



Analysing Research Trends in Urban Low-Carbon Mobility: Insights for the Future

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Abstract: Countries in the world are currently facing a common challenge: the climate crisis. Transportation and energy sectors contribute a large share of urban emissions. To mitigate climate change and achieve the 2050 Net Zero Carbon target, many countries develop various concepts, such as low-carbon cities (LCCs) and low-carbon mobility (LCM), with the specific intent to reduce urban carbon emissions. This research aims to observe the latest trends in LCM, identify the research gaps, and estimate potential research developments. We used the VOS viewer to analyse 990 Scopus publications related to LCM up to 2024. The results showed that developed countries like the UK, China, Germany, the US, and Japan are the top contributors of LCM studies, but the integration between LCM research and non-motorised transport modes, particularly walking and cycling, remains understudied. This gap allows future research to strengthen the linkage between LCC and LCM concepts, focusing on non-motorised mobility strategies applicable to Southeast Asian urban contexts.

Keywords: Emission; Mobility; Climate change; Urban; Low-carbon

1 Introduction

The increase in urban carbon emissions contributes 70% to the global percentage [1], worsening the climate effects in countries around the globe. It is mainly due to the rise of urban development, population, and car ownership from 1970–2015 [2]. Many megacities in the southern US (e.g., Indianapolis, Boston, Salt Lake City, and Los Angeles) are facing issues of transportation and air pollution due to carbon emissions generated by fossil fuel-based vehicles. Gurney et al. [3] reported that urban carbon emissions were the first contributor to Los Angeles' carbon footprint in 2015 (47%), followed by the energy sector (32%). Similarly, transportation was the main cause of air pollution and increased local carbon emissions in Central China [4]. In Jakarta, Indonesia, the 6.44% economic growth in 2008 increased motorcycle ownership by 8%, or 5,798,000 units [5], contributing more pollution to the densely populated capital city.

To mitigate disasters from climate change, 75 nations and over 100 entities of national and local governments, private companies, and organizations gathered at the United Nations Climate Action Summit in September 2019, committing to attain net-zero carbon emissions by 2050 [6]. This target inspired the concepts of the low-carbon cities (LCCs) and transportation carbon emissions (TCEs) for urban areas. These promote sustainability, energy efficiency, green energy, green infrastructure, sustainable transportation, and community engagement [7]. Efficient use of public transportation, such as LCCs pilot projects [7] and interventions on movement patterns, is expected to reduce congestion and improve life quality [8]. One of the main elements in LCCs is low-carbon transportation, or low-carbon mobility (LCM). LCM is applicable in many areas, including renewable fuels, thus encouraging intelligent transportation systems, appropriate land use, mass public transportation, and non-motorized transportation (NMT), such as cycling and walking.

LCCs have been intensively researched in the past 15 years. A systematic review by Fan et al. [9] focused on the TCEs to identify the advantages and drawbacks of TCEs, especially with the use of motorized vehicles.

A meticulous bibliometric analysis across countries and regions by Badassa et al. [10] highlighted the intricate relationship between green transport infrastructure and its associated economic returns, reporting that reduced CO₂ emissions are crucial to boost regional and national economies. Another study emphasized the importance of a robust framework of key performance indicators for evaluating the effectiveness and efficiency of urban mobility strategies, which helps key actors to formulate policies of LCM solutions and guide future research initiatives [11]. Additionally, innovation plays a crucial role in promoting and enabling LCM [12], necessitating seamless technology transfer and collaborative efforts to boost the circular economy. Despite these varied studies, an in-depth systematic review to identify the research trends is still lacking.

This research aims to determine research trends, identify research gaps, and seek potential research development related to LCM in the future. It will analyze multiple indicators of urban mobility performance to reveal common specific metrics in the evaluation of urban mobility systems in different settings and geographic areas.

2 Methodology

This study extracts data from the Core Collection Database of Scopus Journals published up to September 6, 2024, with keywords “low-carbon” and “mobility.” A total of 1,025 publications were collected, then we filtered only English-language articles, resulting in 990 documents, which we used for this study.

