



Literature Review on Economic and Ecological Comparisons of Alternative Drivetrain Technologies in Road Freight Transport

Maeva MEYER¹, Thomas BOUSONVILLE²

Review
Submitted: 7 Oct 2025
Accepted: 1 Dec 2025
Published: 28 Apr 2026

¹ Corresponding author, maeva.meyer@htwsaar.de, Department of Economics, Saarland University of Applied Sciences, Saarbrücken, Germany
² thomas.bousonville@htwsaar.de, Department of Economics, Saarland University of Applied Sciences, Saarbrücken, Germany



This work is licensed under a Creative Commons Attribution 4.0 International Licence.

Publisher:
Faculty of Transport and Traffic Sciences,
University of Zagreb

ABSTRACT

This literature review synthesises current academic research on alternative propulsion systems in road freight. Analysing over 150 scientific papers, it explores both economic and environmental dimensions. A structured bibliographic approach was employed, involving a three-phase selection process: evaluating the relevance of research platforms, identifying the most effective keyword combination and determining whether keyword searches in abstracts or full texts provide more pertinent results. A statistical evaluation highlights prevailing research trends and uncovers notable gaps, particularly in regional representation and vehicle type diversity, with a bias towards HDTs. Moreover, while the literature heavily emphasises electrification and hydrogen-based technologies, biofuels – despite their compatibility with existing internal combustion vehicles and their potential as a transitional fuel – remain underrepresented. Given their expected role in achieving EU climate objectives, further research is needed on the ecological, financial and operational impacts of their integration into freight networks. The review ultimately calls for more comprehensive investigations into infrastructure development and enhanced prospective analyses. Such research is critical for policymaking and for building stronger cooperation between shippers and carriers. In brief, given the transformative investments required for electric vehicle deployment, a deeper analysis of collaborative models could provide valuable strategies to accelerate the transition to zero-emission freight solutions.

KEYWORDS

road freight; alternative fuels; literature review; battery electric vehicles (BEVs); life cycle assessment (LCA); total cost of ownership (TCO).

1. INTRODUCTION

According to [1] and [2], road freight transport is a major contributor to greenhouse gas emissions and urban air pollution, primarily due to its reliance on fossil fuels. Faced with growing environmental and health concerns, it becomes imperative to seek and adopt alternative solutions that can offer comparable performance while minimising negative environmental impacts. Among the explored alternatives are electric vehicles, biofuels, hydrogen and hybrid technologies. Each of these alternatives offers specific advantages and unique challenges in terms of performance, cost and long-term viability. Rather than evaluating the viability of these technologies, this literature review aims to systematically map and assess the existing body of research. It focuses on when studies were published, which vehicle types and drivetrain technologies they cover, as well as the geographical and methodological scope they represent.

Although the decarbonisation of road freight transport is a growing area of concern, relatively few comprehensive literature reviews have been conducted to date on alternative solutions to fossil fuels.

While [3] addresses road freight sustainability from environmental, economic and social perspectives, providing a comprehensive and multi-dimensional analysis, the issue of eco-friendly vehicles is only superficially treated and tends to be overshadowed by broader systemic considerations.

[4] provide a structured overview of the state of system dynamics models applied to freight transport decarbonisation. The review classifies the selected studies within the green logistics framework, distinguishing strategies such as decreasing the overall demand for freight transport, transitioning to cleaner transport modes, making more efficient use of transport infrastructure and vehicles, improving energy performance, and adopting low-carbon energy sources. However, only 13 out of the 50 studies reviewed specifically address alternative solutions to diesel, limiting their direct relevance to the scope of this review.

In addition, several case studies provide valuable insights by presenting specific analyses of fossil fuel alternatives in road freight transport. While these studies help contextualise the topic, they often present limited perspectives due to methodological and thematic constraints.

For instance, the literature review in [5] focuses primarily on studies of light-duty vehicles in Europe and the United States, using techno-economic models such as LBST and ANL GREET to compare hybrid, plug-in hybrid, battery electric and fuel cell technologies. While detailed, it is based on a limited number of reference studies and excludes medium- and heavy-duty vehicles, which reduces the applicability of these alternative solutions in freight transport.

The review in [2] focuses exclusively on the electrification potential of heavy-duty trucks in countries such as the United States [6], Canada [7] and China [8], analysing costs and emissions. However, this leaves out light- and medium-duty freight vehicles, potentially hindering a comprehensive overview of fossil fuel alternatives or resulting in a biased one.

Finally, the literature review in [6] includes 31 studies that primarily focus on the environmental impacts of freight vehicles of all sizes in developed areas. Nevertheless, these works offer limited economic analysis and do not address the specific challenges faced by emerging regions. Therefore, caution must be exercised in generalising conclusions.

In response to these limitations, the present literature review stands out by its breadth and depth. Covering 158 scientific publications, it encompasses a wide and diverse range of fuel technologies and vehicle types in diverse geographic contexts, including both developed and emerging regions. Moreover, this review includes ecological and economic analyses, relying on various methods such as total cost of ownership (TCO) [9], life cycle assessment (LCA) [10, 11], simulation [9, 11, 12], well-to-wheel analysis [13], and mathematical optimisation [14-18]. It includes both retrospective and prospective studies to analyse the evolution of technologies and policies related to alternative solutions, while identifying emerging trends that could sustainably transform the sector. This literature review also encompasses studies modelling scenarios related to charging conditions, energy prices, and vehicle mileage. This comprehensive and diversified approach provides more robust guidance for policymakers, researchers, and practitioners in their search for sustainable and efficient solutions to replace fossil fuels in road freight transport.

The paper is organised as follows. Section 2 defines the scope and describes the methodology used for the bibliographic search, including the selection of platforms, the keyword strategy and the multi-step filtering process. Section 3 presents and discusses the results, including descriptive statistics and research trends. Section 4 highlights existing gaps in the literature and offers recommendations for future research. Section 5 provides a discussion, analysing the main findings, explaining the dominance of electric solutions in road freight transport, and interpreting the implications for future research and policy. Section 6 outlines the limitations of the review. Finally, Section 7 concludes the paper.

2. METHODOLOGY

In order to refine the search, several limits have been set. The exclusion criteria were defined as follows:

- Language: Publications in English were prioritised to ensure consistent comprehension and access to a broad scientific database. German terms were also included in the search. However, no studies in German were ultimately retained;

- Year of publication: Only studies published after the year 2000 were considered, to ensure the relevance and currency of technologies and data;
- Peer review: Only peer-reviewed articles were included to guarantee the credibility and reliability of the information.

2.1 A three-step decision-making process

A rigorous bibliographic methodology was employed using a three-step decision-making process. This included choosing the most effective platform, selecting the most informative keyword combination, and deciding whether to search for keywords in abstracts or full texts to obtain more relevant results.

Selection of the research platform

The literature review process began with the selection of three prominent academic platforms: EBSCO Discovery Service (EDS)¹, EBSCOhost² and Web of Science (WoS)³. Each platform was assessed for its comprehensiveness, search precision and capacity to retrieve relevant documents.

Preliminary analyses revealed that EDS generated an extremely high number of results, but with a low relevance ratio. This is partly due to EDS's tendency to retrieve documents where keywords appeared in the bibliography or footnotes, without substantive discussion of the topic. EBSCOhost, while providing specialised databases, yielded a more limited number of studies and required pre-selection of specific sub-databases, which restricted its coverage. In contrast, WoS demonstrated a superior balance of coverage and relevance, with a significantly higher proportion of pertinent documents.

To validate the platform selection, comparative searches using identical keyword combinations were performed across all three platforms. WoS consistently provided the highest ratio of relevant studies to total search results. Therefore, WoS was chosen as the exclusive platform for the remainder of the review.

Choice of keywords

Keywords are used to target searches within databases. Identifying keyword combinations is essential for filtering results relevant to the subject under study.

For this literature review, which aims to explore alternative solutions to fossil fuels in transport, a systematic method of combining keyword sets was implemented. This method allows for a focused examination of the ecological and economic impacts of alternative propulsion technologies while covering the two main transport domains: freight and passenger transport. Including keywords related to passenger transport helps ensure that no potentially useful studies are excluded due to overly strict categorisation. For example, this approach can capture studies that primarily focus on passenger transport but also include relevant sections or analyses related to freight transport. Similarly, both ecological and economic aspects are included as they contribute significantly to the research objective. Adjustments to keyword combinations may be made depending on the relevance and quality of the results retrieved.

Thus, six different combinations of five keyword sets were formulated to optimise the search. Each set is defined by a group of keywords, as listed in *Table 1*.

Keyword sets used:

- Set E_1 : “Alternative drives” – Includes terms related to various alternative propulsion technologies;
- Set E_2 : “Economic aspect” – Focuses the analysis on the economic impacts of propulsion technologies;
- Set E_3 : “Ecological aspect” – Focuses the analysis on the ecological impacts of propulsion technologies;
- Set E_4 : “Freight transport” – Specifies freight transport as the application domain;
- Set E_5 : “Passenger transport” – Specifies passenger transport as the application domain.

¹ <https://research.ebsco.com/c/6az4lk/search/advanced/filters?autocorrect=n>

² <https://research.ebsco.com/c/jpkfed/search/advanced/filters?autocorrect=n>

³ <https://www.webofscience.com/wos/alldb/advanced-search>

Table 1 – Keyword sets

Set	Keywords
Set E_1 : Alternative drives	“Autogas*” OR “LPG” OR “CNG” OR “natural gas*” OR “fuel cell” OR “diesel” OR “electr*” OR “battery” OR “internal combustion engine*” OR “hydrogen*” OR “alternative drives” OR “alternative propulsion” OR “biofuel” OR “biogas*” OR “Elektr*” OR “Wasserstoff*” OR “Hybrid*” OR “Autogaz” OR “Erdgas*” OR “Bioethanol” OR “Bio-diesel” OR “Kraftstoff*” OR “Brennstoffzelle*” OR “Batterie*” OR “alternative Antriebe”
Set E_2 : Economic aspect	“total cost of ownership” OR “TCO” OR “life cycle cost*” OR “operational lifetime costs” OR “LCC” OR “Gesamtbetriebskosten” OR “gesamte Betriebskosten” OR “Gesamtkosten des Betriebs” OR “Lebenszykluskosten*”
Set E_3 : Ecological aspect	“life cycle assessment” OR “life cycle analysis” OR “sustainability assessment” OR “carbon footprint” OR “cradle-to-grave analysis” OR “LCA” OR “Ökobilanz” OR “Umweltbilanz” OR “Lebenszyklusanalyse” OR “CO ₂ -Fußabdruck”
Set E_4 : Freight transport	“ground transport*” OR “land transport*” OR “transport by road” OR “road traffic” OR “heavy goods vehicles” OR “HGV” OR “road freight” OR “road carriage” OR “road haulage” OR “trucking” OR “truck transport” OR “Straßenfracht” OR “Straßengüterverkehr*” OR “Lkw-Transport”
Set E_5 : Passenger transport	“passenger transport*” OR “public transport*” OR “mass transit” OR “passenger car*” OR “Bus*” OR “Personentransport*” OR “öffentlicher Verkehr” OR “Massenverkehrsmittel” OR “ÖPNV”

Keyword set combinations defined for the search:

- Combination C_1 : E_1 AND E_2 AND E_4 – Focuses on the economic analysis of freight transport;
- Combination C_2 : E_1 AND E_3 AND E_4 – Focuses on the ecological analysis of freight transport;
- Combination C_3 : E_1 AND E_2 AND E_3 AND E_4 – Targets studies that address both economic and ecological aspects of freight transport;
- Combination C_4 : E_1 AND E_2 AND (E_4 OR E_5) – Focuses on the economic analyses of freight and/or passenger transport;
- Combination C_5 : E_1 AND E_3 AND (E_4 OR E_5) – Focuses on the ecological analyses of freight and/or passenger transport;
- Combination C_6 : E_1 AND E_2 AND E_3 AND (E_4 OR E_5) – Targets studies that address both economic and ecological aspects of freight and/or passenger transport.

