

A Comparative Analysis of Low Carbon Road Transport Policies between Poland and India: A Systematic Literature Review Using Prisma

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Abstract: The road transport industry is one of the largest carbon-emitting sectors globally. Consequently, it is important to assess the development of the low-carbon policy literature to decarbonize the transportation sector. This study analyzes the low-carbon road transport (LCRT) policies in a developed country, Poland, and a developing country, India, over the past two decades – two countries with distinct socioeconomic contexts but similar environmental objectives. A total of 84 studies were identified through Scopus, Google Scholar, Research Rabbit, and government repositories. Of these, 39 manuscripts met the selection criteria and were included in the review. The PRISMA 2020 checklist was used for methodological evaluation. The findings indicate that Poland outperforms India in technological advancement, infrastructure development, road safety, and digitalization. Both countries need to align their policymaking trajectories with public participation and adopt a multidimensional, people-centric approach. A notable gap in the existing literature is identified: this study provides an in-depth analysis focused exclusively on low-carbon road transport, while broader transportation services remain outside the scope of the research.

Keywords: low-carbon policies, transport policies, policy analysis, systematic review, comparative analysis

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1. Introduction

The transport sector is one of the leading contributors to carbon emissions. The transportation sector accounts for approximately 75% of total greenhouse gas emissions [1], while road transport contributes nearly 40% of total primary PM2 emissions, and more than 40% of nitrogen oxide emissions across all sectors [2]. Road transport consumes 2.25 times more energy and emits 2.32 times more greenhouse gases than rail transport for the same freight load [3]. The transportation industry continues to be a significant source of harmful gases, particulate matter, and nitrogen dioxide pollution, all of which have increased over the past three decades [2, 4]. Conventional fuel-based passenger cars remain the largest contributors to dust and gaseous pollution, along with NOx and particulate matter worldwide [4]. The adoption of low-carbon (LC) transport policies presents a potential solution to these complex problems. Sustainable mobility involves a transition away from traditional, often polluting and environmentally damaging modes of transportation toward eco-friendly alternatives. This approach encompasses hybrid transport systems, technological advancements, sustainable planning, and public education [5]. Therefore, improving public transport systems and infrastructure, introducing non-motorized vehicles, investing in green initiatives, and prioritizing biofuel research are highly essential [6–8].

The decarbonization of transportation sectors has become a top policy priority, as countries worldwide seek to fulfil their international climate commitments and achieve sustainable development goals. Consequently, with the growing population and urbanization, the transport sector has seen a rapid increase in vehicle numbers and passenger transport. The European Environment Agency (EEA) predicts a global increase of 310.1 Mtoe in transport energy demand by 2030 with road transport consuming the highest share of energy compared to other transport modes [9]. Projections indicate that by 2035, the energy demand in the transport sector will increase by 4.4 times, resulting in an additional 4 million t of CO₂ emissions; however, these emissions could be reduced by up to 50% if LC policies are strictly enforced [4]. Air pollution, excessive energy consumption, depletion of resources, and environmental degradation are all significantly influenced by the transportation sector. The transition to Low Carbon Road Transport Policy (LCRT) is influenced by geographic conditions, demographic, and socioeconomic differences, as well as governance issues in both developed and developing economies. In this context, two contrasting case studies were selected: Poland and India; the two countries differ in terms of the aforementioned conditions, with Poland representing a developed economy and India a developing economy. Despite a shared dependency on the fossil fuel-based transport system, the indicators and challenges influencing policymaking in these divergent contexts remain an important and compelling area of investigation.

Indian cities that have adopted green policies and low-carbon initiatives in transport, along with community participation, have shown a significant reduction in carbon emissions [6, 10]. In 2010, private vehicle ownership in India remained relatively

low at 15.7 cars and 81.7 two-wheelers per 1,000 people, significantly below the levels seen in most developed countries [6]. Similarly, electric buses powered by batteries are currently operating in several Polish city centers [11]. In addition, private operators have installed more than 75 fast EV charging stations across Poland [12]. Grid upgrades and widespread smart meters are needed to support large-scale electric vehicle adoption [13]. Understanding the current variations in transport patterns across Indian states, projecting these trends into the future using robust methodologies, and designing national policies that align with global carbon mitigation efforts are critical areas of study [8]. Such contextual understanding prior to policy formulation is equally important for Poland. This article aims to review the following aspects:

- analysis of the current state of LCRT policies in Poland and India;
- challenges faced by these policies based on key policy indicators.

2. Methodology

2.1. Search Strategy

This study follows the PRISMA framework [14] to conduct a systematic review of the literature. Peer-reviewed articles and official government documents published over the last twenty years (2005–2025) were considered the most reliable sources for this review. A well-defined search strategy was prepared to identify peer-reviewed articles in databases such as Scopus, Web of Science (WoS), Research Rabbit, and Google Scholar, using combinations of keywords like (“low-carbon road transport” OR “sustainable transport” OR “decarbonization of transport”) AND (“policy analysis” OR “policy framework” OR “policy comparison”) AND (“Poland” OR “India”); (“road transport policies” OR “transport regulations” OR “transport strategies”) AND (“carbon emissions” OR “CO₂ emissions” OR “greenhouse gases”) AND (“India” OR “Poland”) AND (“policy comparison” OR “case study” OR “systematic review”). In parallel, government documents on transport policies were collected from official websites. However, a gap in the literature persists as the current study is an in-depth analysis focused on LCRT policies. Therefore, broader transport services are beyond the scope of this research and are not examined.

Inclusion criteria:

- published in peer-reviewed journals;
- official government documents;
- manuscripts published within the last twenty years;
- studies in the environment, economics, and social sciences.

Exclusion criteria:

- manuscripts written in languages other than English;
- duplicate documents;
- manuscripts that analyze road transport strategies without focusing on low-carbon initiatives.

2.2. Selection of Indicators

After a rigorous review of the literature, it was observed that most of the LCRT policy analysis studies have considered social, economic, technological and behavioral variables while keeping environmental criteria as the central theme. Together, these criteria support the development of a holistic approach to LCRT policy. Environmental indicators consist of the use of renewable energy sources, the promotion of the energy mix, pollution control measures, the enforcement of low-emission zones in urban areas and the expansion of green spaces. Economic instruments such as market-based mechanisms, enforcing carbon taxes, providing green subsidies and creating incentives, and green jobs can decouple GDP growth from carbon emissions and drive investment in sustainable practices. The availability and affordability of public transport services, the integration of policies at the local and national level, the consideration of public perception, public health, and safety measures, are crucial features of the social indicator. However, the inclusion of infrastructural development, which incorporates electric, biofuel, and hydrogen-powered vehicles, the construction of transport networks, focusing on research, cross-border cooperation, and knowledge transfer, reflects sustainable advancement. The importance of altering individual choices regarding vehicle type, changing personal attitudes, reduced reliance on private vehicles, using public transport, greater uptake of walking and cycling through awareness campaigns and workshops is mentioned in the behavioral indicator. Together, these indicators ensure an economically viable and socially acceptable sustainable policy framework crucial for transitioning to low-carbon mobility.

2.3. Database Creation

A PRISMA 2020 diagram (Fig. 1) illustrates a structured and transparent procedure for the systematic selection of literature published between 2005 and 2025. This detailed breakdown enhances transparency and enables readers to clearly understand the processes of literature identification, screening, and exclusion. Initially, a total of 84 studies were collected from various repositories. Duplicate records were removed first, followed by a detailed abstract screening to ensure relevance. Finally, 39 manuscripts were selected for evaluation.

Table 1 summarizes the reasons for excluding manuscripts initially identified for review. During title and abstract screening, these articles were removed based on the primary research objectives and thematic relevance. The most frequent reason was misalignment with the core focus of the study, 'not focusing particularly on low-carbon road transport' ($n = 6$). Other eliminations consist of studies that evaluated 'only health impacts of transport' ($n = 1$), those 'focusing on climate policy' ($n = 3$), based on 'the context of COVID-19' ($n = 1$), reports 'not specific to India or Poland' ($n = 4$), 'non-scientific manuscripts' ($n = 2$), 'review article' ($n = 2$), 'a gender-based approach' ($n = 1$), and those combining 'agricultural and transport policy approaches' ($n = 1$).

