) and economic growth. They discovered a bi-directional causality between them in the underdeveloped central and western zones.

Listiono (2018) used the simultaneous equation model to examine the interconnection between FT and economic growth in 90 countries between 1980 and 2014. The author found evidence of a bi-directional relationship between economic development and cargo transport in both high-income and low-income countries. In South Asia, Hakim and Merkert (2016) used panel data from 1973 to 2014 to analyze the association between economic growth and air transportation. The findings revealed a unidirectional causality running from GDP to air transportation in the long run for both passenger traffic and freight volumes. In Mexico, Brida et al. (2016a) explored the correlation between air transportation and economic growth using non-parametric cointegration and non-parametric causality tests. The study, covering the period 1995–2013, found evidence of a bidirectional causality between economic growth and air transportation.

Brida et al. (2016b) conducted a similar study in Italy to analyze the nexus between economic growth and air transportation, using time series data from 1970 to 2012. The study applied Johansen cointegration causality approaches and found evidence that air transportation causes economic growth. Joignaux and Verny (2004) investigated the relationship between economic activity and transportation in France and determined that the expanding distance of transportation was a key indicator. Samimi (1995), in Australia, analyzed the cointegrating link between road transportation demand and other macroeconomic variables.

Nexus between the transport sector and environmental degradation

The transportation industry is a major consumer of global energy, with a significant portion of petroleum being burned for transportation, leading to the emission of carbon dioxide and other GHG. These emissions have a significant impact on the environment and contribute to climate change. In the near future, an increase in energy consumption (EC) and FT by approximately 120% and 50% respectively, is expected, which would result in a further increase in GHG emissions. To address the environmental impact of transportation, global policy initiatives are aimed at reducing reliance on fossil fuels and increasing the efficiency of alternative energy sources (Raza and Lin 2020).

To reduce transportation-related carbon dioxide and other pollution emissions, sustainable policies and practices are necessary to promote environmental benefits in the transportation sector (Shen and Feng 2020; Scheelhaase et al. 2021; Li and Solaymani 2021; Erdogan et al. 2022; Tanveer et al. 2023; Kwakwa et al. 2023). In recent years, numerous academics have highlighted the interaction between environmental deterioration and transport. For the case of Canada, Steenhof et al. (2006) used decomposition analysis to examine the factors contributing to GHG emissions from FT through the analysis of energy intensity. Brown-Steiner et al. (2016) evaluated the contribution of rail and truck transportation to CO_2 emissions in the Midwestern and Northeastern regions of the USA. They found that transportation was responsible for 28% of total energy consumption and 26% of carbon emissions in the USA.

Umar et al. (2021) examined the impact of the consumption of biomass and fossil fuel energy on CO_2 emissions from transportation and determined that the use of fossil fuel energy significantly impacts CO_2 emissions. Moreover, they found a negative relationship between the consumption of biomass and CO_2 emissions. According to the findings of Shafique et al. (2020), FT was found to be the primary source of CO_2 emissions in both Hong Kong and Singapore. Kinnear et al. (2015) evaluated the effect of heavy-duty vehicles on CO_2 emissions in the Austrian transport sector.

For the case of Spain, Cardenete and López-Cabaco (2021) showed that FT was responsible for around 30% of the total CO_2 emissions generated by all kinds of transportation. For the case of the Western European Union nations, González et al. (2019) examined the primary contributors to CO_2 emissions over the period 1990–2015. They applied an alternative economic method to estimate a dynamic panel data model and concluded that road transportation is directly responsible for 92% of carbon dioxide emissions.

For the case of 12 EU countries, Georgatzi et al. (2020) investigated the key determinants of carbon dioxide emissions associated with the transportation sector for the period 1994–2014. Using various econometric approaches, they concluded that the transportation sector had a significant impact on total CO_2 emissions. For the case of Thailand, Ratanavaraha and Jomnonkwao (2015) investigated the CO_2 emissions generated by the transportation sector using several econometric techniques, including path analysis, log-linear regression, curve estimation, and an autoregressive integrated moving average linear model. The results revealed a direct relationship between the number of registered vehicles with a large size and the increase in CO_2 levels. The authors emphasized the importance of prioritizing the use of clean and renewable energy sources in the transportation industry.

In the case of Organization for Economic Co-operation and Development (OECD) countries, Neves et al. (2017) looked at the connection between CO_2 emissions and energy consumption in the transportation sector using an autoregressive distributive lag (ARDL) approach. The results showed that the use of fossil fuels in the transportation sector has contributed to the rise in CO_2 emissions. For the same sample country, Churchill et al. (2021) investigated the impact of transportation infrastructure development on CO_2 emissions from 1870 to 2014. Using both parametric and non-parametric approaches, the results found that a 1% increase in transportation infrastructure corresponds to a 0.4% rise in CO_2 emissions.

Tongwane et al. (2015) evaluated the influence of road transportation on GHG emissions in South Africa and Lesotho between 2000 and 2009. The study's empirical results showed an annual increase of 2.6% in road transport emissions in South Africa and 2.5% in Lesotho. Krantz (2017) determined that the growth of transportation infrastructure in Sweden was responsible for 30% of the country's annual CO_2 emissions. Hussain et al. (2020) confirmed a negative relationship between the potential for global warming and transportation infrastructure while development infrastructure is a major contributor of GHG and carbon dioxide emissions.

Timilsina and Shrestha (2009) analyzed the major factors contributing to CO_2 emissions in Asian countries and found that the transportation sector's energy consumption was the largest contributor to carbon emissions. Tian et al. (2014) examined CO_2 emissions from multiple modes of transportation and potential mitigation strategies in China's transportation industry.

Li et al. (2017) investigated the association between CO_2 emissions and various forms of transport in China over the period of 1985–2013 using VECM and ARDL methods. The authors discovered that the railway was found to have a positive effect on environmental degradation in the short-run, but railway expansion was shown to decrease CO_2 emissions in the long term.

Nasreen et al. (2020) examined the impact of transport energy consumption on environmental quality in 18 Asian countries. The results showed a correlation between an increase in transport energy consumption and a decline in environmental quality. Saidi and Hammami (2017) demonstrated, using a sample of 75 countries, the existence of a unidirectional causal relationship between the transportation sector and environmental degradation.

For the case of Tunisia, Ben Abdallah et al. (2013) established the presence of a bidirectional causal relationship between CO_2 emissions and the transport sector, suggesting that both CO_2 emissions influence the transport sector and transportation results in CO_2 emissions. Similar findings were reported by Shahbaz et al. (2015) and Talbi (2017). Abbes and Bulteau (2018) examined the correlation between motorization as a measure of transportation and carbon emissions. The study concluded that an increase in motorization results in a rise in carbon emissions in Tunisia.

Nexus between economic growth and CO_2 emissions

The correlation between economic development and environmental pollution has been extensively studied in various studies (Panayotou 1997; De Bruyn et al. 1998; Roca and Alcántara 2001; Jalil and Mahmud 2009; Lamla 2009; Shahbaz et al. 2012; Zaman et al. 2016; Sarkodie and Strezov 2018; Shahbaz and Sinha 2019; Li et al. 2023; Ayhan et al. 2023). The environmental Kuznets curve (EKC) hypothesis, proposed by Grossman and Krueger 1991, has been widely adopted as a theoretical framework for understanding this relationship. The EKC posits that income has an inverted U-shaped relationship with pollutants, with an increase in income initially leading to an increase in pollutants and environmental degradation. However, as economic development reaches the inflection point of the EKC, pollutants decrease and environmental quality improves as income continues to rise.

The examination of the EKC has revealed a correlation between economic growth and CO_2 emissions caused by energy consumption. In the context of the environment-growth nexus, multiple studies have confirmed an inverse-U-shaped relationship between environmental quality indicators and economic production or income across several nations, as determined by the EKC model. The relationship suggests that decreasing transportation-related environmental pollutants will increase income levels, until environmental pressures start to decrease. However, the limited data on pollutant emissions in metropolitan areas has resulted in limited research focusing on the transportation sector.