While several combinations are applied to explore the use of alternative propulsion technologies from different angles, only one combination will subsequently be selected to ensure the study’s relevance and research results.

The systematic inclusion of Set E_1 in all combinations reflects the central importance of alternative propulsion technologies in the study, emphasising the primary goal of understanding and evaluating their viability and impact in the transport sector.

Including passenger transport in the search significantly increases the number of results, revealing a stronger scientific focus on passenger transport compared to freight transport alone. Depending on whether the keywords are searched within the full text or just the abstract, the number of results increases by a factor ranging from 2.3 to 3.2 when passenger transport is included (see Table 2).

Table 2 – Increase in the number of search results by including passenger transport

	Ecological perspective	Economic perspective	Both
Full text	3.0	3.2	3.0
Abstract	2.3	3.1	2.8

However, including such a large number of articles may hinder the ability to maintain a literature review focused specifically on freight transport. To preserve the overall coherence of the analysis and facilitate the synthesis of results, it is therefore necessary to exclude all keyword combinations that include Set E_5 , which

relates to passenger transport. At the same time, neither the economic nor the ecological dimension should be neglected in this study. As a result, a new keyword combination is proposed:

- Combination C_7 : E_1 AND (E_2 OR E_3) AND E_4 – Targeting studies related to the economic and/or ecological analysis of freight transport.

This new keyword combination C_7 was selected for the literature research, as it adopts a broader logic than C_3 by allowing the inclusion of studies focusing on either economic or ecological aspects (or both). Moreover, this approach remains within the thematic scope, as the selected keyword combination specifically targets road freight transport.

Abstract vs. full-text search decision

A critical methodological decision was whether to limit the search to document abstracts or to extend it to the full text. Preliminary testing indicated that restricting the search to abstracts would have resulted in the omission of a substantial portion of relevant studies. Specifically, analysis showed that 67.6% of the relevant studies identified via full-text searches were absent from abstract-only searches.

Given the depth required for this review and the risk of missing essential documents, it was decided to conduct the search across the full text of articles. Although this approach was more time-consuming due to the increased number of documents to be assessed, it enabled a more comprehensive and accurate retrieval process.

A detailed description of this multi-step bibliographic procedure, including the four successive queries that guided the selection of the research platform, the formulation of the keyword combination, and the decision between abstract-only and full-text searches, is provided in [19].

2.2 Evaluation and classification of documents

Following the establishment of the search strategy, the next step involves assessing the retrieved documents and progressively filtering them to retain only the most relevant ones. The selected documents are then classified, facilitating their analysis.

Progressive filtering process

The literature selection process employed a progressive filtering methodology, systematically narrowing the body of documents through multiple refinement stages:

- Initial search: The WoS platform yielded 2,209 documents using the selected keyword combination and exclusion criteria;
- First filtering stage: Exclusion of irrelevant subject categories⁴, particularly documents classified under “Engineering” that did not directly pertain to transport systems. This step reduced the dataset to 1,814 documents;
- Second filtering stage: Screening of titles and abstracts to remove documents not aligned with the research objectives, focusing on road freight transport. This phase reduced the selection to 297 studies;
- Final filtering stage: Full-text reviews were conducted to ensure each study explicitly addressed road freight transport, rather than passenger or other transport modes. This rigorous review led to a final selection of 158 relevant scientific publications.

Figure 1 provides a detailed overview of the dataset refinement process, highlighting the stepwise reduction from an initial broad corpus to a focused and reliable selection.

⁴ WoS offers a detailed classification system that categorises scientific publications into specific fields, allowing for further refinement of results through targeted filters.

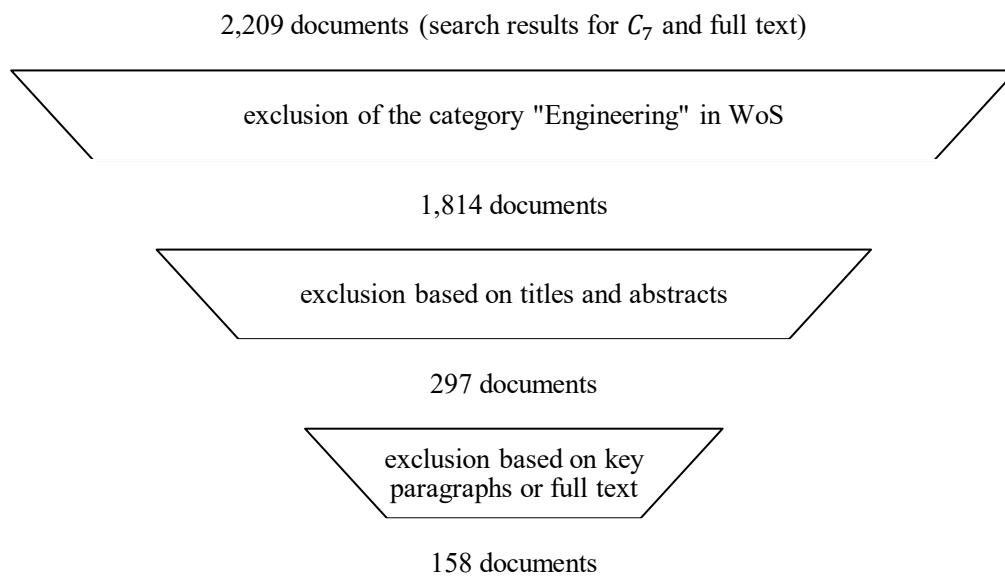


Figure 1 – Stepwise filtering of retrieved documents

Classification framework

Each of the 158 retained studies was systematically classified according to multiple criteria:

- Title, Authors, Journal, Year of publication: These fundamental data provide a quick overview of the source and the time period of the study;
- Geography: Documents are classified by investigated geographic regions, including Africa, Oceania, Asia, America and the EU + UK;
- Perspective: Each study is analysed to determine whether it deals with ecological concerns, economic concerns or a combination of the two;
- Scenario focus: *Table 4* groups the various scenarios identified during the analysis of the studies. The simple consideration of different fuels is not retained as a scenario, since it is the core subject of the study;
- Transport type: A distinction is made between studies dedicated exclusively to freight transport and those that also cover passenger transport;
- Vehicle type: *Table 5* lists the groups of vehicle types;
- Drivetrain technology and fuel: *Table 6* shows the types of fuels studied;
- Study type: A distinction is made between retrospective and prospective studies.

These criteria were chosen to ensure a comprehensive, multidimensional analysis of the retained documents. The aim of this classification was to facilitate a structured and systematic statistical analysis, revealing thematic patterns, methodological diversity and the overall distribution of research efforts. Each criterion addresses a key aspect of the research landscape – technological, geographical, methodological or thematic. Together, they help explain how the literature approaches road freight decarbonisation. Other criteria, like fleet sizing or mileage, were considered but excluded due to inconsistent reporting across studies and a risk of adding complexity without offering clear analytical benefits.

A simplified classification, based on geography, perspective, vehicle type, drivetrain technology, and including all selected documents, is provided in the Appendix (see *Table 9*).

3. EMPIRICAL RESULTS

A statistical analysis was performed to evaluate and interpret the data gathered from the classified documents, with the objective of exploring the evolution of research interest, assessing the frequency of key topics, and identifying potential gaps in the literature.

3.1 Document sources

The selected and analysed papers originate from 55 different scientific journals. *Figure 2* is a Pareto diagram representing the breakdown of publications by scientific journal. With respectively 17 and 16 documents, *Applied Energy* and *Transportation Research Part D* stand out as the most prolific scientific journals on this subject. *Journal of Cleaner Production* totals 13 documents and also emerges as an essential scientific journal. Together, these three account for 29.1% of the documents retained for classification (see *Table 3*).

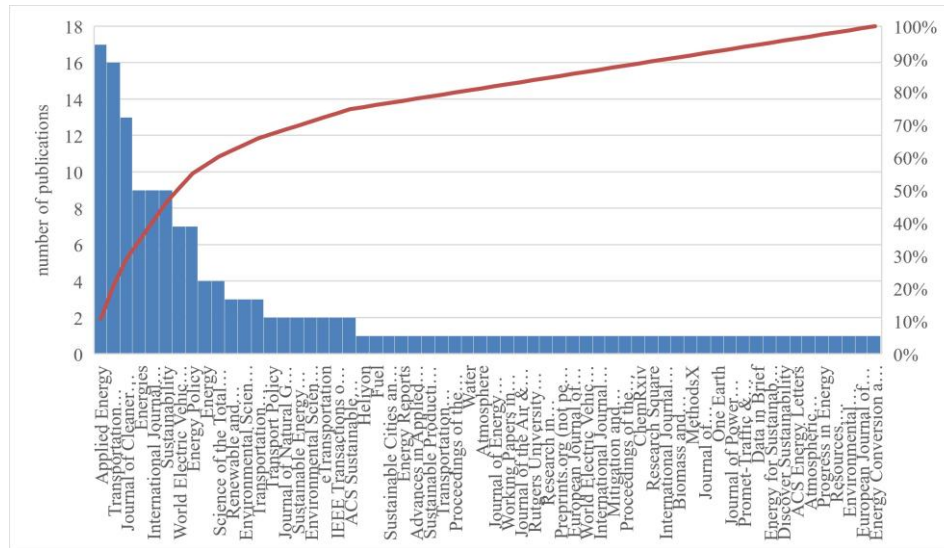


Figure 2 – Number of publications by scientific journal

Table 3 – Share of publications per scientific journal (only the 13 most represented journals are included)

Scientific journal	Quantity	Percentage	Cumulative percentage
Applied Energy	17	10.76%	10.76%
Transportation Research Part D	16	10.13%	20.89%
Journal of Cleaner Production	13	8.23%	29.11%
Energies	9	5.70%	34.81%
International Journal of Hydrogen Energy	9	5.70%	40.51%
Sustainability	9	5.70%	46.20%
World Electric Vehicle Journal	7	4.43%	50.63%
Energy Policy	7	4.43%	55.06%
Energy	4	2.53%	57.59%
Science of the Total Environment	4	2.53%	60.13%
Renewable and Sustainable Energy Reviews	3	1.90%	62.03%
Environmental Science and Technology	3	1.90%	63.92%
Transportation Research Interdisciplinary Perspectives	3	1.90%	65.82%

3.2 Temporal and geographic distribution

Figure 3 shows the cumulative number of publications by world region from 2000 to 2023. Publications from 2024 are excluded from this and subsequent figures to avoid skewing the perspective of the research landscape, as the data extraction from WoS was done mid-year.