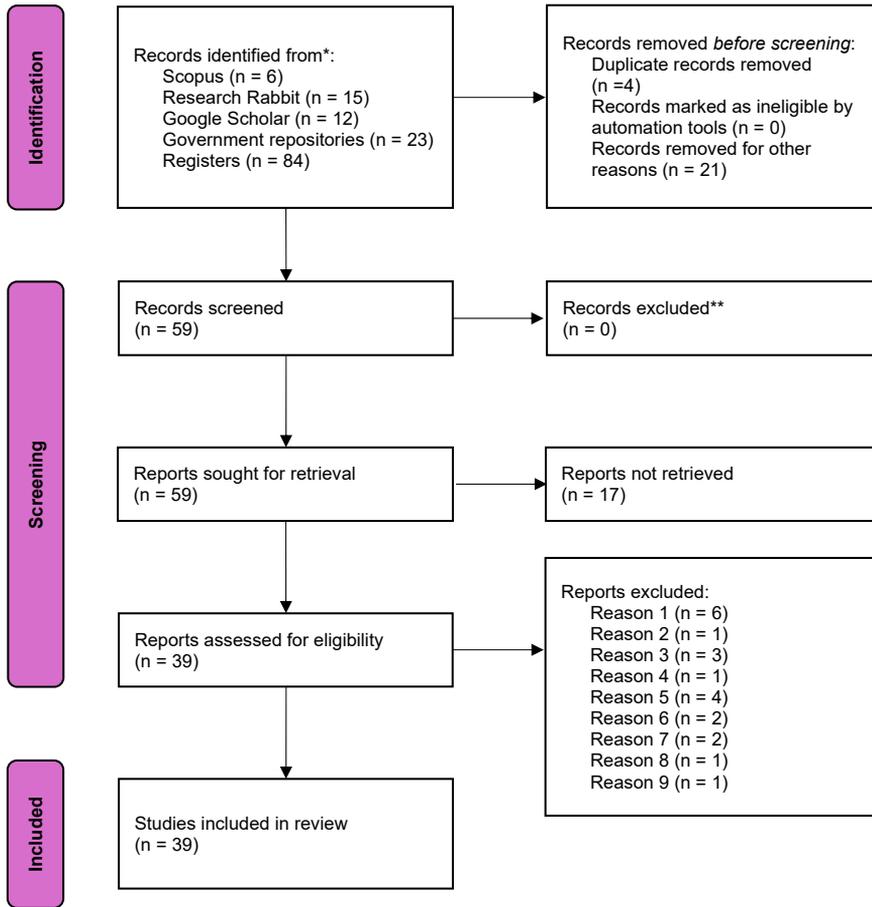


Fig. 1. PRISMA 2020 flow diagram

Table 1. Reasons for exclusion of manuscripts

No.	Reason for Exclusion	Records Excluded
1	Scope of the study was not specifically limited to low-carbon road transport policies	6
2	Assessment of human health impacts due to transport services	1
3	Studies primarily focused on climate policies	3
4	Studies limited to COVID-19 context	1
5	Studies unrelated to defined areas	4
6	Studies that are not scientific manuscripts (e.g., guidebooks or reports)	2
7	Review articles	2
8	Study related to a gender-based approach	1
9	Study related to agriculture and transport policy	1

3. Results

3.1. Manuscript Characteristics

The evaluation of road transport policies is crucial for understanding whether existing policies align with the country's decarbonization goals. Table 2 (on the interleaf) illustrates the indicators used in the selected manuscripts and the policy measures identified through the literature search. This analysis helps determine the key variables shaping low-carbon transport policies, identify less dominant factors, highlight existing policy gaps, and explore potential ways to bridge these gaps.

3.2. Existing Policy Characteristics

Government policies in both countries tried to improve transport facilities for citizens through policy reforms. The National Urban Transport Policy and the National Policy on Biofuels [30] brought a revolution in the Indian transport sector by introducing an energy mix and promoting the use of clean fuel; in Poland the Alternative Fuels Infrastructure Directive [31] was implemented to develop infrastructure for the use of CNG, LNG and hydrogen. India's Bharatmala Pariyojana [32] connected 550 districts through the construction of highways. Furthermore, these policies were integrated with land-use planning and created job opportunities. The FAME (2015–2024) policy was introduced to accelerate progress in EV adoption throughout India, while Poland launched the Electromobility Development Plan [13]. The government of Poland used the EU Trans-European Transport Network to improve nationwide mobility conditions. Polish Centre for Climate and Energy Analyses (Centrum Analiz Klimatyczno-Energetycznych, CAKE) [33] aims to reduce CO₂ emissions from the transport sectors by 74%. CAKE [33] has a lot of potential, but the overall achievements are expected to be assessed in 2050. Most of these policies were people-centric and highly commendable, but failed to fully achieve their targets due to a lack of funds, inefficient planning, and conflicts between central and state governments as seen in Table 3 (on the interleaf).

4. Discussion

4.1. LCRT Scenario in Poland and India

Document Analysis

This review aimed to systematically analyze the variation in the design, implementation, and effectiveness of policies in India and Poland. Almost 80% of the manuscripts directly discuss LC transport policies. Various researchers discuss distinct context-specific policy measures to promote LC road transport policies.

Table 2. Review of low-carbon policy indicators and policy recommendations

No.	Citation	Title	Keywords	Methodology	Indicators					LC Policy Measures
					Environmental	Economic	Technological	Social	Behavioral	
India										
1	Pathak & Shukla, 2016 [15]	Co-benefits of low carbon passenger transport actions in Indian cities: Case study of Ahmedabad	Low-carbon transport; cities; co-benefits; scenarios	Extended snapshot modeling (ExSS), bottom-up approach, and BAU scenario	YES	YES	YES	YES	–	Improvement of public transport facilities, development of infrastructure, introduction of non-motorized vehicles, increased green funds and focus on biofuel and technological advancement are advised
2	Verma et al., 2021 [16]	Evolution of urban transportation policies in India: A review and analysis	Urban transportation; transportation policies; sustainability; developing economies	Literature review, descriptive statistics	YES	YES	–	YES	–	Promotion of equitable transportation, use of non-motorized vehicles and enhancement of public transit are highly encouraged
3	Dhar et al., 2017 [6]	Electric vehicles and India's low carbon passenger transport: A long-term co-benefits assessment	CO ₂ mitigation; co-benefits; electric vehicle; electricity demand	System model ANSWER-MARKAL	YES	YES	YES	–	–	Electrification of two- and three-wheeler vehicles, green infrastructure development, investment in renewable energy generation for electricity production are suggested
4	Manohar et al., 2016 [4]	Integration of on-board diagnostics with system dynamics to study road transport pollution	On-board diagnostics; carbon monoxide; system dynamics; vehicular pollution; transport policies	System dynamics approach	YES	YES	–	–	–	Mandatory installation of on-board diagnostics (OBD) in all private vehicles, improvement of public transportation systems, campaigns promoting green transportation, and strict law enforcement are strongly required
5	Dhar & Shukla, 2015 [10]	Low carbon scenarios for transport in India: Co-benefits analysis	Transport demand; CO ₂ mitigation; co-benefits; energy security	Descriptive statistics	YES	–	–	–	–	Implementation of target-oriented policy measures and efficient green electricity production aligned with global targets should be the focus of policy framing
6	Khandelwal, 2020 [7]	Case studies of sustainable road transport practices in different industry sectors in India	Environmental sustainability practices; case studies on sustainability; road freight transportation; green logistics; and transportation	Qualitative case study approach	YES	YES	YES	YES	–	Providing standardized carbon emission accounting in freight transportation to enable businesses to track and compare their sustainability initiatives, encouraging voluntary carbon footprint disclosure and framing sector-specific policies, mandating eco-driving, rural infrastructure development, technological upgrading, and green fuel investment should be considered
7	Ahmed et al., 2020 [17]	Transport CO ₂ emissions, drivers, and mitigation: An empirical investigation in India	Transport CO ₂ emissions; India; urbanization; economic growth; oil prices	Inferential statistics	YES	YES	YES	YES	–	The use of renewable energy sources, energy-efficient practices, tax breaks, financial incentives, support for green businesses, public awareness and the enforcement of strict environmental laws are proposed
8	Bhatia & Sharma, 2024 [3]	Trends and policy analysis: A case for sustainable transport systems in India	Transport; policy; railways; rail infrastructure; road transport; sustainable transport	Mixed-method approach combining data envelopment analysis (DEA) and the Malmquist productivity index (MPI)	YES	YES	YES	YES	–	Establishing a nodal agency with participation from central, state, and local governments, as well as other stakeholders for better coordination is suggested. Together with enhancement of the performance and design of freight vehicles, discouraging driving on days with high pollution, parking fees and tolls based on daily AQI (air quality index) levels should be collected and allocated to upgrade the infrastructure for non-motorized and public transportation. Providing tax breaks, incentives, alternative fuels, and EVs is also recommended

Table 2. cont.