Cole et al. (1997) confirmed the EKC hypothesis regarding the relationship between per capita income and local air pollutants from the transportation sector in European nations from 1970 to 1992. Additionally, Hilton and Levinson (1998) discovered a correlation between economic growth and plum emissions from transportation using the EKC model for 48 countries over a 20-year period. For the case of the USA, Tanishita and Miyoshi (2007) examined the relationship between the energy intensity of both private and public transportation and per capita Gross Regional Product from 1980 to 1995 and found support for the inverted U shape of the EKC model. In the case of California, Kahn (1998) noted that private mobility's relationship with economic growth resulted in a rise in hydrocarbon emissions from urban traffic.

Sousa et al. (2015) found a continuously increasing correlation between transport CO2 emissions and economic growth in Portugal from 1960 to 2010. Aslan et al. (2018) studied the nexus between sectoral CO2 emissions and economic growth in the United States from 1973 to 2015 using the rolling window estimation method and found evidence supporting the environmental Kuznets curve hypothesis in the residential and electrical sectors, but not in the transport sector.

Ubaidillah (2011) evaluated the EKC between per capita CO2 emissions due to road transportation and per capita GDP from 1970 to 2008. According to the author, the EKC pattern seen in the road transportation sector of the UK can be attributed to the rise in the use of private or passenger vehicles, which mirrors the growth in per capita income.

Systematic review methodology

The primary methodology employed in this study is a systematic literature review. A SLR aims to thoroughly identify and consolidate research related to a specific question, utilizing structured, transparent, and reproducible methodologies at every stage of the process (Stechemesser and Guenther 2012).

The methodology of this study consists of five steps: (i) definition of the research question and choice of keywords, (ii) definition the eligibility criteria, (iii) define sources of information, (iv) eligible scientific articles selection, and (v) discussion and synthesize of the results. The study's methodology is summarized in Fig. 1.

Identification of research questions and choice of keyword

The literature shows that the topic of SLR, as well as the research questions (RQ) must be chosen before starting the systematic review. The RQs identified by this study are listed below:

(RQ1) What are the main papers that study the relationships between transport, economic growth, and environmental degradation? (RQ2) In which journals are these papers published? (RQ3) How have these works developed over time? (RQ4) Which countries show the greatest concern for this specific topic? (RQ5) Which main research methodologies are used and what major conclusions can be deduced from these works?

The keywords for the search were identified through a scoping study and categorized into three areas of interest: "economic growth," "environmental degradation," and "sustainable transport." The search terms needed to occur in the title, abstract, or keyword list of the articles. Table 1 presents the keywords used for this search. The SLR employed Boolean logic to connect the main concepts and related terms.

(SustainableTransport OR Transport sector OR Transport infrastructure OR Road transport sectors OR Transportation OR Freight transport OR Passenger transport) AND (Economic growth OR Economic development OR Gros

Fig. 1 Systematic literature review methodology

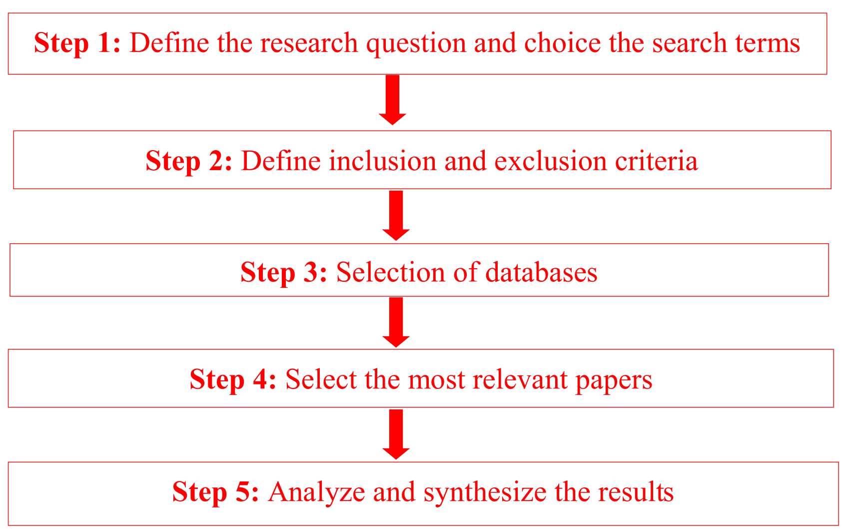

Table 1 Selected keywords and search string for this systematic research

Economic growth	Environmental degradation	Sustainable transport
Economic development	Environmental quality	Transport sector
Gross domestic product	CO_2 emissions	Transport infrastructure
Economic activity	Environmental impact	Road transport sectors
	Transport emissions	Transportation
	Carbon emissions	Freight transport
	Greenhouse gases	Passenger transport
Search string (Boolean)		

domestic product OR Economic activity) AND (Environmental degradation OR Environmental quality OR CO_2 emissions OR Transport emissions OR Carbon emissions OR Greenhouse gases OR Environmental impact)

Define the eligibility criteria

A set of eligibility criteria was created to filter the literature search and to identify the relevant articles that we would focus on. Therefore, four inclusion criteria were used: (i) peer-reviewed articles with full-text, (ii) indexed journal articles, (iii) studies published between 2010 and June 2022, (iv) articles with a clear causal nexus between transport, economic growth, and environmental degradation.

However, we have excluded in this SLR: (i) conference proceedings, articles with restricted access to full text, and no peer-reviewed journal articles, (ii) articles that were not published in English, and (iii) papers that did not investigate this specific topic.

Selection of databases

This SLR covers the period from 2010 to June 2022. The choice of scientific databases is a crucial element in conducting a comprehensive and reliable review. Two of the most significant online electronic databases have been chosen: Web of Science (WOS) and Scopus. These databases were selected due to their largest multidisciplinary and international nature, as well as their more comprehensive search tools compared to other databases (Franciosi et al. 2020)

Selection of the most relevant papers

The SLR process used in this study are detailed in Fig. 2. This SLR adhere to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Tranfield et al. 2003).

In the initial stage of the research process, a prompt examination and filtering of the bibliographic dataset were conducted. A set of exclusion criteria was applied to eliminate unsuitable articles. Overall, 210 articles were excluded during this phase. Subsequently, the second screening phase entailed a comprehensive evaluation of the abstracts, titles, and keywords associated with the bibliographic data. Publications that were determined to be irrelevant to the focal subject matter, specifically the correlation between CO2 emissions, the transport sector, and economic growth, were eliminated from consideration.

A total of 376 items were identified as falling outside the research scope and were subsequently excluded from the dataset. After this exclusion process, a literature search was

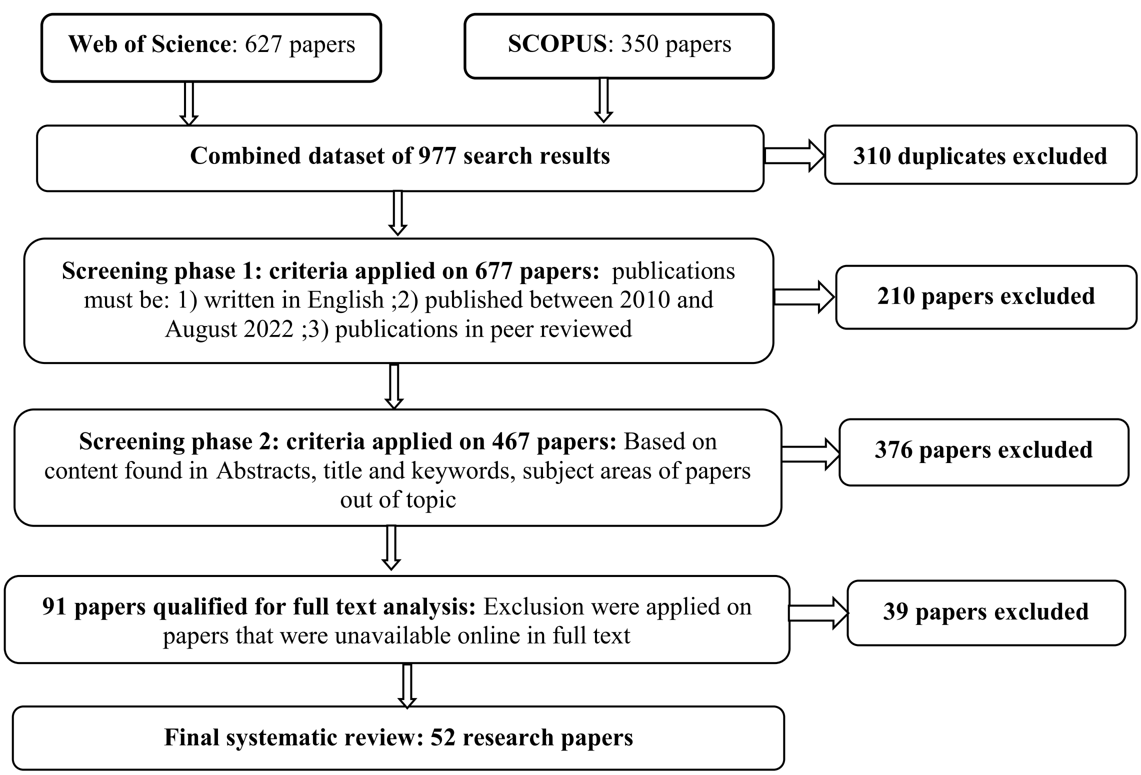

Fig. 2 The systematic literature review process. Adopted from Zieba and Johansson (2022).

conducted to retrieve the remaining 91 publications that met the criteria for comprehensive analysis.