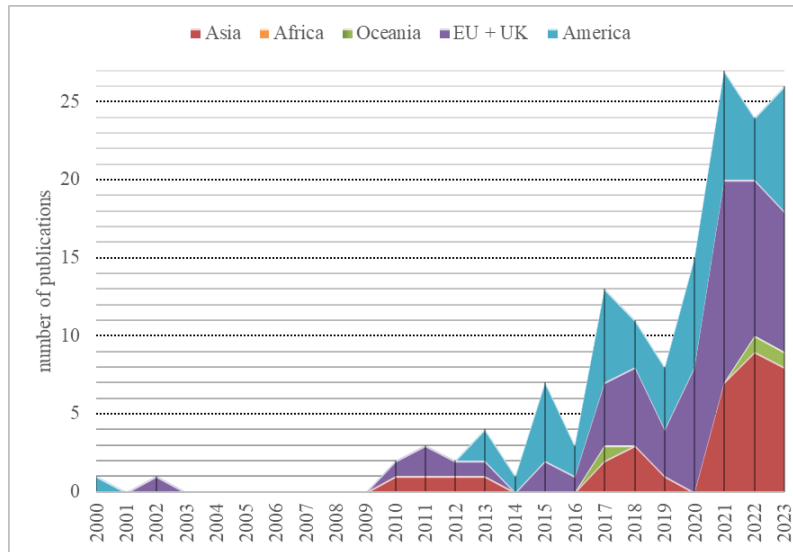


Figure 3 – Number of publications by continent and year (stacked, 2000–2023)

Globally, the number of studies has been gradually increasing since 2010. However, the geographic distribution is quite uneven. Africa is the least represented continent, with absolutely no study conducted in this region during the entire period. Interest in Oceania is also very low, with a few studies emerging in recent years, but this remains marginal (one per year since 2022). Studies concerning the European Union and the United Kingdom have been significantly increasing since 2015, with a notable peak in 2021. With more than 41.4% of studies focusing on this geographic region, it appears to be of great interest in the search for alternative solutions to fossil fuels. The trajectory of the curve for America is similar to the general trend. With 52 studies focusing on this region, it seems to play a key role in research as well. It should be noted that 69.2% of the studies conducted on the American continent focus on the United States. Asia has been modestly represented in studies until 2016, after which the number of studies gradually increased, surpassing those dedicated to the American continent in 2021. The percentage of studies focusing on China (80.0% of studies conducted in Asia) highlights this country’s primacy in the search for alternative fuels.

This graph highlights increased dynamism in recent years (85.3% of the retained studies occurred after 2016), with a particular focus on Europe, America, and, more recently, Asia in this critical field of the energy transition in road freight transport.

3.3 Economic vs. ecological investigation

Figure 4 summarises the perspectives covered in the analysed documents. The majority (82 out of 158) address both the ecological and economic consequences of adopting alternative solutions in the road freight transport sector. The ecological dimension is particularly important, with an additional 52 documents (32.9% of the retained papers) focusing exclusively on this aspect. Finally, 24 documents (15.2% of the retained papers) are dedicated solely to the economic perspective.

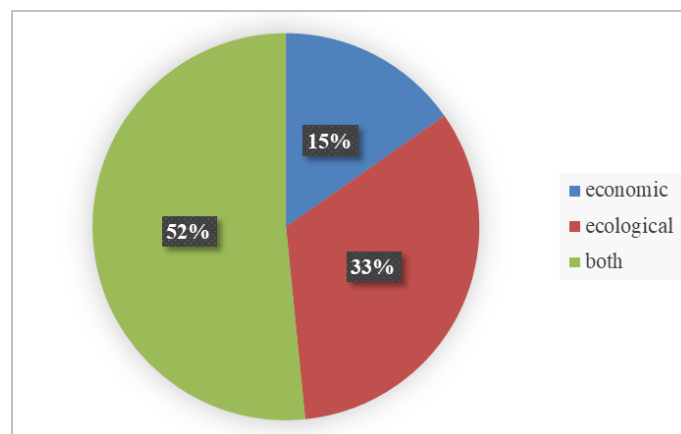


Figure 4 – Percentage distribution of publications by investigation perspective

3.4 Research focus over time

Table 4 presents a list of key scenarios considered in studies on alternative fuels in the transport sector. This helps illustrate which factors are most commonly analysed in the literature and highlights the main variables that influence the assessment of alternative fuel performance. For each scenario, a brief description is provided along with the number of studies in which it appears. It is important to note that the scenarios are not mutually exclusive; a single study may address multiple scenarios simultaneously.

Table 4 – Scenarios

Scenario	Description	Number of studies
Energy production method / energy mix	The source of the energy used to power vehicles (renewable energy, nuclear, fossil fuels) affects the overall life cycle emissions of alternative fuels.	41
Driving conditions	Driving conditions affect energy consumption and vehicle wear (load factor, weather, road and traffic conditions).	24
Energy price (including carbon price)	Fluctuations in energy prices, including the cost of carbon emissions, which varies according to government policies, directly impact the profitability of fossil fuel alternatives.	23
Penetration rate / fleet size	The adoption rate of alternative technologies in the vehicle fleet or the size of the fleet of alternative fuel vehicles influences economies of scale for vehicle and infrastructure acquisition and maintenance.	16
Annual mileage	The total distance covered by a vehicle over a year influences energy demand, operating costs, as well as wear and tear and vehicle depreciation (particularly for electric vehicles, whose range depends on usage).	13
Equipment costs (including subsidies)	The cost of purchasing and installing necessary equipment (vehicles, charging infrastructure, etc.) impacts the financial analysis, as do state subsidies and financial incentives.	12
Vehicle range / battery capacity	The maximum range, depending on battery or fuel tank capacity, affects the operational performance of vehicles and the feasibility of transitioning to alternative solutions.	9
Technological advancements	Future technological advancements can influence the performance, costs, and efficiency of alternative vehicles and infrastructure (e.g. improved batteries).	7
Battery degradation / vehicle age	Battery performance declines over time due to charging and discharging cycles, affecting maintenance costs, vehicle durability and energy efficiency.	6
Vehicle lifetime	The operational lifespan of vehicles impacts the TCO and the amortisation of investments.	5
Vehicle configuration	The specifications of the vehicle (dimensions, weight, type of transmission, tyre size, battery type, etc.) affect energy consumption and carbon emissions.	4
Refuelling / recharging method	Different recharging technologies (slow, standard, fast charging, overnight recharging, etc.) influence the operational efficiency of alternative vehicles.	4

The evolution in the distribution of studies across various scenarios over time reflects shifts in research priorities. Figure 5 shows the cumulative number of publications per year for the six most represented research focuses.

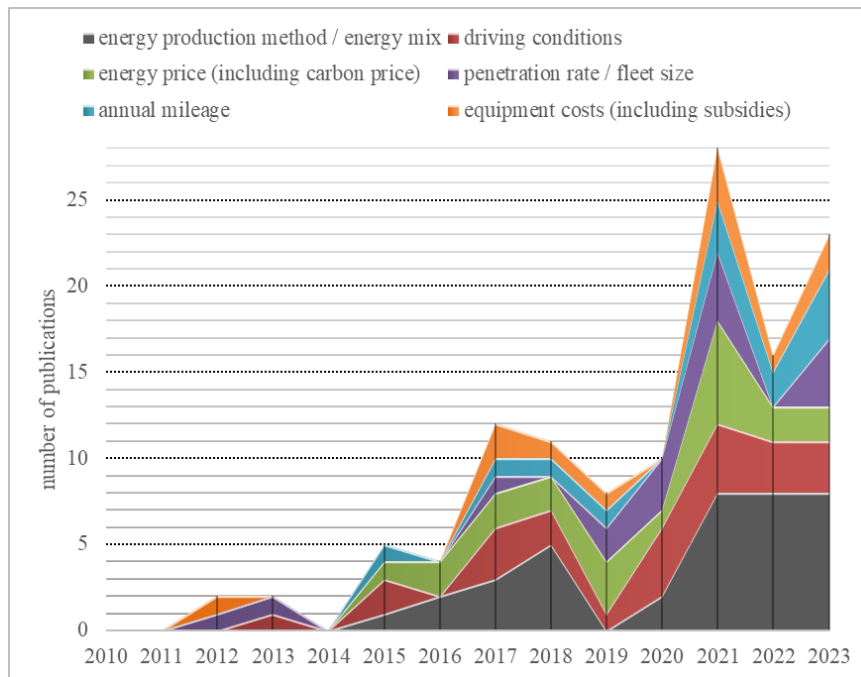


Figure 5 – Number of publications by research focus and year (stacked, 2010–2023)

Since 2015, research topics such as annual mileage, energy prices and driving conditions have shown varied patterns of interest. Research on annual mileage has been sporadic, with a modest peak in 2023, likely due to advancements in vehicle range. Interest in energy prices peaked in 2021, reflecting broader public debate on energy and carbon emissions costs. Driving conditions have remained a consistently studied topic. Although fleet penetration rates were not covered in 2022, they remain a steady area of focus. Since 2017, studies on equipment costs have become more frequent, likely due to evolving subsidies. However, energy mix scenarios remain more prominent, especially with peaks in 2022 and 2023. This trend underscores increasing concern over how energy sources impact diesel alternatives.

3.5 Transport types

As explained in Section 2.1, some studies focus on both freight and passenger transport. 29.6% of the retained studies fall into this category. The rest focus exclusively on freight transport. Figure 6 illustrates this situation.

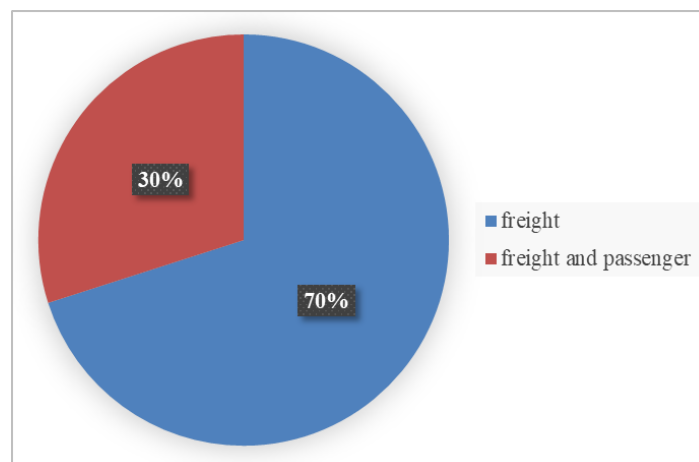


Figure 6 – Percentage distribution of publications by transport type

3.6 Vehicle types

Table 5 provides an overview of the different vehicle types commonly referenced in studies on alternative fuels in road freight transport. Each category is accompanied by a brief description to clarify its usage.