No.	Citation	Title	Keywords	Methodology	Indicators					LC Policy Measures
					Environmental	Economic	Technological	Social	Behavioral	
9	Mittal et al., 2015 [8]	Air pollution co-benefits of low carbon policies in road transport: A sub-national assessment for India	Low-carbon; air quality; road passenger transport; co-benefits; AIM/end-use models	Asia-Pacific integrated assessment/end-use models, inferential statistics	YES	YES	YES	YES	–	It is important to align global and local low-carbon policies to decarbonize transport systems and regional-level planning strategies should be tailored to the specific requirements of each region. Promoting EVs in small cities can play a crucial role in reducing carbon emissions. Implementation of strict carbon taxes is strongly encouraged
10	Agarwal et al., 2020 [18]	Bicycle superhighway: An environmentally sustainable policy for urban transport	Bicycle superhighway; sustainable transport; emissions; accessibility; mixed traffic; MATSim	Simulation modeling	YES	YES	YES	YES	–	The paper highlighted the importance of restricting motorized vehicle use and promoting bicycles in India, which should be aligned with safety regulations, the construction of separate bicycle pathways and equity-sensitive transport planning
11	Dwivedi et al., 2025 [19]	Effectiveness assessment of government promotional policy framework towards climate-neutral mobility in Indian context	Electric vehicles; promotional policies; multi-criteria decision making (MCDM); robustness assessment	Multi-criteria decision making (MCDM) approach	YES	YES	YES	YES	YES	The government should focus on improving infrastructure, establishing more charging points, battery recycling and insurance policies, and providing subsidies for road tax, registration fees and EV manufacturing; industry-academia collaboration should be promoted. Moreover, campaigns and workshops to encourage and educate people regarding EV use and environmental awareness should be expanded
12	Jasti & Ram, 2016 [20]	Integrated and sustainable service level benchmarking of urban bus system	Benchmarking of sustainability; performance evaluation; bus system; public transportation; sustainable benchmarking	Multi-criteria decision-making (MCDM) approach	YES	YES	–	YES	–	Transition from traditional buses to electric, CNG or hybrid models can decrease harmful emissions. Introducing public-private partnerships, demand-based service facilities and passenger feedback collection are important
13	Javed & Nia, 2023 [21]	A shift towards e-mobility in Indian: Challenges and innovations	E-mobility; policy imperatives; sustainability; affordability; availability	Qualitative analysis	YES	YES	YES	YES	–	Government should place emphasis on the affordability of EVs, provide incentives, and prioritize infrastructure development as a first step. In addition, electric buses are an excellent option as they can carry more people and are more efficient than small vehicles; spreading awareness about EV adoption, and encouraging a shift toward public transportation should be strongly encouraged
Poland										
1	Pyra, 2023 [22]	Simulation of the progress of the decarbonization process in Poland's road transport sector	Decarbonization; road transport; emission performance; simulation; sustainable transport; EU climate policy; emission reduction	SWOT (strengths, weaknesses, opportunities, threats) analysis	YES	YES	–	YES	–	Introducing car-free zones, shared mobility platforms and infrastructural development need to be prioritized
2	Pietrzak & Pietrzak, 2020 [2]	Environmental effects of electromobility in a sustainable urban public transport	Electromobility; electric vehicles; EVs; air pollution; transport; public transport; urban transport; sustainable transport; transport management; transportation systems	Case study, descriptive statistics	YES	–	–	–	–	Gradual transition to electric buses, an increased share of renewable energy, the development of an integrated transport network, more charging stations for EVs are recommended

Table 2. cont.

No.	Citation	Title	Keywords	Methodology	Indicators					LC Policy Measures
					Environmental	Economic	Technological	Social	Behavioral	
3	Patalas-Maliszewska et al., 2021 [11]	Modelling the effectiveness of intelligent systems in public transport that uses low-carbon energy: A case study	Electric buses; intelligent transportation system; public transport; smart city; smart mobility	Preparation of a matrix	YES	YES	YES	YES	–	Evaluation of the efficacy of implemented policies and ITS (intelligent transportation systems) in promoting low-carbon transport is recommended
4	Burchart-Korol et al., 2020 [23]	Research and prospects for the development of alternative fuels in the transport sector in Poland: A review	Alternative fuels; electromobility; transport sector; development of alternative fuels in Poland	Life cycle analysis (LCA), descriptive statistics	YES	–	YES	YES	YES	Updating transport technologies, introducing low-carbon fuels, and setting emission standards, along with awareness programs to change public behavior, are recommended
5	Lis & Szymanowski, 2022 [12]	Greening Polish transportation? Untangling the nexus between electric mobility and a carbon-based regime	Electric mobility transition multi-level perspective; historical institutionalism; semi-periphery; carbon-based regime; political economy	Qualitative analysis of policy documents	YES	–	–	–	–	Inclusion of public participation, increased policy transparency, development of balanced policies, and cooperation among governments and NGOs will be helpful policy measures
6	Guzik et al., 2021 [24]	The second generation electromobility in Polish urban public transport: The factors and mechanisms of spatial development	Electromobility; zero- and low-emission buses; urban public transport; cities; sustainable mobility; energy transition; Poland	Mixed-method approach: statistical analysis, scoring-based classification, and spatial mapping across 242 urban transport systems	YES	YES	YES	YES	–	Improved cooperation between the national and local governments is necessary. In addition, a shift from the EU project-based approach toward long-term development goals, along with improvements in peripheral public transport, is proposed
7	Ambroziak et al., 2013 [25]	Identification and analysis of parameters for the areas of the highest harmful exhaust emissions in the model EMITRANSYS	Pro-ecological transport system; transport; air pollution; emission of exhaust gases; EMITRANSYS	Mathematical modeling approach (EMITRANSYS)	YES	–	YES	–	–	Following a sustainable approach to the transportation system including uniform infrastructure development in all rural and urban areas to promote non-motorized vehicles, setting strict emission standards, eliminating outdated vehicles, managing traffic congestion, creating low-emission zones is strongly recommended
8	Dzikuć et al., 2021 [26]	Modernization of the public transport bus fleet in the context of low-carbon development in Poland	Emissions; buses; public transport; scenario analysis; Poland	STEAM (set of tools for energy demand analysis and modeling)	YES	YES	YES	YES	–	This study suggests the use of CNG/LNG powered vehicles in the transitional phase as these are cost-effective compared to EVs. Additionally, providing subsidies, co-financing programs for green transportation, restricting old vehicles, increasing parking fees, creating low-emission zones in urban areas and encouraging local governments to be proactive can reduce carbon emissions
9	Rabiega et al., 2021 [27]	How long will combustion vehicles be used? Polish transport sector on the pathway to climate neutrality	Passenger transport; freight transport; electromobility; electric vehicle (EV); fuel cell vehicle (FCEV); scrappage rate; CO ₂ emissions; climate neutrality; partial equilibrium model	TR3E partial equilibrium model	YES	YES	YES	–	–	Government should implement a ban on ICE (internal combustion engine) vehicle sales by 2035, enforce strict laws, carbon tax on non-ETS (Emission Trading System) sectors, promote zero emission vehicles, and prioritize investment in renewable sectors when framing low-carbon (LC) policy

Table 2. cont.

No.	Citation	Title	Keywords	Methodology	Indicators					LC Policy Measures
					Environmental	Economic	Technological	Social	Behavioral	
10	Gupta, 2021 [28]	A fuzzy decision-making approach to evaluate CO ₂ emissions reduction policies	Road transport; CO ₂ emissions; fuzzy set theory; ordered weighted average operator	A fuzzy decision-making framework	YES	YES	YES	YES	YES	Combination of policy options suggested to prioritize sustainable fuels and low-emission vehicles including fuel taxes, vehicle ownership duties, expansion of public transportation, sustainability-oriented behaviors (such as eco-driving, walking, and cycling), congestion fees and green transportation subsidies to reduce CO ₂ emissions
11	Brzeziński & Kolinski, 2024 [5]	Challenges of the green transformation of transport in Poland	Green transformation; green transformation of transport; challenges of green transformation; strategy of green transformation; greening transport	SWOT analysis and descriptive statistics	YES	YES	YES	YES	YES	Commencing pro-ecological policies, funding pro-ecological companies, supporting education, research and development, international collaboration, and awareness among people to change travel habits strongly recommended
12	Verma et al., 2023 [1]	Local resilience for low-carbon transition in Poland: frameworks, conditions, and opportunities for Central European countries	Bibliometric analysis; energy policy; low carbon economy plan; Polish cities; resilience; stakeholders; sustainable energy transition	Bibliometric analysis	YES	YES	–	YES	YES	Polish cities are advised to tailor city-level low-carbon policies, increase the share of renewable energy sources, promote environmental education, provide subsidies for green initiatives, and encourage public participation to drive behavioral change
13	Godzisz et al., 2021 [29]	Selected determinants of sustainable transport in the context of the development of a low-carbon economy in Poland	Energy; economy; low-carbon development; electromobility; road transport	Deductive approach and descriptive statistics	YES	–	YES	–	–	Preventive planning of urban management, restoration of habitats, promotion of electric vehicles and eco-friendly infrastructure for this purpose are considered essential

Table 3. Strengths and weaknesses analysis of government-enforced transport policies