The 990 articles were filtered for the transportation field and carbon emissions themes in the classifications and abstracts and exported to a CSV file for data processing. First, all documents were input to the Open Refine software for data cleaning, where we eliminated duplication and inconsistent terms and standardized keyword spelling. To do this, we extracted keywords from both publication files and the Scopus-indexed database. Then, we applied co-occurrence analysis to the remaining keywords, where each keyword should appear five times to ensure the most relevant publications were mapped. Keywords with fewer than five occurrences were removed. After that, we merged synonymous terms (e.g., “electric vehicle” and “EV”) and excluded irrelevant and generic terms. Duplicate records were identified based on identical article titles and authors, followed by manual verification to ensure accuracy.

Second, we used VOS viewer for mapping the relationships among keywords based on their co-occurrence frequency. We identified key research clusters and thematic directions in LCM studies with the full counting method and association strength normalization. The clustering was generated automatically using the default resolution settings. Clustering in the VOS viewer was conducted using the association strength normalization with the default resolution value of 1.00 and a minimum cluster size of five keywords.

3 Result and Analysis

3.1 Literature Characteristics

All 990 articles were input into Excel spreadsheets and categorized based on the publication year to observe publication trends, and the result is illustrated in Figure 1.

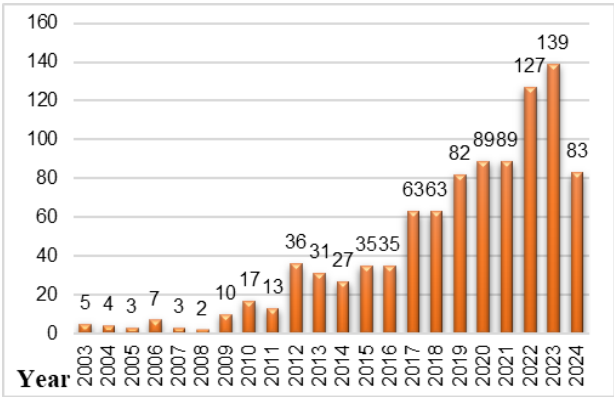


Figure 1. Publication per year

Based on Figure 1, research on LCM was started in 2003 with the five studies influencing transportation policies around the world. Research on LCM gained traction between 2015 and 2020, experienced a 42.7% increase in 2021–2022, and then peaked in 2023 with 139 papers.

3.2 Quantitative Analysis of Major Countries

The UK gained the top publication of LCM studies, amounting to 188 papers, 8,231 citations, and 19% of the total global publications, as illustrated in Figure 2. At the second rank, China pioneered the low-carbon concept in

Asia with 138 journal publications. The distribution and comparative positions of the top contributing countries are further visualized in Figure 3.