Table 5 – Vehicle types

Vehicle type	Description
Forklift + Pushback tractor	Specialised transport for short distances (in warehouses and airports)
Goods and logistics vehicle + Truck	Generic terms that require more specific details and are used when neither the class nor the weight is specified
LDT + MiDT + LDV + LCV + Van	Light-duty truck, mini truck, light-duty vehicle, light commercial vehicle and van
MDT + MDV	Medium-duty truck and medium-duty vehicle
HDT + HGV + HDV	Heavy-duty truck, heavy goods vehicle and heavy-duty vehicle

The analysis reveals that most studies focus on heavy vehicles, which are often considered the most challenging segment to decarbonise due to their high energy demands and long-haul usage patterns. As shown in Figure 7, this type of vehicle is studied in nearly half of the cases. The light vehicle category and the medium vehicle category complete the top three, in that order. However, they are significantly less represented and together account for fewer studies than those dedicated to heavy vehicles.

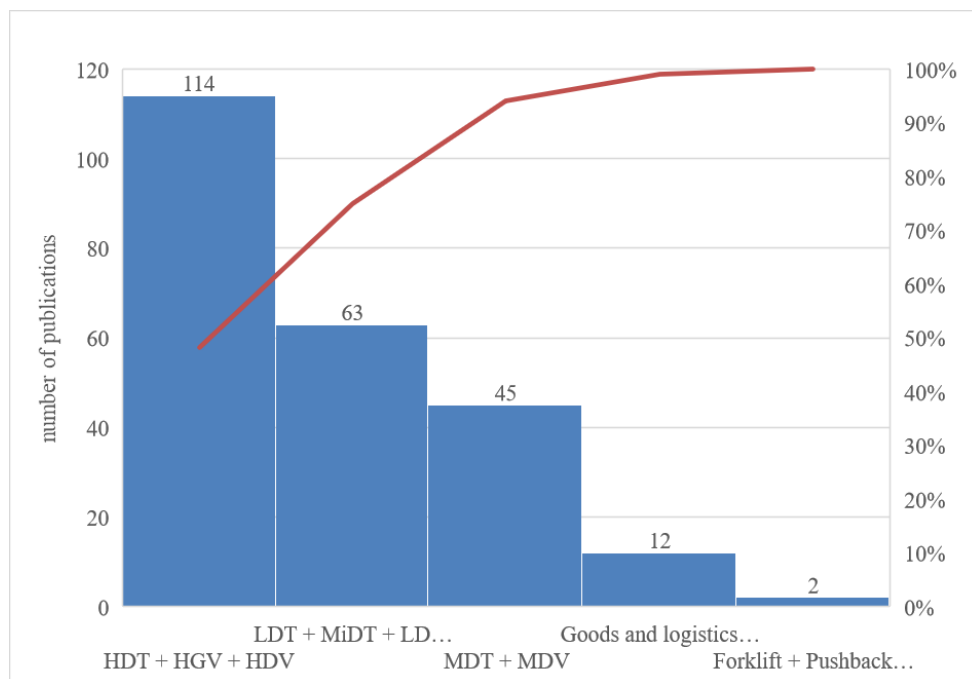


Figure 7 – Number of publications by vehicle type

3.7 Drivetrain technologies

In the context of research on alternative fuel solutions, ICEVs are generally used as a reference baseline, compared to other transmission categories. Figure 8 represents the percentage of studies dedicated to each alternative powertrain group. Studies mainly focus on a few technologies. Thus, BEVs account for 44.7% of the studies. With 24.0%, FCEVs are also well represented. These are the only categories that exceed 15.0%. Two other categories surpass the 5.0% mark: HEVs with 13.4% and their counterparts, whose batteries can be plugged into an electrical socket for recharging, the PHEVs, with 8.9%. None of the other powertrain groups exceeds 2.5%.

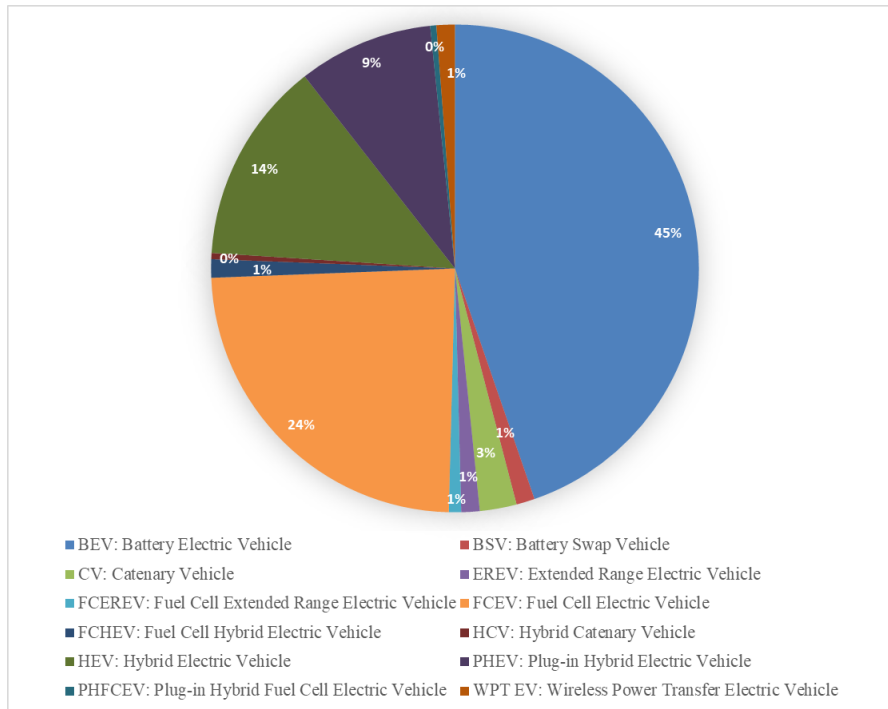


Figure 8 – Percentage distribution of publications by drivetrain technology

3.8 Fuels

Table 6 provides an overview of the various fuel types considered in the studies. Each fuel is briefly described, highlighting its origin, composition or production pathway.

Table 6 – Fuels

Fuel	Description
Biodiesel / oxygenated fuel (ether, ester, alcohol) / FAME	Produced by transesterification of vegetable oils (soybean, rapeseed, sunflower, palm) or animal fats – a reaction between the feedstock and an alcohol
Biofuel	Generic term for liquid and gaseous transport fuels (such as biodiesel, bioethanol and biogas) made from biomass
Biogas (gaseous, liquefied)	Mixture of methane, CO ₂ and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment
CNG / LNG	Compressed or liquefied natural gas
Electricity	Generated from fossil fuel, solar energy, biomass, wind, nuclear or hydropower plants (no distinction is made)
Fischer-Tropsch diesel	Synthetic diesel resulting from the FT-synthesis – a reaction between carbon monoxide and hydrogen
Hydrogen	Produced from fossil fuels, nuclear or hydropower plants, solar energy, biomass, wind, renewable or grid electricity (no distinction is made)
Hythane	Blend of hydrogen and compressed natural gas
LPG	Liquefied petroleum gas
Renewable diesel / HVO	Produced by hydrotreating (hydrotreated vegetable oil), gasification or pyrolysis of biomass feedstock
Renewable NG / biomethane	Near-pure source of methane produced either by “upgrading” biogas (a process that removes any CO ₂ and other contaminants present in the biogas) or through the gasification of solid biomass, followed by methanation
SVO	Straight vegetable oil

Figure 9 represents the interest in the different fuel types. Logically, electricity and hydrogen are present in proportions similar to those observed in Figure 8 for BEVs and FCEVs. Indeed, these two types of energy are mainly used by BEVs and FCEVs, respectively. With slightly more than 16.0% of all studies, CNG / LNG complete the podium of substitute fuels. New-generation biofuels are relatively underexplored in the literature, providing limited additional perspective on alternative options.

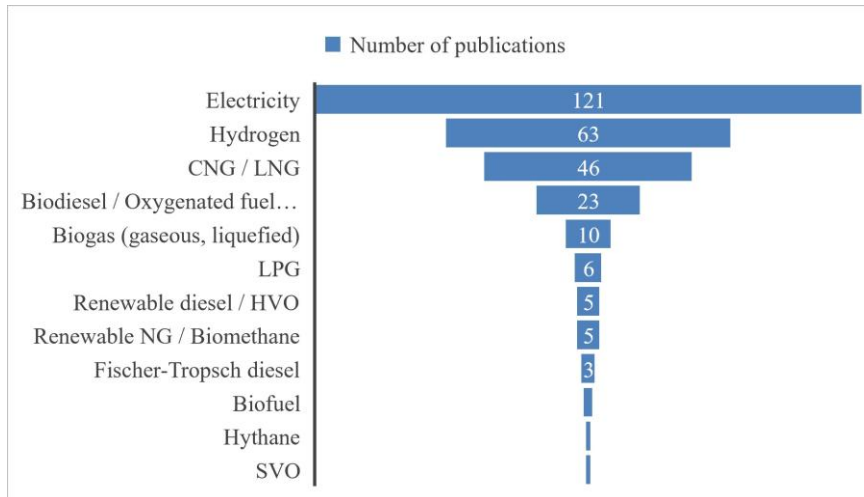


Figure 9 – Number of publications by fuel

3.9 Vehicle type and drivetrain technology distribution

Figure 10 shows the distribution of publications by drivetrain technology for the three most represented vehicle types. For each category, the distribution generally aligns with the previous conclusions, with BEVs dominating the literature. FCEVs and hybrid solutions appear less frequently. However, the proportion of FCEV-focused studies for LDTs and MDTs is somewhat higher than anticipated. These vehicle categories are typically associated with regional and urban transport, where BEVs are generally considered more viable due to their shorter-range requirements and compatibility with predictable routes. In this context, an even higher share of BEV studies could have been expected. It should be noted that CVs are only considered in the context of heavy-duty vehicles, where the relative share of hybrid vehicle studies is slightly below average. Besides, despite the well-known challenges of fully electrifying long-haul operations due to range limitations and infrastructure constraints, BEVs appear somewhat overrepresented in this segment.

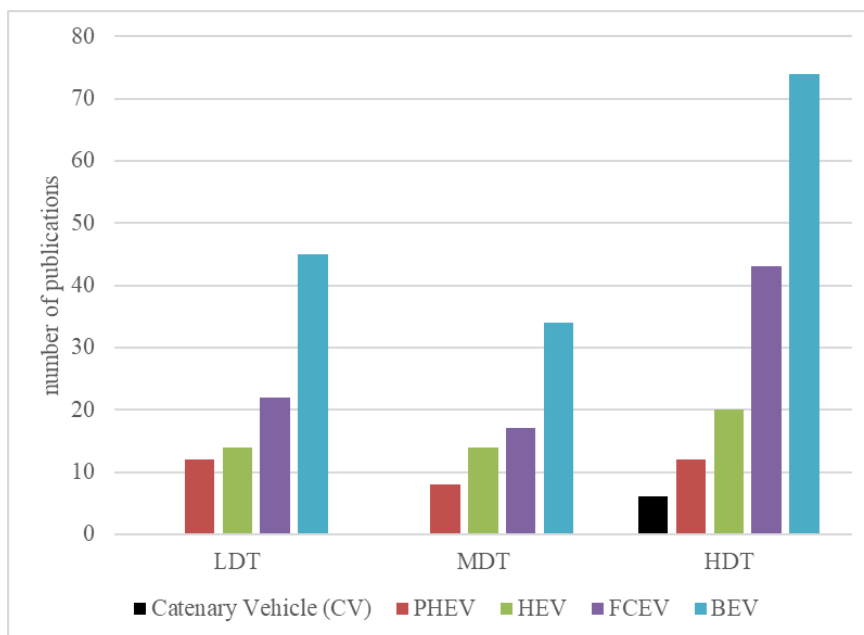


Figure 10 – Number of publications by vehicle type and drivetrain technology

3.10 Temporal and drivetrain technology distribution

Figure 11 represents the year-by-year evolution of the number of studies dedicated to different powertrain groups since 2010.