Title	Year of Adoption	Strength	Weakness	Publisher
Electromobility Development Plan in Poland “Energy for the Future”(Government of Poland, Ministry of Energy, 2018) [13]	2018	The policy considers the energy sector, the existing transport scenario, and industrial capacity to reach its target of mobilizing up to 1 million EVs by 2025. It aims to promote better health by reducing air and noise pollution in cities and to ensure energy self-sufficiency for electricity generation from renewable sources to meet the demand for EVs. By following a three-phase plan (2016–2025), it mandates that 50% of public fleets be electrified by 2025 aiming to lead market adoption and introduce dynamic pricing mechanisms to enable EVs to support energy demand	The initial high investment has partially delayed the progress of this policy. The cost of EVs is higher compared to traditional cars, making them less affordable; limited availability of fast-charging stations between cities hinder long-distance travel. Additionally, Poland relies on imported EV battery components, reducing its independence. Consequently, the preference for traditional vehicles over EVs, poor coordination between academia, research, industry, slow innovation, and start-ups remain key obstacles	Government of Poland
Alternative Fuels Infrastructure Directive (Government of Poland, Ministry of Energy, 2019) [31]	2019	This policy established rules for all EU members to develop infrastructure for electricity, hydrogen, LNG, and CNG, aiming for a unified internal market and required adoption by Poland. There are strict deadlines for providing public recharging and refueling points, including urban areas and TEN-T routes, by 2025. The policy seeks to promote low-emission transport across roads, ports, and airports in accordance with the EU’s climate goals. This policy established a feedback mechanism for the progress of the Commission through regular reviews	Despite the presence of stringent deadlines and ambitious targets, many National Policy Frameworks (NPFs) remain incomplete by 2025. For instance, hydrogen projects, shore-side electricity operations, and vehicle deployment projections. Poland set ambitious EV targets, but lacked the infrastructure necessary to fulfil them. Hydrogen and LNG plans were often minimal or underdeveloped, and targets for charging-vehicle density varied widely. Furthermore, insufficient infrastructure at airports and ports has led to slower decarbonization	Government of Poland
CAKE report (Poland Net-Zero 2050: The Role of Public Transport in the Context of the ‘Fit for 55’ Package) [33]	2022	This policy aligns with EU goals, including the 2035 ICE vehicle ban and a 74% CO ₂ reduction in transport by 2050. It promotes shifting from private cars and short flights to rail and bus travel, potentially reducing the need for 1 million EVs. Passenger transport emissions are projected to fall to 8 Mt CO ₂ by 2050, with significant cost savings for buses (37%) and rail (–35%). The policy supports subsidies and efficiency improvements to boost public transport use. By 2050, electric buses will make up 53% of the fleet and hydrogen buses 20%, requiring major energy infrastructure upgrades. This policy models various scenarios and includes €47 billion investments to support the transition	Success hinges on political commitment, inter-agency coordination, and consistency	Government of Poland
Poland Transport Policy (World Bank, 2011) [34]	2011	This policy has utilized EU funds through the Trans-European Transport Network (TEN-T) program to upgrade major road and rail infrastructure with the aim to improve national and regional connectivity while focusing on socio-economic, institutional and environmental dimensions in Poland. This approach offers a strategic balance between mobility, sustainability and financial considerations. It aims to reduce emissions through transport network management, multisector coordination, and capacity building (e.g., the National Road Safety Council, and reforms within GDDKiA), as well as road safety measures, pricing reforms, eco-driving, support for EVs, and the promotion of non-motorized transport	Overinvestment in improving the road network accelerated rapid vehicle growth but weakened rail competitiveness and failed to meet emission reduction goals, while the railway sector remained underfunded with outdated infrastructure. This policy raised fiscal concerns due to excessive reliance on EU funds and low rates of road and fuel taxes. High costs and inefficient coordination between central and local authorities contributed to the decline of the rail system	Government of Poland
Emission Reduction Strategies for the Transport Sector in Poland (Transport & Environment, 2018) [35]	2018	It analyses emissions from Poland’s transport sector between 1990 and 2016, identifying a 2.5-fold increase. Using the EUTRM model, it projects results under various initiatives. It proposes national actions such as limiting CO ₂ emission levels, fuel tax reform, ZEV mandates, and road charges based on pollution. Modal shifts, electrification strategies, and behavioral change are also taken into account. These combined efforts have the potential to reduce 58% of the emissions gap by 2030. It also highlights Poland’s strength in electric bus production and urges leveraging this advantage. The plan is technically and economically viable with political assistance	Many initiatives remain incomplete due to lack of budget and weak political commitment. Without a dedicated plan, Poland could exceed its 2030 climate targets by 47.2 Mt CO ₂ e, resulting in fines or requiring purchasing up to 297 million emission allowances. Despite being ambitious, the country’s progress in EV goals, electrification, and charging infrastructure remains slow. Moreover, the ageing vehicle fleet in Poland (average age of 17.3 years) hinders emission cuts. Inconsistent tolling and heavy reliance on coal fail to promote cleaner vehicles effectively and undermine the climate benefits	Government of Poland

Table 3. cont.

Title	Year of Adoption	Strength	Weakness	Publisher
National Policy on Biofuels (Government of India, Ministry of New and Renewable Energy, 2009) [30]	2009	Promotes renewable and indigenous resources to reduce dependence on imported fossil fuels while encouraging plantations on wastelands, generating jobs and income for farmers and laborers. Led by the Prime Minister, the National Biofuel Coordination Committee ensures high-level coordination. The policy offers fiscal incentives, financial support, and advances research on second-generation biofuels while avoiding the food vs. fuel conflict by prohibiting the use of agricultural land and edible feedstocks	The policy sets a 20% blend goal, but lacks mandatory targets for biodiesel and clear enforcement. It leans on the current oil marketing infrastructure without defined upgrade timelines. Implementation details, especially at the state level, are vague. Dependence on multiple agencies may cause bureaucratic delays. Although FDI is promoted, restrictions on plantation land limit private sector involvement in early-stage production	Government of India
Bharatmala Pariyojana (India's national highway development programme) (Government of India, Ministry of Road Transport and Highways, 2017) [32]	2017	This policy aims to connect 550 districts through National Highways using technology-driven tools like traffic surveys and satellite mapping. This is expected to boost trade, create logistics hubs, and generate employment. Additionally, it is expected to cut logistics costs by over 25% and enhance connectivity with neighboring countries and coastal areas	This kind of mega large-scale construction is likely to impact the natural ecosystem and biodiversity. Legal challenges and opposition have delayed progress and timely implementation. The ongoing maintenance of the vast road network demands continuous funding; the proposed investment of INR 5.35 trillion (US\$ 61.18 billion) could place significant pressure on public finances	Government of India
National Urban Transport Policy (Government of India, Ministry of Urban Development, 2009) [36]	2006	This policy represents a people-centric approach. It promotes cleaner fuels, public transport, land-use planning, high-occupancy vehicles, and it does not support a one-size-fits-all framework	The policy outlines strategies, but lacks clear timelines and a phased implementation framework. It offers limited enforcement measures, risking the failure of initiatives like bus lanes and non-motorized corridors. Excessive reliance on land monetization may benefit wealthier cities, while sidelining poorer areas. Although it acknowledges paratransit issues, it lacks concrete plans for their integration. Furthermore, the policy could do more to address the mobility needs of women, seniors, and people with disabilities, and it fails to define success metrics or evaluation mechanisms	Government of India
National Urban Transport Policy (revised) (NUTP) (Government of India, Ministry of Urban Development, 2009) [37]	2014	This policy focuses on public-centric principles like affordability, accessibility, and equity while encouraging public transport and non-motorized transport. It encourages all cities to prepare Comprehensive Mobility Plans (CMPs), land-use planning, the integration of transport networks, incorporating Intelligent Transport Systems (ITS), and the National Mobility Card. Moreover, it encourages public-private partnerships for transport development projects and seeks to protect vulnerable road users based on age groups prone to road accidents	Implementation of the policy has been delayed due to the absence of compulsory enforcement mechanisms and financial constraints. It also lacks a robust monitoring system, prudent decision-making authorities at the city level, service benchmarks, effective interagency coordination, and adequate skilled personnel. Furthermore, overlapping functions among various organizations create inefficiencies in transport governance, particularly in the public sector. Fragmented and paratransit systems are frequently neglected, despite their importance. Although the policy adopts a public-centric perspective, local participation in planning remains limited. Consequently, the NUTP can be seen as a more theoretical framework than a policy that has been effectively implemented	Government of India
FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) (Government of India, Ministry of Heavy Industries, 2015) [38]	2015–2019	INR 8.95 billion (US\$ 104 million) was invested for promoting electric vehicles projects, technological and infrastructural development. A total amount of INR 3.6 billion (US\$ 41.1 million) in subsidies was provided to 285,000 buyers. By the end of 2019, the total funds utilized were reported to be INR 5.29 billion (approximately US\$ 60.5 million)	Despite advances, this represents a relatively minor accomplishment given the size and population of the country. Additionally, public and commercial vehicles received more attention than private vehicles. Batteries and other essential EV components are still largely imported, a situation that hinders local manufacturing targets	Government of India
FAME II (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles – Phase II) (Government of India, Ministry of Heavy Industries, 2015) [39]	2019–2024	This project invests INR 104.99 billion (approximately US\$ 1.20 billion) to boost EV demand across two-, three-, and four-wheelers, with a focus on e-buses, charging stations, and shared mobility. This is expected to support a reduction of approximately 120,000 t of CO ₂ emissions. It supports research and development to build domestic manufacturing and charging infrastructure, raise consumer awareness, and aims to cut fossil fuel use	Despite these admirable initiatives, this policy has struggled to meet its goals across states. EV charging infrastructure remains underdeveloped, while expensive batteries, limited consumer awareness and low consumer trust continue to hinder EV adoption	Government of India

Table 3. cont.