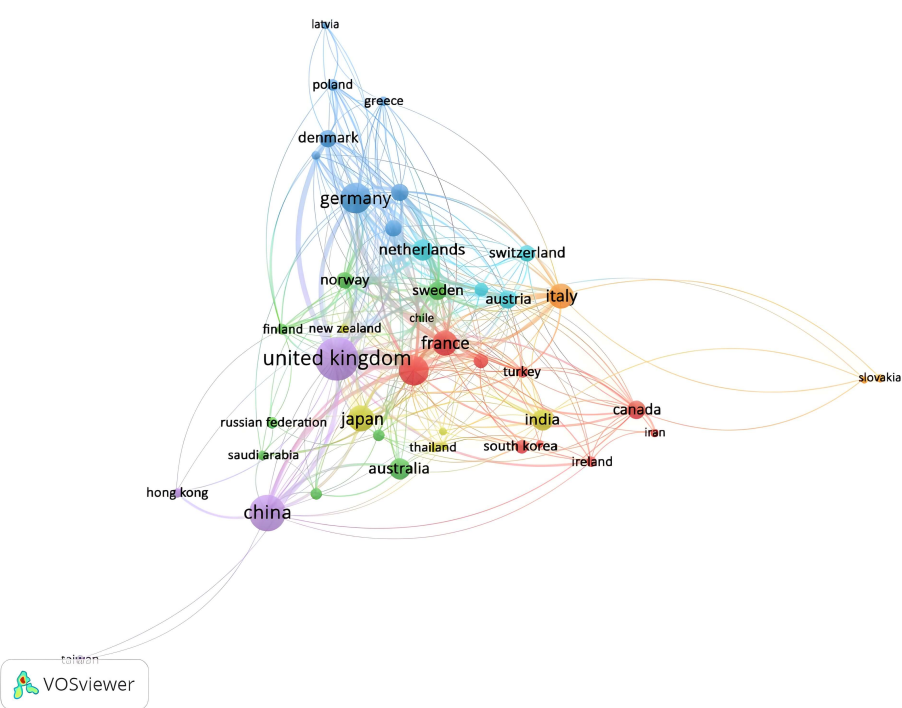


Figure 2. Major countries on low-carbon mobility (LCM) research



Figure 3. Publication mapping of the top ten major countries

Note: Rank 1: United Kingdom (UK)—Doc: 188; Citations: 8,231; Rank 2: China—Doc: 138; Citations: 2,256; Rank 3: Germany—Doc: 93; Citations: 2,748; Rank 4 (Location 4): United States—Doc: 91; Citations: 3,105; Rank 5 (Location 5): Japan—Doc: 67; Citations: 1,032; Rank 6 (Location 6): France—Doc: 64; Citations: 2,026; Rank 7 (Location 7): Italy—Doc: 64; Citations: 1,364; Rank 8 (Location 8): India—Doc: 47; Citations: 664; Rank 9 (Location 9): Netherlands—Doc: 46; Citations: 1,792; Rank 10 (Location 10): Australia — Doc: 45; Citations: 713

3.3 Quantitative Analysis of the Main Research Organizations

The UK 2003 White Paper had prompted domestic governments and other European countries to rigorously reduce carbon emissions. Together, they established research organizations to conduct robust research on this issue. The UK has 4 out of 10 top global research organizations, including the Science Policy Research Unit, Oxford University, Manchester University, and Leeds University, as shown in Figure 4 and detailed in Table 1. Denmark leads in the LCM research field with its Centre of Energy Technologies, producing 12 articles with 1,257 citations. In general, Denmark, the UK, the US, Germany, France, and Norway excel in the LCM research landscape due to their strong national policy support and leading research institutions on low-carbon transportation.

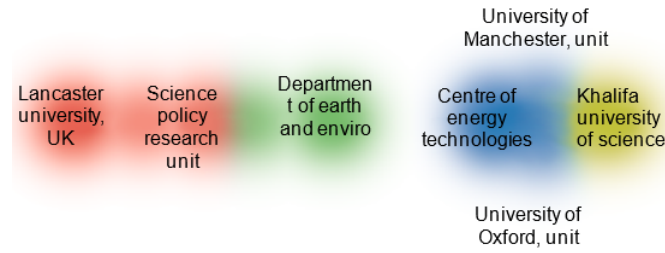


Figure 4. Main research organization

Table 1. Top ten main research organization on low-carbon mobility

Rank	Main Research Organization	Country	Document	Citations
1	Centre of Energy Technologies	Denmark	12	1,257
2	Science Policy Research Unit	UK	7	806
3	Wuppertal Institute for Climate, Environment & Energy	Germany	5	7
4	Climate Action Implementation Facility	US	4	5
5	University of Oxford	UK	3	271
6	University of Manchester	UK	3	218
7	Economix-CNRS	France	3	160
8	Western Norway Research Institute	Norway	2	386
9	University of Leeds	UK	2	357
10	Khalifa University of Science	UAE	2	146

3.4 Quantitative Analysis of the Main Source Journals

We listed 20 top-publishing journals among 990, as presented in Table 2. The first ranking is “Sustainability” (Switzerland) (41 articles), followed by “Energies Journal” (22 articles) and “Transportation Research Part D: Transport and Environment” (21 articles).

Table 2. Main source journal

Rank	Sources	Country	Articles	H-Index
1	Sustainability	Switzerland	41	169
2	Energies	Switzerland	22	152
3	Transportation Research Part D: Transport and Environment	UK	21	135
4	Journal of Cleaner Production	UK	17	309
5	Energy Research and Social Science	UK	17	113
6	Transportation Research Procedia	Netherlands	17	69
7	International Journal of Hydrogen Energy	UK	15	263
8	Journal of Transport Geography	UK	15	144
9	Renewable and Sustainable Energy Reviews	UK	14	421
10	Applied Energy	UK	13	292
11	Energy Policy	UK	13	272
12	ISIJ International	Japan	11	132
13	SAE Technical Papers	US	11	122
14	Technological Forecasting and Social Change	US	10	179
15	Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science	US	9	190
16	Climate Policy	UK	8	85
17	International Journal of Sustainable Transportation	UK	8	59
18	Energy	UK	7	251
19	Materials Science Forum	Switzerland	7	87
20	Sustainable Cities and Society	Netherlands	7	130