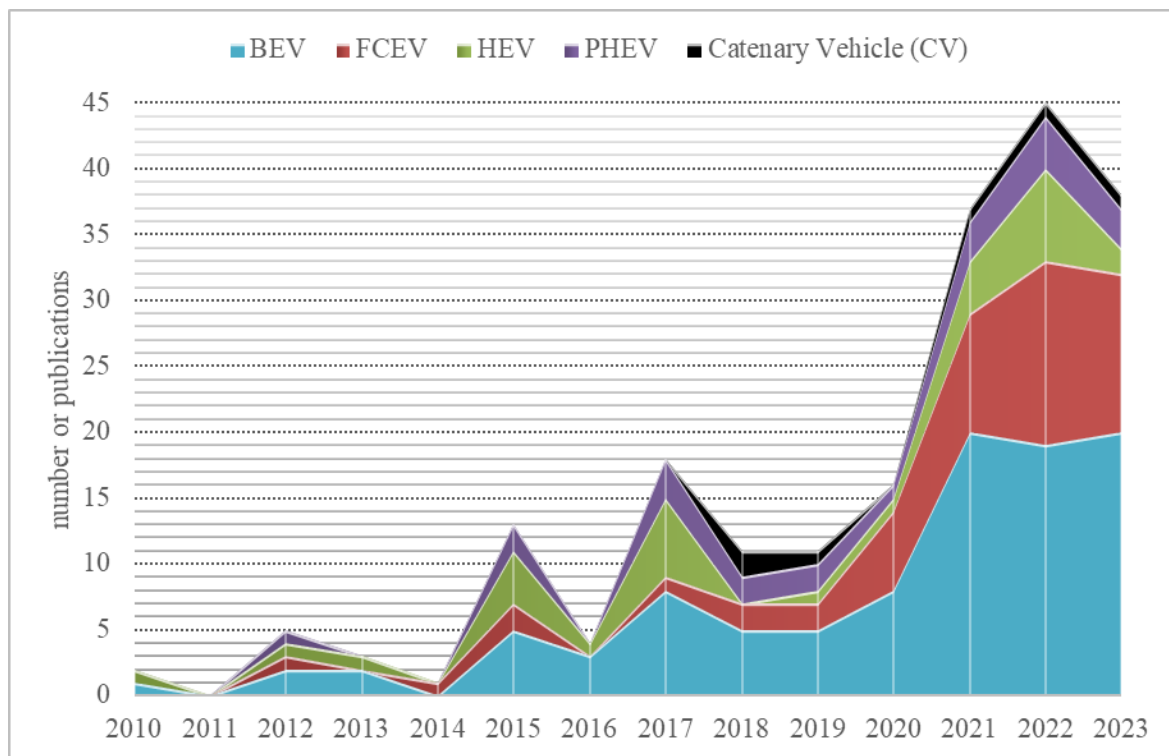


Figure 11 – Number of publications by drivetrain technology and year (stacked, 2000–2023)

The number of studies on BEVs has been steadily increasing since 2011. A significant rise can be observed starting in 2019, reaching a peak of 20 studies in both 2021 and 2023. This powertrain group has been the most studied in the past four years. Studies on FCEVs started to increase significantly in 2016, with notable growth beginning in 2019 and peaking at 14 studies in 2022. Although the number of studies slightly decreased in 2023 (12 studies), FCEVs continue to attract considerable attention.

Studies on HEVs and PHEVs have gradually increased until 2017, after which their numbers dropped to lower levels in the following years. A slight resurgence in the number of studies on hybrid vehicles can be observed in 2022. However, the declining interest in this technology compared to BEVs and FCEVs remains unchanged, as evidenced by the fact that, in 2023, the number of studies dedicated to hybrid vehicles decreased once again, while research on alternative solutions reached its peak. Despite their potential role in a gradual transition to fully decarbonised vehicles, hybrid vehicles (HEVs and PHEVs) appear to be receiving less and less attention in research. CVs have been a very underrepresented topic, with an average of one study published per year since 2018.

In summary, studies on hybrid vehicles seem to be declining, possibly due to growing interest in zero direct-emission technologies such as BEVs and FCEVs, which have dominated research on alternative fuels for road freight transport since 2020.

3.11 Temporal design of studies by scenario

Table 7 summarises the number of retrospective, prospective and mixed studies considered in the various scenarios.

Table 7 – Temporal design of studies by scenario

Scenario	Retrospective	Prospective	Mixed
Energy production method / energy mix	20	20	1
Driving conditions	15	9	0
Energy price (including carbon price)	8	13	2
Penetration rate / fleet size	3	13	0
Annual mileage	7	6	0
Equipment costs (including subsidies)	4	7	1
Vehicle range / battery capacity	6	3	0
Technological advancements	3	4	0
Battery degradation / vehicle age	4	2	0
Vehicle lifetime	4	1	0
Vehicle configuration	4	0	0
Refuelling / recharging method	3	1	0

Overall, the studies are fairly evenly divided between retrospective and prospective studies, with a slight dominance of retrospective studies, as shown in Figure 12. This indicates that research on alternative fuels in road freight transport is fairly balanced between analysing past data and future predictions. Mixed approaches (incorporating both retrospective and prospective elements) are occasionally employed for scenarios such as energy prices, equipment costs and energy production methods. This reflects the correlation between historical trends and their impact on future key factors.

However, depending on the scenario, there is often a clear tendency to focus predominantly on either retrospective or prospective analysis. For example, vehicle configuration and vehicle lifetime are predominantly, if not exclusively, investigated retrospectively. This is likely due to the reliance on long-term data for these variables. For instance, vehicle configuration evolves with innovation but at a relatively slow pace compared to other factors. Similarly, vehicle lifetime inherently requires prolonged observation periods. Conversely, scenarios involving the penetration rate of new technologies in the market are primarily explored through prospective studies. This is because this variable depends on future factors such as public policies, economic developments, technological advancements and market acceptance. Furthermore, retrospective analyses are often constrained in this area due to the relatively recent emergence and limited market penetration of alternative technologies. Consequently, researchers naturally turn to prospective analyses to anticipate their development.

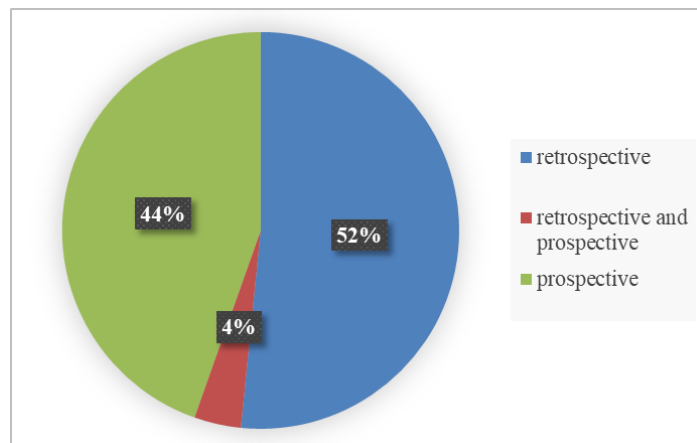


Figure 12 – Percentage distribution of publications by temporal design of studies

4. RESEARCH GAPS AND PROPOSED FUTURE RESEARCH DIRECTIONS

Despite recent advancements in the field of alternative fuels for road freight transport, this statistical analysis reveals several research gaps. These are detailed in the following paragraphs.

4.1 Insufficient integration of infrastructure in prospective research

Although BEVs and FCEVs are increasingly studied for their environmental benefits and potential to replace internal combustion engines, the development of the infrastructure needed to support them has not received the same attention. However, it is essential to include a study of the infrastructure needed for their implementation in order to assess the relevance and viability of the project. Indeed, the lack of fast and accessible charging stations may limit the adoption of BEVs, particularly for long-distance transport, as well as in rural areas. For FCEVs, the challenge is even greater, as the production, storage and distribution of hydrogen on a large scale requires significant investments and technological advancements to be viable. Just like the lack of fiscal support and incentives for electromobility [20], the lack of charging infrastructure is a major obstacle to the adoption of electric vehicles [21]. For this reason, electric vehicle penetration remains particularly low in Africa, accounting for less than 1.0% of total car sales across the continent [22]. In contrast, more mature markets like China, Europe and the United States have implemented extensive charging infrastructure and benefit from policy frameworks that support electric vehicle adoption. China, for example, aims to have sufficient infrastructure for more than 20 million electric vehicles in 2025, and the United States has allocated billions of dollars to support a charging network across 122,000 km of highway [20]. Besides, policy initiatives such as the European Union's Alternative Fuels Infrastructure Regulation (AFIR) underline the necessity of extending the TEN-T network. This includes adding fast charging stations in strategically important urban nodes [23].

In brief, it is important to rebalance research to include not only vehicle improvements but also the development of appropriate infrastructure. This includes studies on the optimal geographic distribution of charging stations and hydrogen refuelling stations, fast charging technologies, and the economic and environmental impacts of these infrastructures. Although some recent studies have begun to address infrastructure development for trucks in the United States and in Germany [24, 25], further research efforts should be more systematically directed toward this area to support the effective deployment of alternative fuel technologies. Future research should therefore integrate comprehensive infrastructure considerations, including geographic distribution, advancements in charging and refuelling technologies, as well as the associated economic and environmental impacts. Other recent studies addressing the challenges and prospects of electric vehicle adoption in Sub-Saharan Africa have predominantly focused on passenger transport [26, 27]. However, there is a noticeable research gap concerning the electrification of freight transport. Unlike passenger transport, freight applications require more energy-intensive solutions, which impose greater demands on infrastructure. As such, the integration of freight-specific considerations is necessary to ensure a comprehensive transition to sustainable road haulage.

4.2 Underrepresentation of biofuels in the literature

While significant attention has been given to electrification and hydrogen-based solutions, biofuels remain relatively underexplored in the academic literature on freight transport. Given their compatibility with existing internal combustion engines and their potential as a transitional solution – particularly in regions where electrification is less feasible – biofuels deserve more focused investigation. Furthermore, despite variations across scenarios, biofuels are expected to significantly support EU climate goals, with contributions expected to reach 24.5 Mtoe (million tons of oil equivalent) by 2030 and 48.3 Mtoe by 2050. [28] point out that this increase is largely driven by a shift towards advanced biofuels, whose contribution is projected to rise from 8.7 Mtoe to 36.5 Mtoe over the same period. Therefore, future studies should further assess the environmental, economic and logistical implications of integrating biofuels into road freight systems, considering regional feedstock availability, lifecycle emissions and potential policy incentives.