Title	Year of Adoption	Strength	Weakness	Publisher
National Electric Mobility Mission Plan (NEMMP) 2020 (Government of India, Ministry of Heavy Industries and Public Enterprises, 2012) [40]	2012	This policy envisaged the sale of 6–7 million hybrid and electric sales by 2020 to boost fuel security. It promotes collaboration among stakeholders via the National Council for Electric Mobility (NCEM) and the National Board for Electric Mobility (NBEM) and offers subsidies to lower initial costs and escalate the adoption rate. It also focuses on local manufacturing, addressing research and development, charging networks, supply chains, and public awareness	The rollout of the policy has been delayed and inconsistent. Limited public awareness and low confidence in EVs are affecting purchase decisions. The key components for manufacturing are still largely imported, undermining India’s self-sufficiency	Government of India
Motor Vehicles (Amendment) Act (Government of India, Ministry of Law and Justice, 2019) [41]	2019	This policy has imposed strict traffic laws, mandatory driver training, helmet requirements, and high penalties. It regulates services such as Ola and Uber, introduces a vehicle recall system, and allows authorities to mandate manufacturers’ safety upgrades to ensure passenger safety. Another positive aspect is the creation of a national register, along with online registration and certification systems to enhance transparency; these measures provide legal safeguards for accident victims, clearly define the rights of third-party victims and insurance claimants, and mandates a streamlined settlement process to ensure quicker compensation by insurers	Several states are opposing this policy, causing resistance to successful nationwide implementation. The stricter and higher penalties for violating traffic rules can be significant challenge for low-income groups and the underlying causes of traffic violations may remain unaddressed. There is a lack of public awareness regarding the new rules, insurance policies, traffic guidelines, and infrastructure limitations. Additionally, centralized digital records create concerns about data privacy and security due to the lack of well-defined protective measures	Government of India

Figure 2 presents the thematic associations of within the literature with “transport” as the central node, closely linked to other master terms such as “policy” and “analysis.”

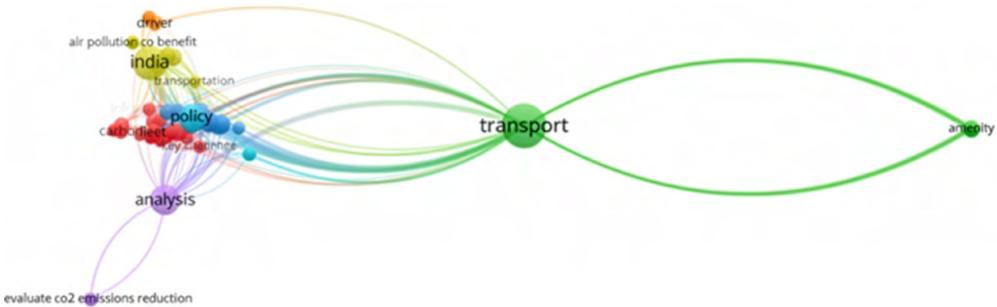


Fig. 2. Bibliometric representation

This network highlights the multidimensional nature of LC transport studies, where technological progress, policy analysis, and geography intersect. The prominence of terms like “amenity,” “fleet,” and “driver” reflects the broad thematic areas ranging from infrastructure and environmental benefits to issues related to behavior. The map was generated using VOS viewer (1.6.20) (Fig. 2). The analysis indicates several distinct clusters of research emphasis. The green cluster links transport to amenities, with increasing sensitivity to demand for less polluting but more livable transport modes, improving quality of life and urban livability. The blue and red clusters focus on policy, fleet transition, and investment in infrastructure, indicating the relevance of institutional choices and technological change in shaping the outcomes of the LC transport. The yellow cluster, dominated by India, captures the increasing emphasis on the specific concerns and opportunities in developing economies, with a policy of transport growth and a response policy still to emerge. The purple cluster is closely associated with analysis and appraisal, as well as a trend toward more quantitative, evidence-based policy analysis approaches over the last few years.

A striking result of Figure 2 is the relatively weak connectivity of the behavior components, such as mindset change and sustainability-oriented behavior, with transport as the hub node. This reflects a gap in the literature, where most attention remains in technological and policy measures, and far less attention is paid to behavioral change despite its known contribution to achieving long-term emission reductions. Furthermore, the topology of the network mirrors the fact that most of the research is clustered around specific solutions, such as EV rollout, clean fuel adoption, and carbon pricing, whereas more systemic challenges, including equity, social acceptance, and integration of land-use planning, are less apparent. This means that additional research might be needed to take on a more holistic viewpoint, encompassing both the hard and soft dimensions of LC transport transitions.

The positioning of India within the network also highlights the importance of learning from beyond the EU context. Given the scale of urbanization, transport demand, and air pollution challenges in India, learning in this context not only enriches the global debate but also helps identify scalable solutions that can be transferred to other rapidly growing economies.

Vehicle Characteristics

Based on the literature analysis, the vehicles listed in Table 4 are identified as the dominant modes of road transport for daily commute in Poland and India. India has more transport options compared to Poland, especially when it comes to micro-mobility. Most Polish citizens use private cars as a micromobility option, while in India, residents rely on public transport to commute over shorter distances.

Table 4. Road transport vehicles considered for this study

Country	Modes of road transport								
	Bus	Truck	Car	Motor-cycle	Bicycle	Electric scooter	Auto rickshaw	Rickshaw	Micro-mobility
Poland	+	+	+	+	+	+	-	-	-
India	+	+	+	+	+	+	+	+	+

“+” – applicable; “-” – not applicable.

Typology of Variables

Urban centers contribute disproportionately to the majority of greenhouse gas emissions compared to rural areas. According to the reviewed literature, measures, such as fuel mix, blending of ethanol with gasoline, along with reducing the carbon intensity of grid electricity and implementing vehicle efficiency standards, play a crucial role in shaping LC transport policies (Fig. 3). Furthermore, the use of combined policy instruments is recognized as more effective than relying on a single parameter to promote LC mobility [28].

In general, most researchers considered environmental pollution, air quality, low-emission zones, and the share of renewable energy as environmental indicators. Socioeconomic conditions received equal weight, including infrastructural development, accessibility and affordability of public transport, public health and road safety, GDP, green taxes, carbon tax, green job generation, financial subsidies, and incentives, followed by technological indicators when formulating LC policies. The technological parameters include research and development, the inclusion of EVs, and green technologies; most researchers did not take ‘behavioral indicators’ into consideration. However, changes in people’s mindsets are an important factor. Environmentally conscious individuals tend to prefer public transport over private vehicles, as well as bicycles, clean fuel, EVs, and a sustainable lifestyle which will automatically diminish emissions.