However, it was discovered that 39 of these publications were not accessible online in full-text format, rendering them unsuitable for further examination by the authors and, consequently, excluded from further consideration. Finally, 52 published articles that met all the eligibility criteria were examined in this review.

Analysis, synthesis, and results reporting

This final step aims to analyze and synthesize the findings of the existing literature. Firstly, a descriptive study of the scientific literature was carried out in accordance with the distribution of the articles across the various journals and over time. Secondly, in line with the RQs mentioned in the first step, the reviewed studies have been classified based on the research methodology employed. The findings of the descriptive analysis in this systematic review are presented in the following section.

Results

The purpose of this section is to summarize the retained studies and examine different parameters, including year of publication, published journals, number of citations, country examined, and methodology, for a comprehensive examination of the data.

Papers per year

In this section, a distribution analysis of selected papers published between 2010 and June 2022 is conducted to examine current research trends in the area of sustainable transportation. Figure 3 illustrates the annual distribution of these studies, showing an upward trend in the number of publications, with 73% of the papers having been published since 2017.

This trend highlights the increasing attention paid to research on the causality between economic development, CO_2 emissions, and the transportation sector in recent years.

The identification of 4 papers in the first half of 2022 (7.7%) suggests continued growth in research efforts aimed at investigating the nexus between indicators for sustainable transportation. Given transportation's crucial role in economic development and planetary sustainability, this area of research is of great importance.

Most cited papers

The final sample of this literature review comprised 52 scientific articles. The research impact of these articles was evaluated through citation analysis utilizing Google Scholar (GS) (Harzing 2020). Citation analysis is a method to identify the most important and influential papers in a specific field of study. Table 2 presents the most frequently cited articles in the literature examining the nexus between transportation, economic growth, and the environment.

The highest cited paper is by Chandran and Tang (2013), which explores the complex linkages between carbon dioxide emissions, road transportation energy use, foreign direct investment, and economic growth in Southeast Asian countries including Singapore, Thailand, Malaysia, Philippines, and Indonesia. This paper was cited in 514 citations. The second most frequently cited article, Saboori et al. (2014), with 279 citations, analyzes the long-term correlations between energy consumption in the transportation sector, CO_2 emissions, and economic prosperity within the context of OECD countries.

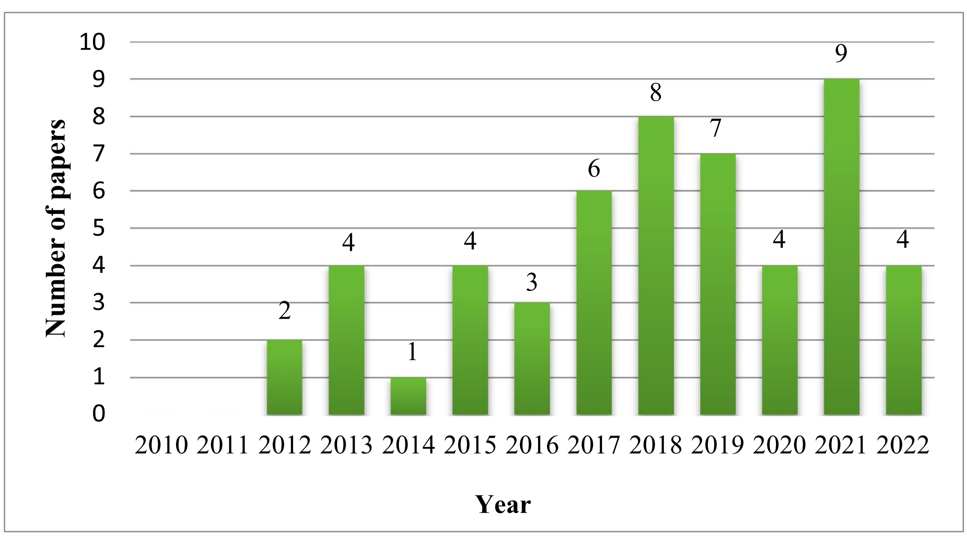

Fig. 3 Number of publications per year (2010–June 2022)

Table 2 Top 10 most-cited articles from 2010 to June 2022

Author(s)	Title	Journal name	GS*
Chandran and Tang (2013)	The impacts of transport energy consumption, foreign direct investment and income on CO_2 emissions in ASEAN-5 economies	Renewable and Sustainable Energy Reviews	514
Saboori et al. (2014)	Economic growth, energy consumption and CO_2 emissions in OECD (Organization for Economic Co-operation and Development)'s transport sector: A fully modified bi-directional relationship approach	Energy	279
Alshehry and Belloumi (2017)	Study of the environmental Kuznets curve for transport carbon dioxide emissions in Saudi Arabia.	Renewable and Sustainable Energy Reviews	168
Achour and Belloumi (2016a)	Investigating the causal relationship between transport infrastructure, transport energy consumption and economic growth in Tunisia	Renewable and Sustainable Energy Reviews	156
Arvin et al. (2015)	Transportation intensity, urbanization, economic growth, and CO_2 emissions in the G-20 countries	Utilities Policy	146
Mohsin et al. (2019)	Integrated effect of energy consumption, economic development, and population growth on CO2 based environmental degradation: a case of transport sector.	Environmental Science and Pollution Research	131
Saidi et al. (2018)	The long-run relationships between transport energy consumption, transport infrastructure, and economic growth in MENA countries.	Transportation Research Part A: Policy and Practice	129
Achour and Belloumi (2016b)	Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method	Transport Policy	119
Ben Abdallah et al. (2013)	Indicators for sustainable energy development: A multivariate cointegration and causality analysis from Tunisian road transport sector.	Renewable and Sustainable Energy Reviews	114
Shahbaz et al. (2015)	On the casual nexus of road transport CO2 emissions and macroeconomic variables in Tunisia: Evidence from combined cointegration tests	Renewable and Sustainable Energy Reviews	99

Citation details were retrieved in January. 26. 2023: * Google Scholar

Papers across journals

The final sample of the SLR comprised 52 scientific articles published in 25 academic journals from various disciplines. Table 3 lists a summary of the distribution of these articles across the journals, including the number of articles published by each journal, its h-index as obtained from the Scimago Institution Rankings, and its impact factor (IF) for the year 2021. The quality of journals is an important consideration in scientific research.

Environmental Science and Pollution Research, Renewable and Sustainable Energy Reviews, and Sustainability and Transport Policy have published the highest number of articles included in the final sample, representing 26 out of 52.

Papers by studied country

This section displays the geographic distribution of the selected articles, which are categorized as single-country studies and multi-country studies. The results indicate that China is the most frequently studied country in single-country studies, with 9 papers out of 52, due to its significant transport CO_2 emissions and the environmental impacts resulting from rapid economic development. In multi-country studies, the ASEAN and OECD countries had the highest number of published articles, each with 5. Table 4 illustrates the distribution of the reviewed papers by the analyzed regions.