3.5 Keyword Co-Occurrence Analysis

Figure 5 presents the keyword co-occurrence network of LCM research generated using VOS viewer. The analysis identifies seven dominant keyword clusters, including sustainable development, electric vehicles, carbon reduction, renewable energy, air pollution, behavioral research, and CO₂ emissions.

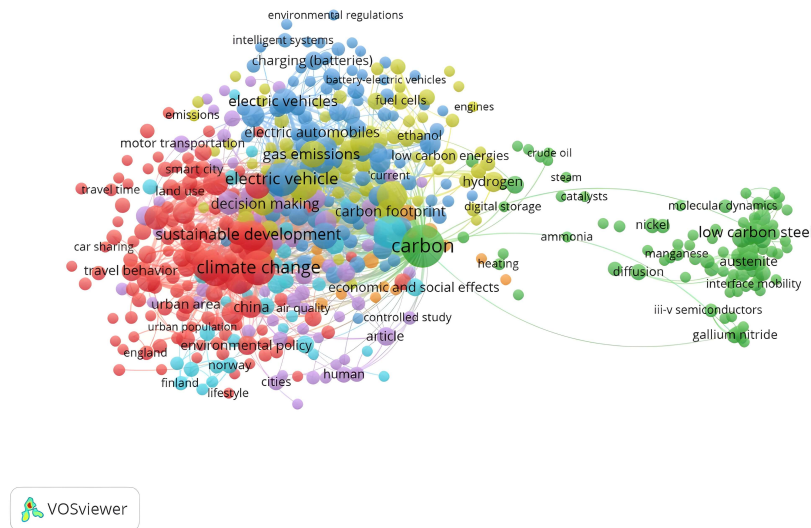


Figure 5. Keyword co-occurrence

Red—Cluster 1 (Sustainable development) with keywords: smart city, strategic approach, sustainable transportation, traffic congestion, transportation development, travel demand, travel behaviour, transportation system, transportation planning, urban mobility, urban policy, urban population, urban sustainability, walking. It highlights the rules and strategies for achieving sustainable urban development.

Green—Cluster 2 (Electrical vehicle) with keywords: electron mobility, catalysts, atoms, activation energy, heat treatment, semiconductor, performance, transmission electron. It shows the shift to electric motorized vehicles as an effort to reduce carbon emissions.

Dark Blue—Cluster 3 (Carbon footprint) with keywords: reductions (%), alternative energy, artificial intelligence, carbon emission, climate mitigations, cost effectiveness, electric mobility, energy conservation, energy efficiency, energy resources, global warming, housing, low carbon economy, low carbon futures, low carbon societies, low carbon transitions, integrated approach, information management, optimization, renewable energies, smart grid. It represents carbon reduction in urban areas and the tools to help achieve it.

Yellow—Cluster 4 (Renewable energy) with keywords: alternative fuels, biofuels, carbon capture, fossil fuels, e-mobility, ethanol, gasoline, hybrid vehicles, hydrogen fuels, low-carbon fuels, natural gas, methanol, and zero carbon. It represents the types of fuel used in cities and the levels of carbon emissions they produce.

Purple—Cluster 5 (Air pollution) with keywords: air pollution, atmospheric pollution, cities, exhaust gas, fuel consumption, energy security, nitrogen oxides, pollution, quality of life, human, cities, transportation sector, and vehicle emissions. It shows air pollution in urban areas.

Light Blue—Cluster 6 (Behavioural research) with keywords: behavioural research, built environment, consumer innovations, consumption behaviour, energy justice, energy planning, energy policy, equity, perception, questionnaire survey, neighbourhood, social influence, technology adoption, and economic and social effects. It embodies the extensive range of anxieties and reflections that are inherently connected to the various arrangements and structural traits of urban settings and particular shapes that neighbourhoods can adopt within those settings.