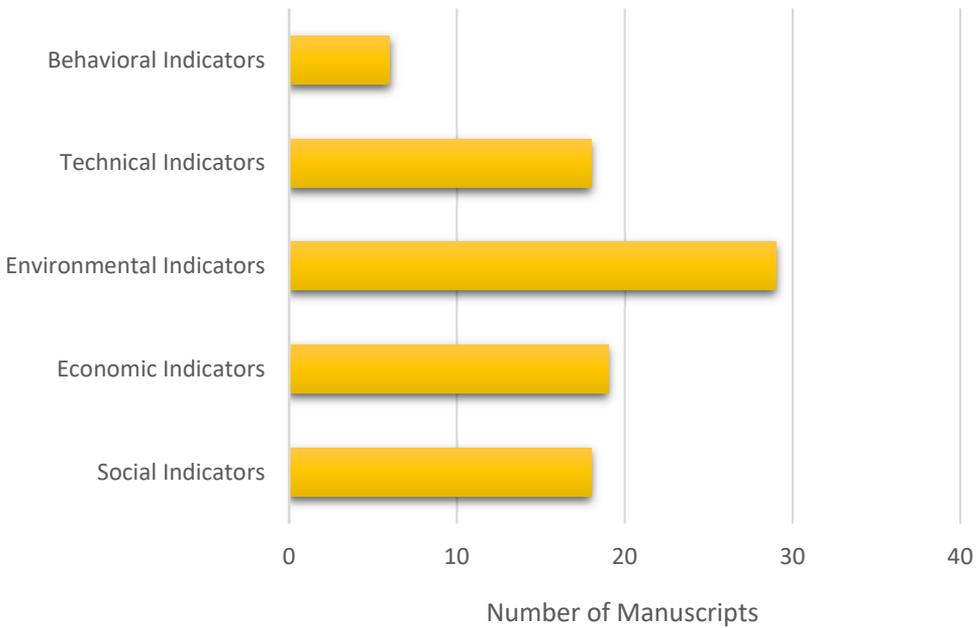


Fig. 3. Low-carbon policy indicators

Methodological Characteristics

The global trajectory towards an LC transport system has been significantly marked by quantitative assessment methods in the past two decades. Some papers have used various mathematical models and statistical analyses to measure the most suitable policy indicators both with and without the BAU (business as usual) scenario. The distribution of methodologies used in the reviewed manuscripts is summarized in Table 5.

A total of nine articles accounts for mathematical modeling analysis. Seven manuscripts are based on descriptive and inferential statistics, followed by four qualitative analysis papers. The rest of the articles adopted efficient policy analysis tools such as SWOT, MCDM, matrix-based approaches, and life cycle analysis. In the first half of the decade, the articles were mostly based on qualitative analysis, literature review, content analysis, and descriptive statistics. In contrast, recent articles have adopted more quantitative analysis techniques to measure policy indicators. Most manuscripts suggest that EVs with clean electricity, carbon tax enforcement, use of non-conventional fuel, clean electricity generation, and the provision of financial incentives are more effective LC indicators to rapidly reduce atmospheric CO₂ levels. However, one of the manuscript [15] reports that low-emission vehicles (0.866) and sustainability-oriented behavior (0.849) ranked highest, while fuel taxes (0.695) and vehicle ownership duties (0.647) ranked lowest in the context of LC policy.

Table 5. Methodologies used to assess low-carbon transport policies

Methodology	Number of Manuscripts
Extended Snapshot Modeling	1
Descriptive Statistics	6
SWOT Analysis	2
Matrix	1
System Model ANSWER-MARKAL	1
System Dynamic Approach	1
Life Cycle Analysis	1
Qualitative Analysis	4
EMITTRANSYS Modeling	1
Fuzzy Decision-Making Model	1
Malmquist Productivity Index (MPI)	1
End-use Model	2
Bibliometric Analysis	1
Simulation Modeling	1
Multiple Criteria Decision-Making Approach	2
STEAM Modeling	1
TR3E Partial Equilibrium Model	1
Inferential Statistics	1

4.2. Challenges Faced by LCRT Policies in India and Poland

There is a significant gap between the tailoring of policies and their implementation [12]. Poor urban infrastructure, inefficient traffic distribution, and the concentration of activities in cities contribute to increased greenhouse gas (GHG) emissions from road transport [29]. The observations from an environmental perspective [6, 16, 24] demonstrate that the dominance of economically powerful stakeholders in influencing policy at the expense of environmental protection is at its peak [12]. However, an LCRT policy must be internally consistent and be sustained through supporting initiatives framed by the government to become efficient [41]. Therefore, the ultimate choice lies in the hands of policymakers.

In Poland, an increase in investment in bike paths and non-motorized transportation (NMT) infrastructure shows a promising trend to achieve decarbonization objectives and reducing urban transport emissions [22]. EVs help reduce greenhouse

gas emissions and promote better air quality, such as a significant reduction in PM_{2.5} and NO_x [6, 19, 42]. Zero local emissions are the main benefit of battery-powered electric buses; they also reduce noise pollution [11]. A stringently implemented LC transport policy has the potential to reduce CO₂ emissions by 80% by 2050, in Poland [27]. Addressing road transport emissions through strict policy measures can help improve air quality and thus reduce respiratory diseases. The overall quality of life of the inhabitants can be improved. The study [18] focused on building bicycle lanes, as it is not only a cost-effective solution to reduce emissions but also promotes better health. Study [20] suggested the use of clean fuel and the development of infrastructure for public bus services, as they can transport large numbers of people at an affordable price with a lower carbon footprint. In contrast, study [26] recommended using CNG- and LNG-based vehicles in the transitional phase due to their cost-effectiveness. According to the study, carbon emissions can be reduced by 200 t per year from 6,391 t per year in the city of Szczecin, Poland, if electric buses (replacing diesel engine variants V1 or EURO 6) are in operation [2]. Imposing a strict emission tax can be beneficial in reducing emissions. However, introducing penalties for non-compliance with CO₂ emission targets can hamper the capacity of the transport industry to update their infrastructure. This can reduce revenue generation and the pace of vehicle transition in the EU transport market [22]. Instead of restrictive measures such as carbon taxes, a combination of behavior-driven and incentive-based strategies is advised as a useful policy tool [28].

Policies often fall short in India due to inadequate governance, the lack of monitoring, and the lack of integration of land-use policies with transport planning [16]. Additionally, the Indian transport system has significant problems such as air pollution, traffic congestion, and ineffective public transportation. Urban transport policy has changed from supply-oriented to demand-oriented after implementing the national policies, which emphasizes improving public transport [16]. The bus industry faces financial challenges due to inappropriate route selection and the provision of inadequate services in most Indian states [16]. In contrast to this, a strong institutional coordination can be observed in Poland [11]. Although the major Polish cities have modernized their public transportation systems, smaller cities often have inadequate service coverage and quality; larger cities such as Warsaw, Krakow, Poznań, Jaworzno, and Zielona Góra receive more funds for development compared to smaller cities [24]. A similar scenario can be seen for Indian metro cities such as Mumbai, Delhi [7]. The policy framework depends heavily on stable public funding, which may be uncertain. Poland must rely on external funding to assist in the modernization of the fleet [22]. In addition, the effective implementation of LCRT policies faces challenges due to India's overpopulation, rapid urban agglomeration, industrialization, and continuous motorization. On the contrary, Poland has obstacles such as heavy coal dependence, the use of old cars, and a lack of farsighted policies that make it very challenging to align decarbonization objectives with land-use planning. The EU has indicated that the transition of Polish transport sectors will not be easy [35]. This difficulty is further

compounded by the fact that very few studies have been published on LC transport policies [6]. The concentration of harmful pollutants (NO₂, CO, PM₁₀, and PM_{2.5}) exceeds the permitted limits mainly in the urban areas of central and southern Poland due to heavy traffic and increased road transportation [25]. Carbon monoxide emissions from road transport were 23.14%, while PM_{2.5} and PM₁₀ had lower shares at 10.18% and 7.79%, respectively, in Poland, levels that are higher than recommended safety standards [33]. The growing congestion on Polish roads also increases safety risks, travel times, and transport costs, highlighting the urgent need for policies to reduce transport-related GHG emissions [29]. In addition, vehicle age is another critical issue. In 2018, the average age of cars on Polish roads was 14.1 years, significantly higher than the European average of 11.5 years, and only 8% of people were planning to buy a new vehicle [29]. According to the Fit for 55 framework, compared to most EU countries (12%), 40% of passenger cars in Poland are more than 20 years old [33]. Therefore, Poland's roads are dominated by older, less eco-friendly cars, leading to higher emissions of harmful substances and greenhouse gases. EV adoption rates remain low in both countries despite policy formulation. India reported having only 25,000 registered EVs by 2021 [6], which has a negligible impact on decarbonization compared to the total population and emissions rate of the country. Poland's national policy aimed to have 70,000 EVs by 2020, but this target remained at only 18,875; at the end of that year, 53% were battery electric vehicles (BEVs) and 47% were plug-in hybrid (PHEVs) cars [29]. The shared proportion of electric buses remains lower compared to vehicles powered by fossil fuels in urban areas of Poland [11, 23]. Furthermore, it has not been studied whether a Polish person can afford both the subsidies and the costs of an electric vehicle [23]. Sixty-one percent of the 242 Polish cities that were examined lack innovation in second-generation electromobility [2]. A similar scenario can also be seen in India. Since 1920, cars and buses have been introduced on Indian streets, and auto-rickshaws have gradually become popular among low-income groups. Despite having a diverse transportation network, two-wheelers (motorcycles, scooters) and cars comprise over four fifths of the road transport system [1]. The socioeconomic conditions of Indian states varies; the rich states are heavily motorized and have a dense transport network, leading to higher carbon emissions compared to less wealthy states. A key concern is that these emissions are expected to increase under a BAU scenario. However, this trend can be reversed through the implementation of low-carbon policies [8]. In India, between 2001 and 2011, car ownership among households increased by 88% and 2-wheeler ownership by 79%, as reported in the literature [6]. Subnational analysis indicates that two-wheeler ownership is expected to increase in middle-income regions in the coming decade [43]. In 2017, the total number of registered motor vehicles increased to 253 million and Bangalore was identified as the most traffic-congested Indian city [16]. The National Transportation Development Policy Committee (NTDPC) predicts that road transport travel demand will reach 163,111 billion passenger-kilometers by 2031, in India, representing a 17-fold increase from 2011 levels [44]. The growth in private ownership

is driven by rising purchasing power parity, increased loan availability, higher automobile productivity and expanded road connectivity in rural areas of India [16]. There is an urgent need for efficient policy measures to stabilize the level of CO₂ in the atmosphere [4]. LC policies have the potential to improve air quality by reducing NO_x emissions by 74% and PM 2.5 emissions by 83% in India [4].