Papers by research methods

The empirical methodologies most frequently used by researchers to discuss the relationship between transport activity, environmental effects, and economic growth, with the aim of developing efficient transport policies, are categorized as "multivariate co-integration techniques and Granger causality" (26 articles) and "decomposition analysis" (13 articles). The category of generalized method of moments (GMM) is represented by 6 articles, while the category of structural equation modeling (SEM) is represented by 2 articles. Models appearing only once in an

Table 3 The distribution of papers across journals

Journal name	No. of articles	Percentage	H-index in SJR*	Impact factor (IF)
Environmental Science and Pollution Research	11	21.15%	132	5.190
Renewable and Sustainable Energy Reviews	6	11.53%	337	16.799
Sustainability	5	9.61%	109	3.889
Transport Policy	4	7.70 %	103	6.173
Energy	2	3.84%	212	8.857
Transportation Research Part D: Transport and Environment	2	3.84%	113	7.041
International Journal of Sustainable Transportation	2	3.84%	46	4.066
Environmental Sustainability and Economy	2	3.84%	62	3.219
Journal of Cleaner Production	2	3.84%	232	11.072
Research in Transportation Economics	1	1.92%	52	2.904
Transportation Research Part A: Policy and Practice	1	1.92%	142	6.615
Resources, Conservation and Recycling	1	1.92%	150	13.716
International Journal of Transport Economics	1	1.92%	24	0.18
International Journal Global Energy Issues	1	1.92%	26	0.08
Journal of Environment and Sustainability	1	1.92%	19	3.219
Marine Economics and Management	1	1.92%	61	1.851
Utilities Policy	1	1.92%	54	3.247
Sustainable Cities and Society	1	1.92%	82	7.587
Natural Hazards	1	1.92%	114	3.14
Journal of Engineering Management and Competitiveness	1	1.92%	92	4.955
Environment, Development and Sustainability	1	1.92%	62	4.080
Technological Forecasting and Social Change	1	1.92%	134	10.884
International Journal of Environmental Science and Technology	1	1.92%	84	2.860
Energy Policy	1	1.92%	234	7.37
Environmental and Resources Economics	1	1.92%	98	4.49
Total	52	100%		

*Data retrieved from SJR in January. 28. 2023

article were classified under the category of "Others." Figure 4 illustrates the distribution of articles according to the research methodologies.

In the next sections, we will discuss the studies that were selected according to the primary research methodologies presented in Fig. 4.

Discussion

The 52 articles included in our SLR can be found in Table 5.

Multivariate co-integration techniques and Granger causality

The examination of the dynamic causal relationship between CO_2 emissions, transport, and economic development through the application of multivariate co-integration and Granger causality tests has revealed a significant degree of disparity among research findings. The causality between these variables may take the form of unidirectional, bidirectional, or non-existent relationships. According to Pesaran et al. (2001), ARDL models based on least squares have been demonstrated to be effective for analyzing small sample sizes and situations involving a mix of stationary and non-stationary variables in time series data (Shrestha and Bhatta 2018).

Alshehry and Belloumi (2017) employed the ARDL model and Granger causality co-integration analysis to examine the correlation between transport carbon dioxide (TCO_2) emissions, transport energy consumption (TEC), and GDP in Saudi Arabia for the period of 1971–2011. The empirical results indicate the presence of bidirectional causal relationships between TCO_2 and TEC in both the short run and the long run. However, in the long run, there exists only a unidirectional causal relationship from GDP to TCO_2 and TEC. These findings suggest that the elevated levels of road transport energy consumption in

Table 4 Published articles by studied country

References	No. of papers	Studied country	References	No. of papers	Studied country
Multi-countries		**Single-countries**			
Chandran and Tang (2013); Khan (2019); Nasreen et al. (2020); Shafique et al. (2021); Huang et al. (2021)	5	**ASEAN countries**	Li et al. (2015); Liang et al. (2017); Fan and Lei (2016); Zhang et al. (2018); Han et al. (2018); Zheng et al. (2019); Wang and wang (2019); Peng and Wu (2020) Yang et al. (2021)	9	**China**
Saboori et al. (2014); Cantos Sanchez and Gumbau Albert (2015); Neves et al. (2017); Dzator et al. (2021a); Hussain et al. (2022)	5	**OECD countries**	Mraihi et al. (2013); Ben Abdallah et al. (2013); Shahbaz et al. (2015); Daldoul and Dakhlaoui (2016); Achour and Belloumi (2016a); Achour and Belloumi (2016b); Ben Jebli and Belloumi (2017); Benali and Feki (2020)	8	**Tunisia**
Krautzberger and Wetzel (2012); Gherghina et al. (2018); Acheampong et al. (2022)	3	**EU countries**	Baloch (2018); Mohsin et al. (2019); Mohmand et al. (2021); Sharif and Tauqir (2021); Rehman et al. (2022)	5	**Pakistan**
Arvin et al. (2015); Habib et al. (2021); Habib et al. (2022)	3	**G20 countries**	Parker (2021)	1	**Vietnam**
Saidi et al. (2018)	1	**MENA countries**	Taghvaee et al. (2019)	1	**Iran**
Saidi and Hammami (2017)	1	**75 countries**	Liimatainen and Pöllänen (2013)	1	**Finland**
Dzator et al. (2021b)	1	**113 countries**	Meng and Han (2018)	1	**Shanghai**
Listiono (2018)	1	**90 countries**	Říha and Honců (2012)	1	**Czech**
Anwar et al. (2020)	1	**33 countries**	Alshehry and Belloumi (2017)	1	**Saudi Arabia**
Shafique et al. (2020)	1	**Hong Kong, Singapore, and South Korea**	Engo (2019)	1	**Cameroon**
Saleem et al. (2018)	1	**11 countries**			

OECD Organization of EconomicCooperation and Development, *MENA* Middle East and North African countries, *EU* European Union, *ASEAN* Association of Southeast Asian Nation