4.3 Lack of research on industry cooperation for electrification

Another neglected dimension is the potential role of shipper-carrier collaboration in facilitating the electrification of road freight transport. The transition to battery electric requires substantial investment in new infrastructure and adjustments in operational practices, such as route planning and charging schedules.

Coordinated strategies between shippers and carriers could facilitate this transition by enabling shared investments, optimising charging infrastructure usage and reducing operational costs through better scheduling and load management. Despite its importance, this topic is scarcely addressed in the existing literature. Future research should investigate collaborative business models, multi-actor investment strategies and policy frameworks that encourage cooperation across the supply chain, while also exploring how industry-wide collaboration could accelerate the deployment of zero-emission freight solutions, especially for long-haul and high-frequency roundtrip operations.

4.4 Limited vehicle types

Most studies concentrate on heavy-duty vehicles, while light and medium-duty vehicles are understudied. However, these types of vehicles play a key role in freight transport, particularly in last-mile delivery. This gap is even more problematic given the rapid expansion of e-commerce and the growing importance of sustainable urban logistics. Developing alternative technologies for these vehicles is therefore essential, as they constitute a significant share of the global fleet and generally present fewer technical challenges. Future research should further investigate light- and medium-duty vehicles, with particular attention to their specific operational profiles, charging requirements and integration within city infrastructures.

4.5 Drivetrain technology bias

As mentioned in Section 3.9, the proportion of studies focusing on FCEVs and hybrid solutions is somewhat higher than expected for LDTs and MDTs. In contrast, their coverage remains relatively limited for HDTs. This divergence suggests a potential misalignment between the technological relevance of these solutions and the current distribution of research efforts. Indeed, while the academic community's focus on zero-emission solutions is understandable, there is a noticeable bias towards BEVs for HDTs, often at the expense of FCEVs and hybrid vehicles. This may reflect current policy priorities, but it risks neglecting transitional technologies that could support the shift toward decarbonisation. Hybrid and plug-in hybrid vehicles can play an important intermediary role, particularly in contexts where electrification is constrained by infrastructure or where operational limitations restrict the use of fully electric options. Similarly, FCEVs could be further explored as a complementary solution, especially for long-haul HDT applications where their operational advantages, such as longer range and faster refuelling, may offer significant benefits.

4.6 Restricted geographical coverage

The majority of studies focus on Europe, America (especially the United States), and, more recently, Asia (primarily China). Africa and Oceania are significantly underrepresented, with few or no studies conducted on these continents. This limits the global understanding of regional specifics regarding alternative fuels and the challenges faced by developing countries. It would be relevant to develop studies on Africa and Oceania to understand the barriers to the adoption of alternative fuels, considering the socio-economic and infrastructural specificities of these regions.

However, this lack of research on alternative solutions in developing countries can also be explained by a lack of infrastructure. Indeed, without adequate infrastructure, it is materially difficult to conduct studies that collect empirical data to assess the impacts and effectiveness of alternative solutions. Africa lags behind other continents in terms of infrastructure for electric vehicles. Charging infrastructure, in particular, is far less developed in Africa compared to regions like Europe, China or the United States, which are investing heavily in public charging stations and fast-charging networks [20]. Recent research about the barriers for vehicle electrification was conducted in [24, 25] but only for passenger transportation. Work on freight operations is still lacking.

Table 8 summarises the identified research gaps and their implications for future investigation. Bridging these gaps is essential to support a globally coherent and context-sensitive energy transition in the transport sector. Future research should therefore aim to develop more integrated and inclusive frameworks that reflect the complex interplay between vehicle technology, infrastructure deployment, business ecosystem and geographic context.

Table 8 – Identified research gaps

Research gap	Description	Implication for future research
Insufficient integration of infrastructure	Charging and hydrogen refuelling infrastructure underexplored in prospective studies	Include geographic, technical, organisational, economic and environmental infrastructure dimensions
Underrepresentation of biofuels	Limited focus despite their near-term compatibility with existing fleets and EU climate potential	Evaluate environmental impacts across the full lifecycle, regional resource availability (feedstock potential), and the role of biofuels in multi-pathway transition strategies
Lack of cooperation models	Missing analysis of shipper-carrier coordination in deploying electric trucks	Explore shared business models, investment mechanisms and policy incentives
Limited vehicle types	Bias on heavy-duty vehicles	Expand scope to light- and medium-duty vehicles, which play a crucial role in urban freight and last-mile delivery
Drivetrain technology bias	Overrepresentation of BEVs, particularly for HDTs, and limited attention to FCEVs and hybrid technologies	Provide a basis for the comparative assessment of FCEVs and hybrid solutions, particularly for long-haul operations and transitional scenarios
Restricted geographical coverage	Sparse research on alternative fuels in Africa and Oceania due to data and infrastructure limitations	Promote context-sensitive studies that address the specific challenges of underrepresented regions and infrastructure gaps

5. DISCUSSION

The analysis of existing research shows that the transition to alternative fuels is strongly oriented toward electricity, reflecting technological, economic and policy priorities. The focus on BEVs, even for heavy-duty trucks, is explained by the rapid increase in battery energy density, falling costs and the progressive development of charging infrastructure, which make this solution increasingly viable for long-distance routes.

Electric mobility is currently establishing itself and is expected to dominate in the future, primarily for reasons of energy efficiency and the availability of low-carbon electricity. In contrast, hydrogen is still largely produced from fossil fuels, while biofuels are constrained by resource availability and environmental impacts. Even when low-carbon hydrogen becomes widely available, its use will likely be prioritised in sectors where substituting fossil fuels is particularly challenging. For instance, in heavy industry, processes often require very high temperatures or specific chemical reactions for which direct electrification is not feasible, making hydrogen a suitable replacement for coal or natural gas. Similarly, in synthetic fuel production, hydrogen can be combined with CO₂ to produce fuels compatible with existing infrastructure for aviation or maritime transport, sectors where electrification remains difficult. As a result, hydrogen's role in mainstream road transport is expected to remain limited.

The technological and economic maturity of electric vehicles, combined with a charging network that is both rapidly expanding and already more developed than hydrogen infrastructure, reinforces this trend. These factors explain why research and investment are heavily focused on electric solutions for road transport, relegating hydrogen to a niche market. This orientation has important implications: it justifies concentrating future research efforts on electricity storage, battery optimisation, the deployment of shared infrastructure and coordination among stakeholders.

6. LIMITATIONS OF THE REVIEW

While this review offers a structured overview of the current academic landscape on alternative traction modes in road freight transport, several limitations should be acknowledged. First, the scope of the review was limited to peer-reviewed academic publications written in English or German. As a result, relevant studies published in other languages or in grey literature may have been neglected, potentially reducing the perspective on region-specific practices or policy innovations. Second, the classification framework relied on predefined criteria. Although these categories captured key dimensions of the literature, they may have excluded certain studies. Third, while the review aimed for objectivity in data extraction and categorisation, the interpretation of scenario focus can be partly subjective, particularly in studies that use qualitative approaches. Fourth, the

review does not assess the quality or methodological rigor of the individual studies, but rather offers an overview of the research areas covered. Finally, the rapid pace of technological and regulatory change in the transport sector means that some findings may evolve quickly.

7. CONCLUSION

This literature review provides a comprehensive overview of current research on alternative fuels in road freight transport. Rather than comparing specific technologies, it assesses the overall scope and focus of academic work in this field, indicating which technologies have been studied, along with their geographical distribution and research contexts. The analysis shows a clear upward trend in research on diesel substitutes, yet notable gaps remain, particularly concerning the diversity of vehicle types and regional coverage. These limitations constrain the generalisability of findings and call for a more inclusive research agenda. Greater emphasis should be placed on light- and medium-duty vehicles, especially within urban logistics and last-mile delivery systems. Additionally, regional disparities should be addressed through context-sensitive approaches that account for local infrastructure, policy environments and operational constraints.

Hydrogen is likely to remain a niche solution, primarily for industrial applications requiring high-temperature processes or for synthetic fuel production, while biofuels can serve as a transitional option in areas where electrification is not yet feasible. However, despite their potential, combustion-based alternatives still produce emissions. This explains why many high-income countries increasingly focus on zero-emission vehicles, supported by public policies such as subsidies, toll reductions and access to low-emission zones. Consequently, BEVs are expected to dominate the future of road freight due to their technological maturity, declining costs and the availability of low-carbon electricity.

Still, the review shows that vehicle technology alone is insufficient. Indeed, large-scale adoption also depends on adequate infrastructure and improved coordination among all actors involved. The interdependence between charging infrastructure deployment and electric vehicle adoption creates a feedback loop that may hinder progress if not properly addressed: insufficient infrastructure slows electric vehicle uptake, while low adoption rates discourage further investments in charging networks. Breaking this cycle requires integrated planning. Policymakers should also promote collaborative approaches that encourage partnerships between shippers and carriers, for instance by supporting joint investments in charging infrastructure. Such measures can help accelerate electric truck adoption by reducing individual investment burdens and optimising infrastructure use. Ultimately, stronger collaboration between public and private actors is essential to expand charging networks and align them with long-term sustainability objectives. To support this shift, future research should incorporate real-world freight data to develop more practical and operationally relevant models for the decarbonisation of road freight transport.

ACKNOWLEDGEMENTS

The authors would like to thank Saarland University of Applied Sciences for providing access to relevant resources. This work is part of the project TIM, funded by the Zentrales Technologieprogramm Saar (ZTS) under grant number EFRE-0000423. The project is co-financed by the European Regional Development Fund (ERDF).

REFERENCES

- [1] Pietrzak K, Pietrzak O. Environmental effects of electromobility in a sustainable urban public transport. *Sustainability*. 2020;12(3):1052. DOI: [10.3390/su12031052](https://doi.org/10.3390/su12031052).
- [2] Zhang X, Lin Z, Crawford C, Li S. Techno-economic comparison of electrification for heavy-duty trucks in China by 2040. *Transportation Research Part D: Transport and Environment*. 2022;102:103152. DOI: [10.1016/j.trd.2021.103152](https://doi.org/10.1016/j.trd.2021.103152).
- [3] Nkesah SK. Making road freight transport more sustainable: Insights from a systematic literature review. *Transportation Research Interdisciplinary Perspectives*. 2023;22:100967. DOI: [10.1016/j.trip.2023.100967](https://doi.org/10.1016/j.trip.2023.100967).
- [4] Ghisolfi V, et al. Freight transport decarbonization: A systematic literature review of system dynamics models. *Sustainability*. 2022;14:3625. DOI: [10.3390/su14063625](https://doi.org/10.3390/su14063625).
- [5] Contestabile M, et al. Battery electric vehicles, hydrogen fuel cells and biofuels. Which will be the winner? *Energy & Environmental Science*. 2011;4(10):3754-3772. DOI: [10.1039/c1ee01804c](https://doi.org/10.1039/c1ee01804c).