Poland's heavy dependence on coal restricts the environmental advantages of electric buses. In Poland, inefficient strategic planning by local authorities results in the fragmentation of natural systems such as ecological corridors and urban ventilation areas [29]. Since 1989, the Polish urban transportation system has been under the jurisdiction of local governments, leading to weak coordination between the national government, regional authorities, and municipalities, which results in inconsistent policies [24]. The rapid increase in both the number of cars and the distance they travel is outpacing regulations aimed at reducing CO₂ emissions [29]. Continuous urban sprawl and shifts in economic growth have strengthened car-centric development, which has resulted in a dramatic rise in private vehicle ownership [24]. In 2017, road transport was the largest source of nitrogen oxide emissions in Poland, accounting for 37% of the total, surpassing emissions from industry and energy sectors [34, 35]. Road transportation is responsible for 17.18% of PM_{2.5}, 10.36% of PM₁₀, 23.15% of CO, and 33.18% of NO₂, 0.15% of SO₂, and 2.84% of Pb emissions in major Polish cities such as Warsaw, Krakow, Wrocław, Częstochowa, and the Silesian conurbation, which are above safety limits [25].

Poland has high road fatality rates due to poor enforcement and limited safety funding [35]; this highlights inefficient policy management. Poland ranks fourth and accounts for 66 road deaths per million people (2020), which is higher than the average of 42 in the EU [35]. Despite a 36% decrease in fatalities between 2010 and 2020, the country lags behind overall EU progress. In this scenario, policy measures such as driver reward programs, health monitoring, and eco-driving training by high-performing businesses can be beneficial in reducing the risks of road accidents and harmful emissions [7]. Unfortunately, policies are often driven by economic and political priorities, and most of the time the environment is ignored.

5. Conclusions

This study reviews the indicators, efficacy, constraints, and areas for improvement of policies for low-carbon transport strategies in Poland and India. Both countries are dealing with land-use planning, promoting clean fuels, clean electricity generation, and building and expanding road transport networks. Despite socioeconomic disparities and financial constraints at the subnational level, Indian transport policy has evolved over time. The inclusion of an energy mix, the production of green hydrogen, the enforcement of stringent traffic laws, and investment in research represent a promising future. Poland is ahead of India in terms of technological innovation, digitalization of

the transport sector, infrastructure development, road safety, and the incorporation of public feedback in policy formation. The mobility system in both countries highlights the urgent need for an integrated, context-specific, holistic, multidimensional, people-oriented approach that works better than fragmented policies. Although technological solutions such as electric buses and electric vehicles have potential, their success depends on the production of clean electricity, cost effectiveness, inclusive planning, and equitable access to infrastructure. The findings demonstrate that both developed and developing countries face similar challenges, such as a lack of governmental coordination, faulty planning, inadequate infrastructure support, differences between urban and rural transport facilities, limited public awareness residents, and financial challenges. Achieving significant reductions in carbon emissions depends on the alignment of policies with environmental benefits, funding availability, public affordability, strong governance, and policy coherence across developmental sectors that promotes equitable and sustainable mobility transitions. To achieve maximum benefit, road transport policies should align with policies from other development sectors. For future studies, we will use “sustainable transport” OR “low-carbon transport” OR “decarbonization” OR “clean transport” OR “green transport” OR “electric vehicles” OR “public transport” OR “micromobility”) AND (“policy” OR “strategy” OR “analysis” OR “regulation” OR “governance” OR “public perception” OR “travel behavior”) AND (“India” OR “Poland”) to broaden our research outlook.

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CRedit Author Contribution

T. C.: conceptualization, methodology, formal analysis and investigation, writing – original draft preparation, writing – review and editing.

R. A.: writing – review and editing, supervision.

Declaration of Competing Interests

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

Data Availability

No data.

Use of Generative AI and AI-Assisted Technologies

No generative AI or AI-assisted technologies were employed in the preparation of this manuscript.

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References

- [1] Verma P., Chodkowska-Miszczuk J., Lewandowska A., Wiśniewski Ł.: *Local resilience for low-carbon transition in Central European Countries: Frameworks, conditions and opportunities*. Sustainable Development, vol. 31(3), 2023, pp. 1278–1295. <https://doi.org/10.1002/sd.2500>.
- [2] Pietrzak K., Pietrzak O.: *Environmental effects of electromobility in a sustainable urban public transport*. Sustainability, vol. 12(3), 2020, 1052. <https://doi.org/10.3390/su12031052>.
- [3] Bhatia V., Sharma S.: *Trends and policy analysis: A case for sustainable transport systems in India*. Transport Policy, vol. 153, 2024, pp. 76–86. <https://doi.org/10.1016/j.tranpol.2024.05.006>.
- [4] Manohar G., Chandiran P., Rao K.S., Babu R.D.: *Integration of on-board diagnostics with system dynamics to study road transport pollution*. International Journal of Environmental Sciences, vol. 6(6), 2016, pp. 1006–1026.
- [5] Brzeziński Ł., Kolinski A.: *Challenges of the green transformation of transport in Poland*. Sustainability, vol. 16(8), 2024, 3418. <https://doi.org/10.3390/su16083418>.
- [6] Dhar S., Pathak M., Shukla P.R.: *Electric vehicles and India's low carbon passenger transport: A long-term co-benefits assessment*. Journal of Cleaner Production, vol. 146, 2017, pp. 139–148. <https://doi.org/10.1016/j.jclepro.2016.05.111>.
- [7] Khandelwal A.: *Case studies of sustainable road transport practices in different industry sectors in India*. International Journal of Mathematical, Engineering and Management Sciences, vol. 5(6), 2020, pp. 1091–1107. <https://doi.org/10.33889/IJMEMS.2020.5.6.083>.
- [8] Mittal S., Hanaoka T., Shukla P.R., Masui T.: *Air pollution co-benefits of low carbon policies in road transport: A sub-national assessment for India*. Environmental Research Letters, vol. 10(8), 2015, 085006. <https://doi.org/10.1088/1748-9326/10/8/085006>.
- [9] European Environment Agency: *Energy*. October 10, 2024. <https://www.eea.europa.eu/en/analysis/publications/sustainability-of-europes-mobility-systems/energy> [access: August 12, 2025].
- [10] Dhar S., Shukla P.R.: *Low carbon scenarios for transport in India: Co-benefits analysis*. Energy Policy, vol. 81, 2015, pp. 186–198. <https://doi.org/10.1016/j.enpol.2014.11.026>.
- [11] Patalas-Maliszewska J., Łosyk H., Newelski J.: *Modeling the effectiveness of intelligent systems in public transport that uses low-carbon energy: A case study*. Energies, vol. 14(9), 2021, 2637. <https://doi.org/10.3390/en14092637>.
- [12] Lis A., Szymanowski R.: *Greening Polish transportation? Untangling the nexus between electric mobility and a carbon-based regime*. Energy Research & Social Science, vol. 83, 2022, 102336. <https://doi.org/10.1016/j.erss.2021.102336>.