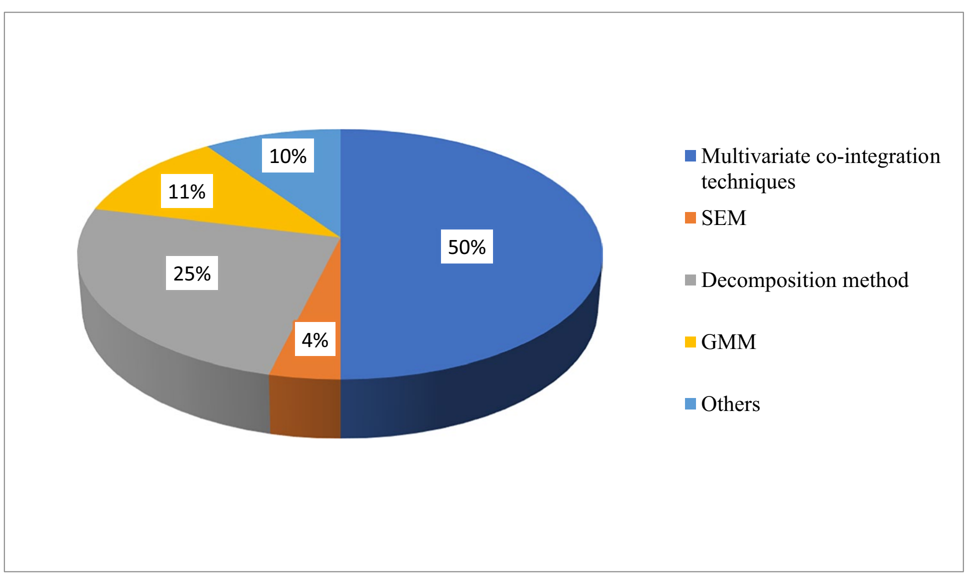

Fig. 4 The distribution of papers according to research methodologies

Table 5 Details of published studies included in the review process

Authors	Countries	Period	Methodologies	Findings
Krautzberger and Wetzel (2012)	17 EU countries	1995 -2006	ML	CO_2 ↗ GDP; TRAN ↗CO_2
Řiha and Honců (2012)	Czech	1961-2005	EKC	Road transport ↗ GDP; GDP ↘CO_2
Liimatainen and Pöllänen (2013)	Finland	1995 -2002	Decomposition method	GDP ↗ CO_2 ; FT ↗ CO_2
Mraihi et al. (2013)	Tunisia	1990-2006	Decomposition method	EG, vehicle fuel intensity, urbanized kilometers and national road network are demonstrated to be the main causes of EC in the road transportation.
Ben abdallah et al. (2013)	Tunisia	1980–2010	Johansen's cointegration	Short run: TVA →ROI; FPrice →ROI; TEC →FP; TEC → ROI; TCO_2 →ROI Long run: TEC↔ TCO_2; TEC↔ ROI; TCO_2↔ ROI; FP→ ROI; FP →TVA; FP →TCO_2 ; TEC ↔ TVA
Chandran and Tang (2013)	5 ASEAN economies	1971-2008	Cointegration- Granger causality	Indonesia: GDP ↔CO_2 Thailand: GDP ↔ CO_2; TEC ↔CO_2 Malysia: GDP →CO_2; TEC ↔CO_2
Saboori et al. (2014)	27 OECD countries	1960-2008	FMLOS	CO_2 ↔ GDP; TEC ↔GDP; CO_2 ↔ TEC
Li et al. (2015)	China	1996-2012	Decomposition method	EG had a greater impact on CO_2 emissions
Cantos Sanchez and Gumbau Albert (2015)	OECD countries	1970-2010	GMM	Transport infrastructures do not generate EG directly, but do so the higher use of the environment indirectly
Arvin et al. (2015)	G20 countries	1961–2012	VAR	Short run: GDP→ CO_2 Long run: GDP →CO_2
Shahbaz et al. (2015)	Tunisia	1980–2012	ARDL- VECM	TEC↔ CO_2; TVA ↔CO_2; FP →CO_2; TEC→ CO_2 ; FP →TEC ; FP →TVA
Daldoul and Dakhlaoui (2016)	Tunisia	1980 - 2011	Decomposition method	EG and vehicle ownership were the factors that contributed the most to the increase of CO_2 emissions
Achour and Belloumi (2016b)	Tunisia	1985–2014	Decomposition method	EG, transportation intensity and transport structure in relation to energy use were positive
Achour and Belloumi (2016a)	Tunisia	1971-2012	Johansen cointegration approach- variance decomposition	Short run: ROI →TVA; TEC →TCO_2 ; Long run: TVA →ROI ; TEC→ROI ; TCO_2 → ROI ; GDP → ROI ; RAI → RAILEC ;TVA→ RAILEC
Liang et al. (2017)	China	2001–2014	Decomposition method	EG is the main factor behind the rise of TCO2, while energy efficiency is the main inhibiting factor
Fan and Lei (2017)	China	1995 -2014	Decomposition method	EG, energy intensity are considered to be the key factors of CO2 emission rises in the transportation sector
Alshehry and Belloumi (2017)	Saudi Arabia	1971–2011	ARDL- granger causality	Short run: TCO_2 ↔ TEC Long run: TCO_2 ↔TEC; GDP →TCO_2
Neves et al, (2017)	15 OECD countries	1995 -2014	ARDL	Road transport ↗ CO_2
Ben Jebli and Belloumi (2017)	Tunisia	1980–2011	ARDL - granger causality	Short run: CO_2 ↔Maritime transport; GDP → CO_2; Road transport → CO_2
Saidi and Hammami (2017)	75 countries	2000-2016	GMM - Dumitrescu-Hurlin panel causality test	FT ↔ GDP; FT →CO_2; CO_2 ↔ GDP
Listiono (2018)	90 countries	1980-2014	SEM	High-income countries: GDP ↔ FT Lower-income countries: GDP↔ FT Upper-middle income countries: TRAN ↔CO_2 Lower-middle income countries: GDP ↔CO_2
Meng and Han (2018)	Shanghai	1989-2014	Johansen cointegration- Granger causality	Road ≠ GDP ; Road ↗ CO_2
Baloch (2018)	Pakistan	1971 - 2014	ARDL -Granger causality	ROI ↗ GDP; TEC ↗ GDP; GDP ↘CO_2; TEC ≠ CO_2
Han et al., (2018)	China	1997 - 2015	Decomposition method	TCO_2 and TVA was characterized by a weak decoupling process
Zhang et al., (2018)	China	1995-2015	Decomposition method	TCO_2 and EG were not synchronized
Gherghina et al., (2018)	28 EU countries	1990-2016	Panel cointegration-VECM	CO_2 ↔ RAI ; CO2↔ GDP
Saleem et al., (2018)	11 countries	1975–2015	Panel cointegration	CO_2 ↔GDP; RAI ↔GDP; TEC →GDP
Saidi et al., (2018)	MENA countries	2000-2016	GMM	TEC ↔ EG ; TRAN ↔ EG
Engo (2019)	Cameroon	1990–2016	Decomposition method	The transport sector represents one of Cameroon's economic sectors with high energy consumption and CO_2
Wang and wang (2019)	China	1997 - 2015	Decomposition method	EG was the major contributor to TCO_2, while the energy intensity effect was the main inhibitor.
Taghvaee et al., (2019)	Iran	1978–2012	SEM	EG elasticities are greater in the air transportation compared to maritime; the maritime transportation is more pollutant and less productive in comparison with the air transportation
Zhang et al., (2019)	China	1995 - 2016	Decomposition method	EG is the major factor behind the strong rise of CO2 emissions in the transportation sector
Khan (2019)	Asian countries	2007 - 2017	GMM	TRAN ↗ CO_2
Anwar et al., (2019)	33 BRI countries	1986-2017	ARDL-FMOLS-DOLS-PMG	FT ↔CO_2
Moshsin et al., (2019)	Pakistan	1975 -2015	Johansen cointegraion test - VECM	GDP resulted in an increase of 4.47% in TCO_2; TCO_2↗EC
Nasreen et al., (2020)	Asian countries	1980-2017	Panel cointegration - granger causality	TEC↔ GDP; TEC ↔CO_2; 1% TEC ↘CO_2 by 0.57%
Benali and Feki (2020)	Tunisia	1982–2016	VECM	FT ↔GDP; FT → CO_2; GDP →CO_2
Shafique et al., (2020)	Hong Kong, Singapore, and South Korea	1995-2017	Johansen cointegration- FMOLS - Granger causality	Hong Kong: FT→CO_2; GDP → FT; GDP→CO_2 South korea: CO_2→FT Singapore: FT ↔ GDP; FT →CO_2; CO2↔ GDP

Table 5 (continued)

Peng and Wu (2020)	China	2004-2016	Panel Pedroni cointegration- panel granger causality	TEC ↔ TCO_2 ; GDP ↔ TCO_2 ; TEC ↔ GDP
Yang et al. (2021)	China	2020	Multiregion – multisectoral CGE model	Road investment ↗ EG than railway investment ; road investment emission reduction in CO_2, CO, SO_2, NO_X, and $PM_{2.5}$ in Hubei, Guizhou, and Guangdong provinces
Mohmand et al., (2021)	Pakistan	1971–2017	ARDL-VECM	GDP ↔ TRAN; GDP → CO_2; TRAN → CO_2
Dzator et al. (2021a)	26 OECD countries	1960 -2018	GMM	ATI ↗ CO_2; Rail transport ≠ CO_2
Sharif and Tauqir (2021)	Pakistan	1972–2017	FMOLS - DOLS	CO_2 ↘ GDP; 1% length of roads ↗ GDP by 1.45%
Parker (2021)	Vietnam	1995-2017	Decomposition method	TRAN ≠ GDP ; TRAN → CO_2
Dzator et al., (2021b)	113 developing countries	1990 -2018	GMM	ATI and GDP does not significantly impact on CO2 carbon emissions while RTI moderates GDP to worsen carbon emissions
Habib et al., (2021)	G20 countries	1990 - 2016	CUP-FM / CUP-BC	RFT → CO_2; RTI → CO_2; GDP ↗ CO_2 RPT ↔ CO_2 ; RPT ↔ CO_2
Shafique et al., (2021)	10 Asian countries	1995-2017	ARDL- PMG	TRAN → GDP; TRAN → CO_2; GDP ↔ CO_2
Huang et al., (2021)	ASEAN countries	1995–2018	ARDL	TRAN ↗ CO_2 ; TRAN infrastructure ↗ GDP
Acheampong et al., (2022)	EU	1995 - 2019	GMM	TEC ↗ GDP; GDP ↘ CO_2; TEC ↗ CO_2 FT infrastructure ↗ GDP and CO_2
Hussain et al., (2022)	OECD countries	2000 - 2020	ARDL -EKC	Road trafic ↗ CO_2 by 54.2% ; Rail trafic ↗ CO_2 by 31.1% ; Air trafic ↗ CO_2 by 13.8 % There is an inverted U-shaped relationship between TCO_2 and GDP
Habib et al., (2022)	G-20 countries	1990-2016	Pedroni and Westerlund panel cointegration	ATI ↔ CO_2; APT ↔ CO_2; AFT ↔ CO_2; GDP ↘ CO_2
Rehman et al., (2022)	Pakistan	1971- 2019	ARDL –FMOLS–DOLS	GDP → CO_2 ; GDP → TRANS