- [6] Sen B, Ercan T, Tatari O. Does a battery-electric truck make a difference? – Life cycle emissions, costs, and externality analysis of alternative fuel-powered Class 8 heavy-duty trucks in the United States. *Journal of Cleaner Production*. 2017;141:110–121. DOI: [10.1016/j.jclepro.2016.09.046](https://doi.org/10.1016/j.jclepro.2016.09.046).
- [7] Lajevardi SM, Aksen J, Crawford C. Comparing alternative heavy-duty drivetrains based on GHG emissions, ownership and abatement costs: Simulations of freight routes in British Columbia. *Transportation Research Part D: Transport and Environment*. 2019;76:19–55. DOI: [10.1016/j.trd.2019.08.031](https://doi.org/10.1016/j.trd.2019.08.031).
- [8] Lao J, et al. Reducing atmospheric pollutant and greenhouse gas emissions of heavy duty trucks by substituting diesel with hydrogen in Beijing-Tianjin-Hebei-Shandong region, China. *International Journal of Hydrogen Energy*. 2021;46(34):18137–18152. DOI: [10.1016/j.ijhydene.2020.09.132](https://doi.org/10.1016/j.ijhydene.2020.09.132).
- [9] Pihlatie M, Ranta M, Rahkola P, Åman R. Zero-emission truck powertrains for regional and long-haul missions. *World Electric Vehicle Journal*. 2023;14(9):253. DOI: [10.3390/wevj14090253](https://doi.org/10.3390/wevj14090253).
- [10] Haugen MJ, et al. A fork in the road: Which energy pathway offers the greatest energy efficiency and CO₂ reduction potential for low-carbon vehicles? *Applied Energy*. 2021;283:116295. DOI: [10.1016/j.apenergy.2020.116295](https://doi.org/10.1016/j.apenergy.2020.116295).
- [11] Zhao Y, Tatari O. A hybrid life cycle assessment of the vehicle-to-grid application in light duty commercial fleet. *Energy*. 2015;93:1277–1286. DOI: [10.1016/j.energy.2015.10.019](https://doi.org/10.1016/j.energy.2015.10.019).
- [12] Teichert O, et al. Techno-economic cell selection for battery-electric long-haul trucks. *eTransportation*. 2023;16:100225. DOI: [10.1016/j.etrans.2022.100225](https://doi.org/10.1016/j.etrans.2022.100225).
- [13] Liu X, Elgowainy A, Vijayagopal R, Wang M. Well-to-wheels analysis of zero-emission plug-in battery electric vehicle technology for medium- and heavy-duty trucks. *Environmental Science & Technology*. 2020;55(1):538–546. DOI: [10.1021/acs.est.0c02931](https://doi.org/10.1021/acs.est.0c02931).
- [14] Castillo O, Álvarez R. Electrification of last-mile delivery: A fleet management approach with a sustainability perspective. *Sustainability*. 2023;15(24):16909. DOI: [10.3390/su152416909](https://doi.org/10.3390/su152416909).
- [15] De la Peña AG, et al. Projecting adoption of truck powertrain technologies and CO₂ emissions in line-haul networks. *Transportation Research Part D: Transport and Environment*. 2020;84:102354. DOI: [10.1016/j.trd.2020.102354](https://doi.org/10.1016/j.trd.2020.102354).
- [16] Romejko K, Nakano M. Portfolio analysis of alternative fuel vehicles considering technological advancement, energy security and policy. *Journal of Cleaner Production*. 2017;142:39–49. DOI: [10.1016/j.jclepro.2016.09.029](https://doi.org/10.1016/j.jclepro.2016.09.029).
- [17] Sen B, Ercan T, Tatari O, Zheng QP. Robust pareto optimal approach to sustainable heavy-duty truck fleet composition. *Resources, Conservation and Recycling*. 2019;146:502–513. DOI: [10.1016/j.resconrec.2019.03.042](https://doi.org/10.1016/j.resconrec.2019.03.042).
- [18] Wang S, et al. A data-driven multi-objective optimization framework for determining the suitability of hydrogen fuel cell vehicles in freight transport. *Applied Energy*. 2023;347:121452. DOI: [10.1016/j.apenergy.2023.121452](https://doi.org/10.1016/j.apenergy.2023.121452).
- [19] Meyer M, Bousonville T. Alternative fuels in road freight transport: Objectives and scope of a literature review. *Technical reports on Logistics (Working Paper No. 24)*. Saarland University of Applied Sciences, Business School. 2025.
- [20] IEA. *Global EV Outlook 2023 – Catching up with climate ambitions*. <https://www.iea.org/reports/global-ev-outlook-2023>.
- [21] Takman J, Andersson-Sköld Y. A framework for barriers, opportunities, and potential solutions for renewable energy diffusion: Exemplified by liquefied biogas for heavy trucks. *Transport Policy*. 2021;110:150–160. DOI: [10.1016/j.tranpol.2021.05.021](https://doi.org/10.1016/j.tranpol.2021.05.021).
- [22] IEA. *Global EV Outlook 2024 – Moving towards increased affordability*. <https://www.iea.org/reports/global-ev-outlook-2024>.
- [23] European Union. Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure. L 234, 22.9.2023, 1-56. Official Journal of the European Union; 2023.
- [24] Liu N, Xie F, Lin Z, Jin M. Evaluating national hydrogen refueling infrastructure requirement and economic competitiveness of fuel cell electric long-haul trucks. *Mitigation and Adaptation Strategies for Global Change*. 2020;25(3):477–493. DOI: [10.1007/s11027-019-09896-z](https://doi.org/10.1007/s11027-019-09896-z).
- [25] Speth D, Plötz P, Wietschel M. An optimal capacity-constrained fast charging network for battery electric trucks in Germany. *Transportation Research Part A*. 2025;193:104383. DOI: [10.1016/j.tra.2025.104383](https://doi.org/10.1016/j.tra.2025.104383).
- [26] Collett KA, et al. Can electric vehicles be good for Sub-Saharan Africa? *Energy Strategy Reviews*. 2021;38:100722. DOI: [10.1016/j.esr.2021.100722](https://doi.org/10.1016/j.esr.2021.100722).
- [27] Gicha BB, Tufa LT, Lee J. The electric vehicle revolution in Sub-Saharan Africa: Trends, challenges, and opportunities. *Energy Strategy Reviews*. 2024;53:101384. DOI: [10.1016/j.esr.2024.101384](https://doi.org/10.1016/j.esr.2024.101384).

- [28] Chiaramonti D, Talluri G, Scarlat N, Prussi M. The challenge of forecasting the role of biofuel in EU transport decarbonisation at 2050: A meta-analysis review of published scenarios. *Renewable and Sustainable Energy Reviews*. 2021;139:110715. DOI: [10.1016/j.rser.2021.110715](https://doi.org/10.1016/j.rser.2021.110715).
- [29] Tanco M, Cat L, Garat S. A break-even analysis for battery electric trucks in Latin America. *Journal of Cleaner Production*. 2019;228:1354–1367. DOI: [10.1016/j.jclepro.2019.04.168](https://doi.org/10.1016/j.jclepro.2019.04.168).
- [30] Rout C, Li H, Dupont V, Wadud Z. A comparative total cost of ownership analysis of heavy duty on-road and off-road vehicles powered by hydrogen, electricity, and diesel. *Heliyon*. 2022;8(12):e12417. DOI: [10.1016/j.heliyon.2022.e12417](https://doi.org/10.1016/j.heliyon.2022.e12417).
- [31] Atkins P, Milton G, Atkins A, Morgan R. A local ecosystem assessment of the potential for net negative heavy-duty truck greenhouse gas emissions through biomethane upcycling. *Energies*. 2021;14(4):806. DOI: [10.3390/en14040806](https://doi.org/10.3390/en14040806).
- [32] Pérez J, Lumbreras J, Rodríguez E, Vedrenne M. A methodology for estimating the carbon footprint of waste collection vehicles under different scenarios: Application to Madrid. *Transportation Research Part D: Transport and Environment*. 2017;52:156–171. DOI: [10.1016/j.trd.2017.03.007](https://doi.org/10.1016/j.trd.2017.03.007).
- [33] Osorio-Tejada JL, Llera-Sastresa E, Scarpellini S. A multi-criteria sustainability assessment for biodiesel and liquefied natural gas as alternative fuels in transport systems. *Journal of Natural Gas Science and Engineering*. 2017;42:169–186. DOI: [10.1016/j.jngse.2017.02.046](https://doi.org/10.1016/j.jngse.2017.02.046).
- [34] Wang Z, et al. A total cost of ownership analysis of zero emission powertrain solutions for the heavy goods vehicle sector. *Journal of Cleaner Production*. 2024;434:139910. DOI: [10.1016/j.jclepro.2023.139910](https://doi.org/10.1016/j.jclepro.2023.139910).
- [35] Charalambous MA, et al. Absolute environmental sustainability assessment of renewable dimethyl ether fuelled heavy-duty trucks. *Sustainable Energy & Fuels*. 2023;7(8):1930–1941. DOI: [10.1039/d2se01409b](https://doi.org/10.1039/d2se01409b).
- [36] Nouni MR, et al. Alternative fuels for decarbonisation of road transport sector in India: Options, present status, opportunities, and challenges. *Fuel*. 2021;305:121583. DOI: [10.1016/j.fuel.2021.121583](https://doi.org/10.1016/j.fuel.2021.121583).
- [37] Keogh N, Corr D, Monaghan RFD. An environmental and economic assessment for biomethane injection and natural gas heavy goods vehicles. *Applied Energy*. 2024;360:122800. DOI: [10.1016/j.apenergy.2024.122800](https://doi.org/10.1016/j.apenergy.2024.122800).
- [38] Noll B, del Val S, Schmidt T, Steffen B. Analyzing the competitiveness of low-carbon drive-technologies in road-freight: A total cost of ownership analysis in Europe. *Applied Energy*. 2022;306:118079. DOI: [10.1016/j.apenergy.2021.118079](https://doi.org/10.1016/j.apenergy.2021.118079).
- [39] Ma X, Wang Q, Xiong S, Yuan Y. Application of fuel cell and alternative fuel for the decarbonization of China's road freight sector towards carbon neutral. *International Journal of Hydrogen Energy*. 2024;49:263–275. DOI: [10.1016/j.ijhydene.2023.08.067](https://doi.org/10.1016/j.ijhydene.2023.08.067).
- [40] Moll C, Plötz P, Hadwich K, Wietschel M. Are Battery-Electric trucks for 24-Hour delivery the future of City Logistics? – A German case study. *World Electric Vehicle Journal*. 2020;11(1):16. DOI: [10.3390/wevj11010016](https://doi.org/10.3390/wevj11010016).
- [41] Wu X, et al. Assessing climate/air quality synergies and cost-effectiveness for Beijing transportation: Insights into sustainable development. *Sustainable Cities and Society*. 2024;104:105296. DOI: [10.1016/j.scs.2024.105296](https://doi.org/10.1016/j.scs.2024.105296).
- [42] Taefi TT, Stütz S, Fink A. Assessing the cost-optimal mileage of medium-duty electric vehicles with a numeric simulation approach. *Transportation Research Part D: Transport and Environment*. 2017;56:271–285. DOI: [10.1016/j.trd.2017.08.015](https://doi.org/10.1016/j.trd.2017.08.015).
- [43] Li J, et al. Assessing the decarbonization potential of China's light-duty truck fleet by electrification. *Energy Reports*. 2023;9:212–225. DOI: [10.1016/j.egyr.2023.03.018](https://doi.org/10.1016/j.egyr.2023.03.018).
- [44] Gray N, et al. Batteries, fuel cells, or engines? A probabilistic economic and environmental assessment of electricity and electrofuels for heavy goods vehicles. *Advances in Applied Energy*. 2022;8:100110. DOI: [10.1016/j.adapen.2022.100110](https://doi.org/10.1016/j.adapen.2022.100110).
- [45] Mareev I, Becker J, Sauer D. Battery dimensioning and life cycle costs analysis for a heavy-duty truck considering the requirements of long-haul transportation. *Energies*. 2017;11(1):55. DOI: [10.3390/en11010055](https://doi.org/10.3390/en11010055).
- [46] Bidart C, Wichert M, Kolb G, Held M. Biogas catalytic methanation for biomethane production as fuel in freight transport - A carbon footprint assessment. *Renewable and Sustainable Energy Reviews*. 2022;168:112802. DOI: [10.1016/j.rser.2022.112802](https://doi.org/10.1016/j.rser.2022.112802).
- [47] Baral NR, et al. Biomass feedstock transport using fuel cell and battery electric trucks improves lifecycle metrics of biofuel sustainability and economy. *Journal of Cleaner Production*. 2021;279:123593. DOI: [10.1016/j.jclepro.2020.123593](https://doi.org/10.1016/j.jclepro.2020.123593).
- [48] Gialos A, Zeimpekis V, Madas M, Papageorgiou K. Calculation and assessment of CO_{2e} emissions in road freight transportation: a Greek case study. *Sustainability*. 2022;14(17):10724. DOI: [10.3390/su141710724](https://doi.org/10.3390/su141710724).