Orange—Cluster 7 (Transportation CO₂ Emission) with keywords: CO₂ emission, renewable resources, technology, transport sector, demand analysis, public policy, low carbon technologies. It represents carbon emissions in urban areas, especially those generated by transportation.

3.6 Literature Citation Analysis

We further analyzed the 990 documents to identify the most prolific authors of LCM studies. The results showed that 267 out of 3,214 authors made at least two publications (Figure 6). Benjamin Sovacool leads with 24 publications on carbon reduction and has been cited 1,854 times, as shown in Table 3.



Figure 6. Author citation

Table 3. Top ten literature citation

Author	Cluster	Document	Citation
Sovacool, Benjamin K.	Carbon reduction	24	1,854
Banister, David	CO ₂ emission	6	809
Kester, Johannes	Behavioural research	7	591
Schwanen, Tim	Renewable energy	7	571
Noel, Lance	Behavioural research	6	553
Anable, Jilian	Air pollution	4	511
Martiskainen, Mari	Carbon reduction	5	471
Hook, Andrew	Carbon reduction	4	400
Hodson, Mike	Electrical vehicle	2	250
Hopkins, Debbie	Sustainable development	5	160

4 Discussion

The Kyoto Protocol multilateral agreement was signed in 1997 to mitigate climate change by reducing carbon emissions. It inspired the UK government to release a White Paper policy in 2003, which emphasized climate change mitigation and low-carbon transportation strategies. This policy encouraged researchers around the world to investigate LCM, sparking international discussions about low-carbon transportation policy [13–15]. In turn, these initiatives significantly increased relevant research publications between 2009 and 2012, focusing on environmental sustainability and wider technology adoption of renewable energy [16]. The concept of LCM emerged as a strategic approach to reducing fossil fuel dependence by promoting electric vehicles, renewable technologies, and green mobility, such as walking, cycling, and mass public transportation. While the UK leads the LCM research in the world, China emerged as a pioneer in Asia of bibliometric analyses related to LCCs and TCEs [7, 17]. It reflects China’s strategic approach to addressing urban emissions challenges through large-scale policy experimentation and data-driven research.

Through keyword co-occurrence analysis, we found interrelated clusters, reflecting the conceptual structure of LCM research. Sustainable development (Cluster 1) aligns technological, environmental, and behavioral dimensions toward emissions reduction goals. Electric vehicles (Cluster 2) and renewable energy (Cluster 4) embody technological transitions that directly support carbon reduction efforts outlined in the transport CO₂ emissions study

(Cluster 7). The air pollution cluster (Cluster 5) provides a methodological basis for measuring urban air pollution, while the carbon footprint (Cluster 3) serves as a proxy for emissions reductions. Behavioral research (Cluster 6) reinforces the link that technological innovations and policies require public acceptance and behavioral adaptation to be effective. Collectively, these clusters reveal a thematic progression from sustainability-oriented planning to technological implementation and behavioral integration. Together, they form a coherent knowledge structure that addresses LCM as a systemic and interdisciplinary challenge.

The following section highlights four interrelated themes—Cleaner Transition, Behavioral Research, Carbon Reduction, and NMT. These are the key directions of LCM studies and the basis for interpreting current research trends and identifying future opportunities.

4.1 Cleaner Transition

CO₂ emissions from transportation contribute to worsening climate change. The LCM reduces dependence on fossil fuels by utilizing renewable technology and facilitating the transition to green transportation, such as vehicles fueled by electricity or liquefied petroleum gas (LPG), or public transport. LPG is an alternative energy source for energy transition due to lesser CO₂, NO_x, and particulate matter emissions compared to gasoline and diesel fuel [18].

Broadbent et al. [19] reported that decarbonizing road transportation will require the use of electric vehicles. Several countries have implemented policies that prioritize the use of electric cars (EVs). For example, China provides direct subsidies for EV users, Norway exempts EVs from taxes and tolls and builds extensive charging facilities [20, 21], and South Korea reduces carbon emissions from diesel vehicles to reduce air pollution [22]. Despite this, the world's countries still struggle to achieve the net-zero emission target by 2050, according to scenarios created by the International Energy Agency [23]. It encourages the EU to strengthen its commitment to achieving net-zero emissions by 2050 [22], supported by government initiatives and automakers.