Source: Prepared by the authors

Note 1: →, unidirectional Granger causality; ↔, bidirectional Granger causality; ≠, absence of Granger causality; ↗, positive effect; ↘, negative effect

Note 2: *GDP*, gross domestic product; CO_2, carbon dioxide emissions; *TRAN* transport, *ATI* air transport intensity, *APT* air passenger transport, *AFT* air freight transport, *TEC* transport energy consumption, *RFT* road freight transport, *RTI* rail transport intensity, *RPT* road passenger transport, *FT* freight transport, *EG* economic growth, *EC* energy consumption, *TVA* transport value added, *RI* road infrastructure, *FP* fuel price, *RAILEC* rail transport energy consumption, TCO_2 transport CO2

Note 3: *ARDL* autoregressive distributed lag, *FMOLS* fully modified ordinary least square, *DOLS* dynamic ordinary least square, *EKC* environmental Kuznets curve, *GMM* generalized method of moments, *PMG* pool means group, *CUP-FM* continuously updated fully modified, *CUP-B*C continuously updated bias-corrected, *VAR* vector autoregressive, *VECM* vector error correction model, *SEM* structural equation modelling, *CGE* computable general equilibrium, *ML* Malmquist-Luenberger

Note 4: *MENA*: The Middle East and North African countries, *EU* European Union, *OECD* Organization of Economic Cooperation and Development, *ASEAN* Association of Southeast Asian, *BRI* belt road initiative

Saudi Arabia negatively affect environmental quality by contributing to critical CO_2 emissions.

Arvin et al. (2015) examined the links between urbanization, transportation intensity (TI), GDP, and CO_2 emissions in G-20 countries over the period 1961–2012, utilizing panel cointegration methods and Granger causality analysis. The study found evidence of a unidirectional causality between GDP and CO_2 emissions in both the short and long run.

For the case of OECD countries, Saboori et al. (2014) applied the fully modified ordinary least squares (FMOLS) methodology to investigate the bidirectional long-term relationship between CO_2 emissions, TEC, and GDP for the period 1960–2008. The findings indicated a bidirectional relationship between GDP, TCO2 emissions, and TEC over the long run.

Neves et al. (2017) conducted a study that looked at the relationship between TEC and carbon dioxide emissions. The results obtained from the ARDL model analysis indicated that the utilization of fossil fuels in the transportation sector has a significant impact on the economic growth of OECD countries.

Hussain et al. (2022) examine the relationship between transportation, economic activity, and environmental expenses and their impact on transport-carbon emissions in the OECD countries over the period of 2000–2020. The findings showed the presence of an inverted U-shaped causal connection between economic growth and transport emissions. In the long term, the study found that railway, road, and air traffic increase transport-carbon emissions by 31.1%, 54.2%, and 13.8%, respectively.

For the case of Pakistan, Baloch (2018) conducted a study investigating the impact of road transportation on economic development. The study used sulfur dioxide as a measure of environmental quality and applied both ARDL and VECM estimations. The results showed a direct relationship between TEC and sulfur dioxide emissions from the transport sector.

Mohsin et al. (2019) explored the nexus between income, energy consumption, urbanization, and TCO_2 emissions. The analysis utilized data from 1975 to 2015 and the Johansen cointegration method, revealing that increases in GDP and energy consumption resulted in an increase in transport CO2 emissions. For the same country, Mohmand et al. (2021) revealed a bidirectional relationship between GDP and road infrastructure (RI) through a long-term analysis. Additionally, unidirectional causality was established to exist from GDP, RI, and TEC to CO_2 emissions.

The study by Sharif and Tauqir (2021) examines the interplay between carbon emissions and RI on GDP using a panel data approach spanning from 1972 to 2017. The authors utilized the FMOLS and dynamic ordinary least square (DOLS) methods to analyze the data. The results indicate that while road infrastructure development can facilitate economic development, it may also come at the cost of environmental degradation. The study finds a positive correlation between RI and GDP, suggesting that elevated carbon emissions have a detrimental impact on economic growth.

Anwar et al. (2020) investigated the relationship between GDP, FT, and carbon dioxide emissions in 33 Belt Road Initiative (BRI) countries. Utilizing ARDL and pooled mean group (PMG) techniques, they discovered a bidirectional causality between FT and CO_2 emissions.

Chandran and Tang (2013) analyzed the impact of TEC and EG on CO_2 emissions in a sample of Southeast Asian countries. The VECM analysis revealed a bidirectional relationship between TEC and CO2 emissions in Thailand and Malaysia.

Nasreen et al. (2020) conducted a panel cointegration analysis to investigate the interconnections between EG, TEC, and environmental quality over the period of 1980–2017. The results of the study reveal the presence of bidirectional long-run causality among TEC, environment, and GDP. The researchers utilized the common correlated effects mean group technique to determine long-run elasticities and discovered that a 1% increase in TEC and GDP corresponds to a decrease in environmental quality by 0.57% and 0.46%, respectively.

For the case of 10 Asian economies, Shafique et al. (2021) identified the correlation between transportation, economic growth, and environmental degradation. The study utilized a multivariate panel methodology on data spanning from 1995 to 2017. Both the PMG and ARDL models were used to examine the long-run interconnections between the variables. The Dumitrescu and Hurlin (2012) causality demonstrates a unidirectional causality between transportation and carbon emissions. Moreover, the results show a bidirectional causality between GDP and CO_2 emissions, indicating that economic development incurs environmental degradation. They suggested that the government adopt environmentally friendly policies, particularly for the commercial transportation sector. They also advised encouraging the use of green freight transport to reduce CO2 emissions and investing in mass transit using green fuels.

Peng and Wu (2020) investigated the long-run causality between TEC, GDP, and TCO2 emissions in the case of China. The study utilized panel data covering thirty provincial regions from 2004 to 2016. The FMOLS tests revealed the presence of bidirectional causal relationships between TEC, GDP, and TCO2 emissions both in the short and long run.

The study by Shafique et al. (2020) examine the causal connections between four indicators of sustainable transportation: FT, GDP, TCO2, and EC in three Asian countries: Singapore, Hong Kong, and South Korea over the period of 1995–2017. The authors used the Johansen co-integration, FMOLS, and Granger causality methods to establish the relationships among the study variables. The results confirmed bidirectional causality between FT and GDP in Singapore, while unidirectional causality from GDP to FT was found in Hong Kong and South Korea. The results emphasize the need to adopt sustainable transportation practices, including the use of clean fuel sources in air, rail, and road transportation and improving transportation infrastructure. Additionally, the study suggests that the Korean government should implement policies to encourage the utilization of biofuels in rail transportation to advance sustainable transportation objectives.

Gherghina et al. (2018) investigated the links between major forms of transportation, accompanying investments, specific air pollutants, and economic growth in the EU-28 countries from 1990 to 2016. Utilizing panel data models, the authors found that all forms of transportation infrastructure, excluding railway transportation, had a positive impact on economic growth.

For the case of Tunisia, Ben Abdallah et al. (2013) aimed to analyze the interrelationships among five indicators of sustainable transportation in Tunisia: TEC, transport value added (TVA), RI, TCO_2, and fuel prices (FP) over the period 1980-2010. The authors employed the Johansen cointegration technique to uncover the causal relationships among the study variables. The results of the cointegration analysis indicated the presence of bidirectional causality between TEC, RI, carbon dioxide emissions, and TVA, as well as unidirectional causality from FP to TEC.

Similarly, Shahbaz et al. (2015) analyzed the interrelationships between TCO_2 emissions, TVA, TEC, and FP during the period 1980–2012. To determine the long-term relationships among the variables, the authors employed the ARDL bounds model and VECM estimation. The results indicated the existence of bidirectional causality between TEC and CO_2 emissions. The authors suggested that the government should reevaluate its energy subsidy program to improve energy efficiency in the transportation sector and decrease CO_2 emissions. Additionally, they observed that an increase in TVA and RI resulted in higher carbon dioxide emissions.