- [13] Government of Poland, Ministry of Energy: *Electromobility Development Plan in Poland "Energy for the Future"*. May 8, 2018. https://www.gov.pl/documents/33372/436746/DIT_PRE_EN.pdf/3d2ca928-3097-2b11-84c9-7a5b546932a7 [access: January 30, 2026].
- [14] Page M.J., McKenzie J.E., Bossuyt P.M., Boutron I., Hoffmann T.C., Mulrow C.D., Shamseer L., Tetzlaff J.M., Akl E.A., Brennan S.E., Chou R., Glanville J., Grimshaw J.M., Hróbjartsson A., Lalu M.M., Li T., Loder E.W., Mayo-Wilson E., McDonald S., ..., Moher D.: *The PRISMA 2020 statement: An updated guideline for reporting systematic reviews*. *BMJ*, vol. 372, 2021, n71. <https://doi.org/10.1136/bmj.n71>.
- [15] Pathak M., Shukla P.R.: *Co-benefits of low carbon passenger transport actions in Indian cities: Case study of Ahmedabad*. *Transportation Research Part D: Transport and Environment*, vol. 44, 2016, pp. 303–316. <https://doi.org/10.1016/j.trd.2015.07.013>.
- [16] Verma A., Harsha V., Subramanian G.H.: *Evolution of urban transportation policies in India: A review and analysis*. *Transportation in Developing Economies*, vol. 7(2), 2021, 25. <https://doi.org/10.1007/s40890-021-00136-1>.
- [17] Ahmed Z., Ali S., Saud S., Shahzad S.J.H.: *Transport CO₂ emissions, drivers, and mitigation: An empirical investigation in India*. *Air Quality, Atmosphere & Health*, vol. 13(11), 2020, pp. 1367–1374. <https://doi.org/10.1007/s11869-020-00891-x>.
- [18] Agarwal A., Ziemke D., Nagel K.: *Bicycle superhighway: An environmentally sustainable policy for urban transport*. *Transportation Research Part A: Policy and Practice*, vol. 137, 2020, pp. 519–540. <https://doi.org/10.1016/j.tra.2019.06.015>.
- [19] Dwivedi A., Kumar R., Goel V., Kumar A., Saxena A.: *Effectiveness assessment of government promotional policy framework towards climate-neutral mobility in Indian context*. *Case Studies on Transport Policy*, vol. 19, 2025, 101352. <https://doi.org/10.1016/j.cstp.2024.101352>.
- [20] Jasti P.C., Ram V.V.: *Integrated and sustainable service level benchmarking of urban bus system*. *Transportation Research Procedia*, vol. 17, 2016, pp. 301–310. <https://doi.org/10.1016/j.trpro.2016.11.096>.
- [21] Javed A., Nia H.A.: *A shift towards e-mobility in India: Challenges and innovations*. *Khulna University Studies*, vol. 20(2), 2023, pp. 245–255.
- [22] Pyra M.: *Simulation of the progress of the decarbonization process in Poland's road transport sector*. *Energies*, vol. 16(12), 2023, 4635. <https://doi.org/10.3390/en16124635>.
- [23] Burchart-Korol D., Gazda-Grzywacz M., Zarębska K.: *Research and prospects for the development of alternative fuels in the transport sector in Poland: A review*. *Energies*, vol. 13(11), 2020, 2988. <https://doi.org/10.3390/en13112988>.
- [24] Guzik R., Kołoś A., Fiedor M., Micek G., Gwosdz K.: *The second generation electromobility in Polish urban public transport: The factors and mechanisms of spatial development*. *Energies*, vol. 14(22), 2021, 7751. <https://doi.org/10.3390/en14227751>.

- [25] Ambroziak T., Gołębiowski P., Pyza D., Jacyna-Gołda I., Merkisz-Guranowska A.: *Identification and analysis of parameters for the areas of the highest harmful exhaust emissions in the model EMITRANSYS*. Journal of KONES Powertrain and Transport, vol. 20(3), 2013, pp. 9–20.
- [26] Dzikuć M., Miško R., Szufa S.: *Modernization of the public transport bus fleet in the context of low-carbon development in Poland*. Energies, vol. 14(11), 2021, 3295. <https://doi.org/10.3390/en14113295>.
- [27] Rabiega W., Gorzałczyński A., Jeszke R., Mzyk P., Szczepański K.: *How long will combustion vehicles be used? Polish transport sector on the pathway to climate neutrality*. Energies, vol. 14(23), 2021, 7871. <https://doi.org/10.3390/en14237871>.
- [28] Gupta M.: *A fuzzy decision-making approach to evaluate CO₂ emissions reduction policies*. Global Business Review, vol. 25(6), 2021 [published 2024], pp. 1484–1497. <https://doi.org/10.1177/09721509211014000>.
- [29] Godzisz K., Dzikuć M., Kułyk P., Piwowar A., Kuryło P., Szufa S.: *Selected determinants of sustainable transport in the context of the development of a low-carbon economy in Poland*. Energies, vol. 14(17), 2021, 5418. <https://doi.org/10.3390/en14175418>.
- [30] Government of India, Ministry of New and Renewable Energy: *National Policy on Biofuels*. 2009. <https://lpr.adb.org/sites/default/files/resource/844/india-national-policy-on-biofuels.pdf> [access: May 18, 2025].
- [31] Government of Poland, Ministry of Energy: *Report on the implementation of the National Policy Framework for the Deployment of Alternative Fuels Infrastructure*. National Implementation Report under Directive 2014/94/EU, 2019. https://www.transportenvironment.org/uploads/files/2019_01_PL_EUKI_report_FINAL_0.pdf [access: May 17, 2015].
- [32] Government of India, Ministry of Road Transport and Highways: *Bharatmala Pariyojana: A Stepping Stone Towards “New India”*. October 2017. <https://morth.nic.in/sites/default/files/officers/BharatMala%20Pariyojna%20Ebook-2076088661.pdf> [access: January 30, 2026].
- [33] Rabiega W., Gorzałczyński A., Pyrka M., Jeszke R., Tobiasz I., Mzyk P.: *Polska net-zero 2050: Rola transportu publicznego w świetle pakietu „Fit for 55” i perspektywy roku 2050* [Poland net-zero 2050: The role of public transport in the context of the “Fit for 55” package]. Centrum Analiz Klimatyczno-Energetycznych (CAKE) report, Instytut Ochrony Środowiska – Państwowy Instytut Badawczy / Krajowy Ośrodek Bilansowania i Zarządzania Emisjami (KOBiZE), Warszawa 2022. https://climatecake.ios.edu.pl/wp-content/uploads/2022/06/CAKE_Transport_publiczny_27_06_2022_final.pdf [access: January 30, 2026].
- [34] Cuttaree V., Czapski R., Park E.J., Giemza J., Marquez P.V., Mircheva B., Olievschi V., Podolske R.C., Shrestha A., Strand J.P.: *Poland – Transport Policy Note: Toward a Sustainable Land Transport Sector*. Report No. 59715-PL, World Bank, Washington, DC, 2011. <http://documents.worldbank.org/curated/en/305451468105546359> [access: January 30, 2026].

- [35] Transport & Environment: *Emission Reduction Strategies for the Transport Sector in Poland*. European Climate Initiative (EUKI) report, Transport & Environment, Brussels 2018. https://www.transportenvironment.org/uploads/files/2019_01_PL_EUKI_report_FINAL_0.pdf [access: May 16, 2025].
- [36] Government of India, Ministry of Urban Development: *National Urban Transport Policy*. 2006. <https://mohua.gov.in/upload/uploadfiles/files/Transport-Policy.pdf> [access: May 16, 2025].
- [37] Government of India, Ministry of Urban Development: *National Urban Transport Policy (Revised)*. March 2014. https://www.changing-transport.org/wp-content/uploads/E_K_NUMP_India_2014_EN.pdf [access: May 16, 2025].
- [38] Government of India, Ministry of Heavy Industries: *Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME)*. Urja Dakshata Information Tool (UDIT). <https://udit.beeindia.gov.in/fame/> [access: January 30, 2026].
- [39] Government of India, Ministry of Heavy Industries: *Faster Adoption and Manufacturing of Hybrid and Electric Vehicles – Phase II (FAME II)*. 2019–2024. https://heavyindustries.gov.in/sites/default/files/2024-09/mohi_fame-2_book_design.pdf [access: May 16, 2025].
- [40] Government of India, Ministry of Heavy Industries and Public Enterprises: *National Electric Mobility Mission Plan (NEMMP) 2020*. August 2012. <https://heavyindustries.gov.in/sites/default/files/2023-07/NEMMP-2020.pdf> [access: May 16, 2025].
- [41] Government of India, Ministry of Law and Justice: *Motor Vehicles (Amendment) Act*. August 9, 2019. https://morth.nic.in/sites/default/files/notifications_document/MV%20Act%20English.pdf [access: January 30, 2026].
- [42] Santos G., Behrendt H., Teytelboym A.: *Policy instruments for sustainable road transport*. Research in Transportation Economics, vol. 28(1), 2010, pp. 46–91. <https://doi.org/10.1016/j.retrec.2010.03.002>.
- [43] Skwierz S.: *The role of transport sector in CO₂ reduction in Poland*. E3S Web Conferences, vol. 14, 2017, 01010. <https://doi.org/10.1051/e3sconf/20171401010>.
- [44] National Transport Development Policy Committee (NTDPC): *India Transport Report: Moving India to 2032. Volume 1: Executive Summary*. Planning Commission, Government of India, 2014. https://www.aitd.net.in/NTDPC/rep_ntdpc_v1.pdf [access: May 16, 2025].