4.2 Behavioural Research

Behavioral studies show that people choose the types of green transport based on their individual mobility, so systematic strategies to encourage LCM are needed. We found four key themes in the behavioral studies pertaining to LCM: public awareness and perception, economic incentives and disincentives, social influences and rules, and convenience and accessibility.

4.2.1 Public awareness and perception

Studies have consistently shown that public awareness and perception significantly affect people's choice of transport. The higher the environmental knowledge they have, the more they choose LCM modes, e.g., public transport, electric vehicles, walking, and cycling [24, 25]. Public awareness campaigns can encourage sustainable travel behavior by linking perceived environmental risks with everyday mobility decisions. Public opinion also supports governmental actions and policy implementation to promote the transition to sustainable transport [26].

4.2.2 Economic incentives and disincentives

Economic incentives and disincentives greatly influence LCM behavior and government policy. Fuel taxation, subsidies for electric vehicles, and improved public transport services can reduce dependence on fossil-fuel-based transport and urban emissions [27, 28]. Countries like China, the US, Germany, France, and the UK have implemented EV subsidies, tax adjustments, and parking or toll fee reductions, resulting in measurable EV adoption and transport-related economic outcomes [29].

4.2.3 Social influence and rules

Behavioral studies highlight that positive social perceptions and cultural values play an important role in encouraging a shift toward sustainable mobility. As cycling, electric vehicles, and public transport become more popular in society, individuals with strong social and environmental values are more likely to use these modes [30].

4.2.4 Convenience and accessibility

Perceived convenience and accessibility are critical factors influencing the adoption of sustainable transportation modes. When people perceive that public transport, cycling, and electric vehicles are comparatively convenient, they are more likely to switch to these transport modes. Behavioral studies state that supporting infrastructure—cycling lanes, adequate EV charging facilities, and reliable public transport schedules—is crucial to enhance these greener transport modes [31]. Multimodal transport systems further improve accessibility by reducing congestion and supporting efficient urban mobility. Meanwhile, inclusive design in public transport can strengthen social sustainability and broaden the adoption of low-carbon transportation alternatives for people with disabilities, women, and children [32, 33].

4.3 Carbon Reduction

Global commitment to carbon reduction started with the Kyoto Protocol in 1997, followed by the British Government White Paper in 2003, and the Paris Agreement. All EU27 countries, except Croatia and Cyprus, were successful in reducing GHG emissions in 2023. The largest emitters—Germany, France, Italy, Poland, and Spain—reduced 20.1% carbon emissions from the electricity industry and 1.8% from the transportation sector [34].

The present study has found that transport distance and population density contribute to carbon emissions. Therefore, mapping the source of carbon enables local governments to encourage the community to shift from gas-powered vehicles (GVs) to the more sustainable ones, such as EVs [35]. Norway, harnessing 97% of its energy from renewable resources, has reported fewer environmental impacts from EVs and only one concern about pollution due to EV production. In contrast, EVs manufactured in Poland produce 150 grams of CO₂ per kilometer, which is relatively efficient, but the electricity is fueled by coal [36, 37]. Accordingly, the manufacturing process of EVs should use green-sourced electricity to achieve optimal carbon emissions and LCCs [35, 38].

4.4 Non-motorized Transportation

Non-motorized Transportation (NMT), e.g., cycling and walking, is an active mode of transport to support carbon emissions and pollution reduction [39]. Areas with more bus stops or metro stations tend to have more pedestrian activity; therefore, public streetscapes should accommodate pedestrians conveniently [40, 41]. Policymakers in Beirut are considering modifying land in urban design to attract more pedestrians and support LCM [42]. Research in Sao Paulo argued that shifting from car to bicycle, walking, and subway train for journeys within a 1.3 km radius of public transport stations can reduce 11.7% carbon dioxide emissions from vehicles [8]. Empirical studies in Canada reported that the greenhouse gas emissions of NMT vs. automobiles in urban travel were 0 vs. 215 grams per passenger-kilometer [43], and that switching from a car to a bicycle can significantly reduce the life cycle CO₂ emissions by approximately 3.2 kg per day [44]. These data support the claim that increasing the proportion of cycling and walking in a trip is one of the best methods for reducing urban carbon emissions.