Achour and Belloumi (2016a) investigated the causal relationships among transportation infrastructure, TVA, total capital, and carbon dioxide emissions for the period 1971–2012 using the Johansen multivariate cointegration technique and VECM. The long-run analysis revealed unidirectional causality from emissions and consumption to railway and road infrastructure.

Benali and Feki (2020) used the Granger causation test and variance decomposition to examine the dynamic relationships between GHG emissions, FT, GDP, and EC from 1982 to 2016. The results showed a unidirectional correlation between FT and CO_2 emissions, as well as bidirectional causality between GDP and FT.

Overall, these findings demonstrate the complex relationships between transportation variables, economic variables, and carbon dioxide emissions. There is evidence of bidirectional and unidirectional causal relationships, suggesting that economic growth and transportation contribute to environmental degradation through increased carbon emissions. Divergences in the outcomes of the selected articles utilizing Granger causality are frequently observed, primarily due to variations in methodology, analyzed periods, and chosen variables. These results emphasize the importance of sustainable transportation practices, energy efficiency improvements, and infrastructure development to mitigate the negative environmental consequences associated with transportation and promote economic growth.

Decomposition method

In our SLR, it was observed that decomposition methods represented 25% of the articles utilized to examine the interconnections between indicators for sustainable transportation. This method is considered a common technique for evaluating the impact of various factors on CO_2 emissions from the transportation sector and providing scientific evidence for the attainment of low-carbon development. The application of decomposition methods to the study of CO_2 emissions was first introduced in the 1980s, particularly in the industrial context (Howarth et al. 1991; Park 1992).

Over time, the method was expanded and widely adopted for use in different sectors, including transportation, in the 1990s and 2000s, in response to growing concerns over environmental issues and the need to analyze the dynamic relationship between energy-related GHG emissions. In the existing body of literature, a significant number of studies have been conducted to analyze the decomposition of the transportation sector.

Li et al. (2015) conducted a study in China to examine the interaction between energy-related carbon emissions and economic growth. The findings showed that economic growth had a greater impact on CO_2 emissions, with limited effects from energy intensity and population density. Additionally, Liang et al. (2017) utilized the logarithmic mean divisia index (LMDI) method to analyze the impact of six variables, including transportation form, transportation development, energy structure, energy efficiency, economic growth, and urbanization, on transportation sector emissions during the period 2001–2014. The results indicated that EG was a major driver behind the increase in CO_2 emissions in the transportation sector, while energy efficiency was found to be the primary factor that inhibited this rise. The LMDI is frequently favored due to its simplicity of application and comprehensiveness, in addition to its capability of delivering exhaustive decomposition results without the residual term (Ang 2004; Dong and Pan 2020).

Additionally, a study by Fan and Lei (2016) employed a generalized multivariate Fisher's index decomposition model to determine the primary drivers of GHG emissions in the transportation sector of Beijing during the period 1995–2012. The results indicated that EG, energy intensity, and urbanization were the key factors contributing to the increase of GHG emissions in the sector.

Han et al. (2018) used the Tapio method to analyze the decoupling relationship between transportation CO_2 emissions and EG. The study found evidence of a weak decoupling between CO2 emissions and value-added. Engo (2019) conducted research on the decoupling relationship between EG and CO2 emissions in Cameroon over the period 1990–2015, utilizing both Tapio and LMDI techniques. The findings revealed weak decoupling and identified the industrial sector as having a significant negative impact on the country's decoupling trend during the period 1990–2015.

Parker (2021) determined that despite Vietnam's economic growth, the expansion of transportation activities has emerged as a major hindrance in reducing CO_2 emissions in the transport sector. Liimatainen and Pöllänen (2013) observed that the development of the road freight transport sector significantly impacts energy efficiency and CO_2 emissions in Finland.

Mraihi et al. (2013) utilized the LMDI method to analyze the driving forces behind energy use change in road transportation during the 1990–2006 period. The results indicated that economic growth, vehicle fuel intensity, urbanized kilometers, and the national road network played a major role in energy consumption in road transportation. Achour and Belloumi (2016b) utilized the LMDI method to examine the drivers of CO_2 emissions in the transportation sector. Data collected from 1985 to 2014 were analyzed, and the results showed that population, energy consumption, transportation intensity, and the transport structure in relation to energy use had a positive effect on CO_2 emissions, whereas energy intensity had a negative effect.

Daldoul and Dakhlaoui (2016) employed the Divisia index approach to study the impact of vehicle fuel intensity, emission factor, population size, vehicle ownership, and economic activity on total CO_2 emissions from road transportation over the period 1980–2011. The findings indicated that the rapid increase in energy consumption and vehicle ownership were significant contributors to the rise of carbon dioxide emissions, while population size played a role in decreasing emissions.

The studies mentioned above emphasize the effectiveness of using a decomposition approach to analyze carbon dioxide emissions from the transportation sector and identify key determinants. The outcomes show that several factors including economic growth, energy efficiency, energy intensity, and population size are important in the context of sustainable transportation and the reduction of CO2 emissions. These studies enhance the scientific comprehension of the interrelationships among indicators pertaining to sustainable transportation and offer valuable insights for the formulation of strategies aimed at achieving low-carbon development.

Generalized method of moments

The generalized method of moments (GMM) has been utilized in the empirical literature to analyze the dynamic relationships between the transportation sector, economic growth, and environmental degradation. Acheampong et al. (2022) employed the dynamic system-generalized method of moments (GMM) to investigate the effect of transportation infrastructure and technological innovation on EG, EC, and CO_2 emissions in the European Union from 1995 to 2019. The findings showed that EC has a unidirectional positive impact on GDP, whereas GDP and EC have a negative and positive effect, respectively, on CO_2 emissions. Additionally, the study found that FT leads to an increase in EG and carbon emissions, but a decrease in EC.

Dzator et al. (2021a) utilized the GMM to investigate the relationship between air and rail transportation infrastructure and carbon dioxide emissions in 113 developing countries over the period 1990–2018. The results indicated that both air and rail transportation infrastructure were positively correlated with higher CO_2 emissions. The study found no impact of air transportation infrastructure and GDP on CO_2 emissions, while rail transportation infrastructure had a moderating effect on GDP that intensified CO_2 emissions.

For the case of ASEAN countries, Khan (2019) employed panel data from 2007 to 2017 and the GMM to analyze the relationship between logistics operations and ED. The outcomes showed a positive and significant relationship between logistics activity and environmental degradation, primarily due to the reliance on fossil fuel use and the resulting emissions of carbon, methane, and greenhouse gases, which can damage the environment and contribute to climate change.

The study by Saidi and Hammami (2017) analyzed the causal relationship between environmental degradation, transportation, and economic growth by utilizing a dynamic panel data set comprising 75 countries over the period of 2000 to 2014. The GMM estimator proposed by Arellano and Bond (AB, 1991) was employed to reveal a bidirectional interaction between environmental degradation and GDP in low, middle, and high-income countries, as well as a unidirectional interaction between the transportation sector and environmental degradation in high-income economies.

In the case of the MENA region, Saidi et al. (2018) investigated the influence of TEC and transportation infrastructure on EG using annual data from 2000 to 2016. The results of the GMM showed that TEC has a significant impact on EG in the MENA countries, while transportation infrastructure increases EG in all regions. The Dumitrescu-Hurlin causality test was used to demonstrate the feedback effect between TEC, transport infrastructure, and economic growth. In the context of the OECD countries, Cantos Sanchez and Gumbau Albert (2015) found that transportation infrastructures do not directly cause economic growth but rather indirectly through increased environmental usage.

Transportation plays a vital role in economic growth as it facilitates the movement of goods, services, and people. However, it is also a major contributor to CO2 emissions, primarily through the combustion of fossil fuels in vehicles. CO2 emissions from transport have detrimental effects on the environment, contributing to climate change and air pollution, which in turn have adverse consequences for human health and ecosystems.