Furthermore, incorporating NMT into urban planning is crucial to create sustainable urban environments and decrease urban need for longer travels and reliance on personal cars. For instance, the transit-oriented development models for bicyclists and pedestrians in a compact urban setting can reduce travel length and boost active transportation [45]. By extension, enacting policies in favor of NMT can positively impact public health outcomes [46] and significantly reduce the risk of coronary heart disease [47].

5 Gap Research and Future Trend Analysis

Our close examination of 990 journal articles has found some gaps in the current research on LCM. High-end modes of transport are discussed, but NMT, like cycling and walking, receives very little attention. Walking is weakly linked to LCM (Figure 7) despite numerous advantages associated with NMT, such as lower pollutants, less traffic, and better public health. These advantages provide compelling evidence to incorporate NMT into sustainable urban transportation plans and the LCM framework to reduce emissions and mitigate climate change in countries around the world.

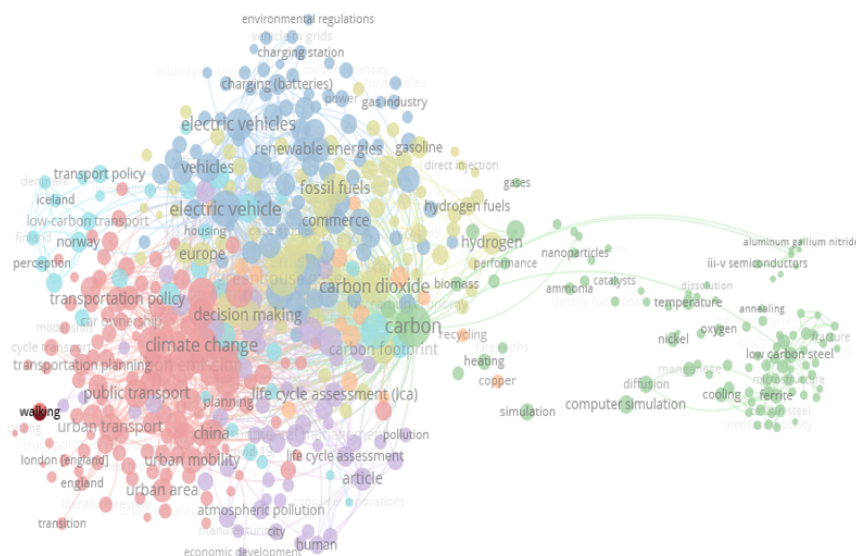


Figure 7. Research gap

6 Conclusion

This research article discusses the latest research trend and research gap in LCM with bibliometric analysis. We used VOS viewer software to analyze the data collected from 990 journal articles related to LCM, map the research trends, and identify future research directions.

We found that research on LCM increased after the UK's 2003 Energy White Paper, the Kyoto Protocol, and the Paris Agreement, marking a 42.7% increase in publications between 2021–2022 and peaked at 139 publications in 2023. The UK and China are among many leading countries in LCM research, with the UK contributing 188 publications (19% of global output) and China producing 138 publications. Upon closer investigation, we identified seven dominant thematic clusters: sustainable development, EV, carbon reduction, renewable energy, air pollution, behavioral research, and CO₂ emissions. From a technical perspective, these clusters are feasible for a conceptual framework of future modelling studies to evaluate LCM strategies based on technological adoption, behavioral factors, and emission indicators. Case studies in various countries demonstrated the significant impact of motorized transportation on urban carbon emissions, air pollution, and the climate crisis. To mitigate this issue, studies suggest that countries' governments implement policies that encourage electric vehicles and green mass transport.

We identified some research gaps, including a limited focus on NMT modes (cycling and walking) and low correlation of research links in developing countries like Indonesia. The potential contribution of LCM to mitigating climate change is evident, but it requires further research to leverage green technology for the transportation sector and to raise public awareness of the importance of LCM.

The future research directions should focus on quantitative modelling of emission reduction potential, behavioral adaptation assessment, and formulating policy frameworks that integrate technical, environmental, and social dimensions for long-term LCM.

Author Contributions

Conceptualization, K.P.A.; methodology, K.P.A. and M.A.B.; formal analysis, K.P.A., B.H.S., and H.S.H.; writing—original draft preparation, K.P.A.; writing—review and editing, K.P.A., B.H.S., H.S.H., and M.A.B.; supervision, B.H.S. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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