Currently, there is increasing interest in implementing the concept of sustainable transportation, with the idea of using clean transportation becoming more and more popular worldwide. Advancing sustainable transportation requires a comprehensive examination of transportation systems and their impacts on economic, social, and environmental factors, as well as the associated challenges. Recent research demonstrates that achieving sustainability objectives through transportation systems has become a top priority for policymakers. Although the analyzed studies have been performed in different countries, addressing regional or global perspectives, through varied models, most of the time, the results show these methods could be efficient in promoting the discussion about disentangling the relationship between the transport sector, economic growth, and CO2 emissions. Furthermore, it is important to highlight that time series data present peculiarities that influence the quality of the analyses. The feasibility and reliability of the model and the interpretability of the analyses are closely related to the pre-investigation and data mining phases, which help in understanding the characteristics of the study area, such as income, demographic statistics, and economic sector structure. Other important characteristics to be considered are the time series properties, concerning sample size, missing data, trends, seasonality, verification of heteroscedasticity and multicollinearity in the sample, and selecting a suitable lag length, as these are also important steps that can reduce biased estimates and improve the quality of the analyses. Due to the multiplicity of modeling approaches and heterogeneity of the analyzed data and results, it was ultimately impossible to conduct a meta-analysis.

Sustainable transport policies

Numerous scholarly articles have extensively investigated various transport policies in the context of sustainable transportation. It is widely recognized that supportive policies are essential for promoting sustainable transport, and the inclusion of public responses is crucial. Neglecting public responses may lead to an overestimation of the efficiency of sustainable transport policies. For the case of the ASEAN countries, Nasreen et al. (2020) proposed that policymakers encourage energy-efficient modes of transportation and explore alternative energy sources such as compressed natural gas, with an emphasis on promoting clean and sustainable transport through a shift from private motorization to non-motorized options. Shafique et al. (2021) suggested that the government adopt environmentally friendly policies, particularly for the commercial transportation sector. They also advised encouraging the utilization of green freight transport to decrease carbon dioxide emissions and investing in mass transit using green fuels. For the case of G-20 countries, Habib et al. (2021) advised policymakers to provide subsidies for environmentally friendly technologies, incentivize research, and development in clean and renewable technologies, and capitalize on green infrastructure such as urban road transport systems. Additionally, regulations should be put in place to gradually decarbonize the transportation sector. The literature on sustainable transportation in Tunisia highlights several key recommendations for policymakers. Ben Abdallah et al. (2013), Mraihi et al. (2013), and Daldoul and Dakhlaoui (2016) recommend urban transport planning, relocating production units, improving fuel efficiency in vehicles, and reinforcing emissions control legislation to align with low-carbon development and climate resilient policies. Shahbaz et al. (2015) advise the government to review its energy subsidy program to reflect world market prices, thereby improving energy efficiency in the road transport sector and reducing CO_2 emissions. Achour and Belloumi (2016a) and Achour and Belloumi (2016b) recommend reducing the number of trips, optimizing the spatial organization of activities, incorporating transport policy in town and country planning, and improving the technology of engines and fuels, including biofuels, battery-driven or hybrid vehicles. They emphasize that shifting towards public transportation is a crucial solution for urban transport planning. Finally, Benali and Feki (2020) propose the development of an energy-efficient road transport policy in Tunisia should take into account urbanism, technological developments, and environmental concerns, and be integrated into traditional transport policies.

Conclusions and policy implications

Conclusions

The transport sector's sustainability is a vital factor in ensuring overall economic sustainability. As the economy expands, the significance of the transport sector also grows, making it a crucial component to consider in environmental regulations. Our systematic review included 52 peer-reviewed journal articles that used various econometric models to discuss the nexus between the transportation sector, economic development, and carbon dioxide emissions. The studies were conducted in different countries, offering both global and regional perspectives and showcasing diverse methodological approaches, analyzed time periods, and study variables.

The review discovered that multivariate cointegration techniques and the decomposition method were the primary models recently used by researchers.

The examined methodologies were found to be efficient in analyzing the complex relationships between the mentioned variables, promoting discussions about the urgent need for investing in renewable energy sources and implementing robust mitigation measures. It is evident that adopting sustainable practices in the transport sector is not only crucial for environmental preservation but also has direct implications for economic stability and long-term prosperity. As a global community, it is imperative that we prioritize the reduction of CO_2 emissions in the transport sector as a paramount objective. By adopting cleaner and more efficient transportation systems, promoting the use of renewable energy, and incentivizing sustainable practices, we can pave the way for a greener and more resilient future

Policy implications

This research provides policy implications for reducing environmental degradation in the transportation sector.

- The modal shift refers to a change from one mode of transportation to another, with the aim of providing energy-efficient alternatives that support sustainability. Innovative mobility services such as carpooling, which involves sharing resources, can reduce energy consumption and GHG emissions. Additionally, improved accessibility through better urban planning and transportation infrastructure can also contribute to sustainability by minimizing travel distances and energy use.

The integration of autonomous driving technology in vehicles also has the potential to further reduce energy consumption through enhanced traffic management and optimized routing.

- Governments should adopt technologies and strategies that substitute non-renewable energy resources with renewable sources and reduce dependence on fossil fuels to decrease GHG emissions. This can be achieved by using carbon-neutral synthetic fuels, a combination of electrification, biofuels, hydrogen, and solar energy. These fuels have the potential to replace traditional fossil fuels and reduce GHG emissions generated by the transportation sector. Energy efficiency is an essential component of sustainable transportation, and the implementation of technologies such as electric vehicles, battery electric vehicles, and plug-in hybrid electric vehicles can improve fuel efficiency and decrease potential GHG emissions. The use of these technologies decreases dependence on fossil fuels and enhances energy efficiency, contributing to the goal of sustainable transportation.
- The use of fuel taxes as a policy instrument has been widely recognized as a potential solution to address sustainability in the transportation sector. Its implementation is expected to bring about changes in individuals' driving behaviors in the short term, such as increased fuel efficiency through slowing driving speeds or maintaining proper tire pressure.
- The impact of fuel taxes on consumer behavior is significant, especially at the point of purchase, where consumers may choose low-emission vehicles to reduce tax payments. Offering a value-added tax exemption for low-emission vehicles and introducing a carbon tax could also play a significant role in promoting sustainability in the transportation sector. This tax could encourage individuals to reduce their carbon emissions, thereby contributing to the sector's transition towards a low-carbon direction.
- The promotion of alternative modes of transportation, including biking and walking, can significantly contribute to fulfilling carbon abatement goals. The dissemination of environmental information and education regarding environmentally conscious attitudes is crucial in promoting sustainability in the transportation sector. The implementation of cost-effective and energy-efficient practices in urbanization, infrastructure development, and economic growth can further support the advancement of sustainable transportation.
- Moreover, raising awareness of sustainable driving practices and cultivating a culture of sustainable driving can have a notable impact on environmental quality. Encouraging individuals to adopt fuel-efficient driving habits, such as reducing speed and proper vehicle maintenance, can result in lower carbon emissions, thus contributing to the sustainability of the transportation sector.
- The use of public transportation as a mode of transportation has been shown to lead to decreased carbon emissions and energy resources. The advantages of public transportation are well-established and numerous, making it a sustainable solution for transportation. Compared to personal vehicles, public transportation generates lower emissions of greenhouse gases, thanks to its energy-efficient design and emission-reducing technologies. Additionally, the high occupancy rate of public transportation vehicles results in lower emissions per passenger compared to personal vehicles. Moreover, public transportation also leads to reduced energy consumption. Public transportation helps to decrease road congestion, making it a cost-effective means of mobility and offering an affordable alternative to personal vehicles, particularly for low-income households.

Limits

The current study is subject to several limitations that can be addressed in future research. The literature review employed may exhibit a language bias, as it was limited to publications in the English language. Additionally, the utilization of multiple search engines in the literature review may not be comprehensive, as other databases may contain valuable studies. Furthermore, the scope of peer-reviewed publications was narrow, excluding other forms of academic research such as books, book chapters, and gray literature. However, it is notable that the analysis did not extensively consider the social sustainability aspect of sustainable transport development, which is a crucial component of overall sustainable development. Hence, it is crucial to examine the development of sustainable transport with a specific focus on its social dimensions and implications. While existing bibliometric analysis studies have focused on the economic and environmental sustainability of sustainable transportation, there is a lack of research on socially sustainable transportation.

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Data availability Research data can be obtained from the corresponding author through email.

Declarations

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