- [49] Zhao Y, Onat NC, Kucukvar M, Tatari O. Carbon and energy footprints of electric delivery trucks: A hybrid multi-regional input-output life cycle assessment. *Transportation Research Part D: Transport and Environment*. 2016;47:195–207. DOI: [10.1016/j.trd.2016.05.014](https://doi.org/10.1016/j.trd.2016.05.014).
- [50] Zhao Y, Tatari O. Carbon and energy footprints of refuse collection trucks: A hybrid life cycle evaluation. *Sustainable Production and Consumption*. 2017;12:180–192. DOI: [10.1016/j.spc.2017.07.005](https://doi.org/10.1016/j.spc.2017.07.005).
- [51] Shafiei E, et al. Comparative analysis of hydrogen, biofuels and electricity transitional pathways to sustainable transport in a renewable-based energy system. *Energy*. 2015;83:614–627. DOI: [10.1016/j.energy.2015.02.071](https://doi.org/10.1016/j.energy.2015.02.071).
- [52] Rajagopal D, et al. Comparative evaluation of total cost of ownership of battery-electric and diesel trucks in India. *Transportation Research Record: Journal of the Transportation Research Board*. 2023;2678(6):235–247. DOI: [10.1177/03611981231195055](https://doi.org/10.1177/03611981231195055).
- [53] Syré AM, et al. Comparative life cycle assessment of battery and fuel cell electric cars, trucks, and buses. *World Electric Vehicle Journal*. 2024;15(3):114. DOI: [10.3390/wevj15030114](https://doi.org/10.3390/wevj15030114).
- [54] Balboa-Espinoza V, Segura-Salazar J, Hunt C, Aitken D. Comparative life cycle assessment of battery-electric and diesel underground mining trucks. *Journal of Cleaner Production*. 2023;425:139056. DOI: [10.1016/j.jclepro.2023.139056](https://doi.org/10.1016/j.jclepro.2023.139056).
- [55] Booto GK, Espegren KA, Hancke R. Comparative life cycle assessment of heavy-duty drivetrains: A Norwegian study case. *Transportation Research Part D: Transport and Environment*. 2021;95:102836. DOI: [10.1016/j.trd.2021.102836](https://doi.org/10.1016/j.trd.2021.102836).
- [56] Feng Y, Dong Z. Comparative lifecycle costs and emissions of electrified powertrains for light-duty logistics trucks. *Transportation Research Part D: Transport and Environment*. 2023;117:103672. DOI: [10.1016/j.trd.2023.103672](https://doi.org/10.1016/j.trd.2023.103672).
- [57] Speth D, Funke SÁ. Comparing options to electrify heavy-duty vehicles: Findings of German pilot projects. *World Electric Vehicle Journal*. 2021;12(2):67. DOI: [10.3390/wevj12020067](https://doi.org/10.3390/wevj12020067).
- [58] Hoshing V, et al. Comparison of economic viability of series and parallel PHEVs for medium-duty truck and transit bus applications. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*. 2020;234(10–11):2458–2472. DOI: [10.1177/0954407020919255](https://doi.org/10.1177/0954407020919255).
- [59] Tong F, Jaramillo P, Azevedo IML. Comparison of life cycle greenhouse gases from natural gas pathways for medium and heavy-duty vehicles. *Environmental Science & Technology*. 2015;49(12):7123–7133. DOI: [10.1021/es5052759](https://doi.org/10.1021/es5052759).
- [60] Middela MS, et al. Complete LCA of battery electric and conventional fuel vehicles for freight trips. *Transportation Research Part D: Transport and Environment*. 2022;110:103398. DOI: [10.1016/j.trd.2022.103398](https://doi.org/10.1016/j.trd.2022.103398).
- [61] Huertas JI, Mogro AE, Jiménez JP. Configuration of electric vehicles for specific applications from a holistic perspective. *World Electric Vehicle Journal*. 2022;13(2):29. DOI: [10.3390/wevj13020029](https://doi.org/10.3390/wevj13020029).
- [62] Gerbens-Leenes W, Holtz K. Consequences of transport low-carbon transitions and the carbon, land and water footprints of different fuel options in the Netherlands. *Water*. 2020;12(7):1968. DOI: [10.3390/w12071968](https://doi.org/10.3390/w12071968).
- [63] Soam S, Börjesson P. Considerations on potentials, greenhouse gas, and energy performance of biofuels based on forest residues for heavy-duty road transport in Sweden. *Energies*. 2020;13(24):6701. DOI: [10.3390/en13246701](https://doi.org/10.3390/en13246701).
- [64] Ping L, et al. Cost–benefit analysis of synergistic CO₂ and NO_x energy-efficient technologies for the road transport sector in China. *Atmosphere*. 2022;13(10):1540. DOI: [10.3390/atmos13101540](https://doi.org/10.3390/atmos13101540).
- [65] Mauler L, et al. Cost-effective technology choice in a decarbonized and diversified long-haul truck transportation sector: A U.S. case study. *Journal of Energy Storage*. 2022;46:103891. DOI: [10.1016/j.est.2021.103891](https://doi.org/10.1016/j.est.2021.103891).
- [66] Carlsson F, Johansson-Stenman O. Costs and benefits of electric vehicles – A 2010 perspective. *Journal of Transport Economics and Policy*. 2003;37(1):1-28.
- [67] Liu F, Mauzerall DL, Zhao F, Hao H. Deployment of fuel cell vehicles in China: Greenhouse gas emission reductions from converting the heavy-duty truck fleet from diesel and natural gas to hydrogen. *International Journal of Hydrogen Energy*. 2021;46(34):17982–17997. DOI: [10.1016/j.ijhydene.2021.02.198](https://doi.org/10.1016/j.ijhydene.2021.02.198).
- [68] Vora AP, et al. Design-space exploration of series plug-in hybrid electric vehicles for medium-duty truck applications in a total cost-of-ownership framework. *Applied Energy*. 2017;202:662–672. DOI: [10.1016/j.apenergy.2017.05.090](https://doi.org/10.1016/j.apenergy.2017.05.090).
- [69] Rouhi K, Motlagh MS, Dalir F. Developing a carbon footprint model and environmental impact analysis of municipal solid waste transportation: A case study of Tehran, Iran. *Journal of the Air & Waste Management Association*. 2023;73(12):890–901. DOI: [10.1080/10962247.2023.2271424](https://doi.org/10.1080/10962247.2023.2271424).

- [70] Haider M, Davis M, Kumar A. Development of a framework to assess the greenhouse gas mitigation potential from the adoption of low-carbon road vehicles in a hydrocarbon-rich region. *Applied Energy*. 2024;358:122335. DOI: [10.1016/j.apenergy.2023.122335](https://doi.org/10.1016/j.apenergy.2023.122335).
- [71] Sacchi R, Bauer C, Cox BL. Does size matter? The influence of size, load factor, range autonomy, and application type on the life cycle assessment of current and future medium- and heavy-duty vehicles. *Environmental Science & Technology*. 2021;55(8):5224–5235. DOI: [10.1021/acs.est.0c07773](https://doi.org/10.1021/acs.est.0c07773).
- [72] Ravigné E, Da Costa P. Economic and environmental performances of natural gas for heavy trucks: A case study on the French automotive industry supply chain. *Energy Policy*. 2021;149:112019. DOI: [10.1016/j.enpol.2020.112019](https://doi.org/10.1016/j.enpol.2020.112019).
- [73] Li Y, Kimura S. Economic competitiveness and environmental implications of hydrogen energy and fuel cell electric vehicles in ASEAN countries: The current and future scenarios. *Energy Policy*. 2021;148:111980. DOI: [10.1016/j.enpol.2020.111980](https://doi.org/10.1016/j.enpol.2020.111980).
- [74] Soares L, Wang H. Economic feasibility analysis of charging infrastructure for electric ground fleet in airports. *Transportation Research Record: Journal of the Transportation Research Board*. 2021;2675(12):1–12. DOI: [10.1177/03611981211033859](https://doi.org/10.1177/03611981211033859).
- [75] Trinko D, et al. Economic feasibility of in-motion wireless power transfer in a high-density traffic corridor. *eTransportation*. 2022;11:100154. DOI: [10.1016/j.etrans.2021.100154](https://doi.org/10.1016/j.etrans.2021.100154).
- [76] Limb BJ, et al. Economic viability and environmental impact of in-motion wireless power transfer. *IEEE Transactions on Transportation Electrification*. 2018;5(1):135–146. DOI: [10.1109/tte.2018.2876067](https://doi.org/10.1109/tte.2018.2876067).
- [77] Levkovych O, Saraceni A. Efficiency in the last mile of autonomous ground vehicles with lockers: From conventional to renewable energy transport. *Sustainability*. 2023;15(23):16219. DOI: [10.3390/su152316219](https://doi.org/10.3390/su152316219).
- [78] Scorrano M, Danielis R, Giansoldati M. Electric light commercial vehicles for a cleaner urban goods distribution. Are they cost competitive? *Research in Transportation Economics*. 2021;85:101022. DOI: [10.1016/j.retrec.2020.101022](https://doi.org/10.1016/j.retrec.2020.101022).
- [79] Schulte J, Ny H. Electric road systems: Strategic stepping stone on the way towards sustainable freight transport? *Sustainability*. 2018;10(4):1148. DOI: [10.3390/su10041148](https://doi.org/10.3390/su10041148).
- [80] Vijayagopal R, Rousseau A. Electric truck economic feasibility analysis. *World Electric Vehicle Journal*. 2021;12(2):75. DOI: [10.3390/wevj12020075](https://doi.org/10.3390/wevj12020075).
- [81] Lee DY, Thomas VM, Brown MA. Electric urban delivery trucks: Energy use, greenhouse gas emissions, and cost-effectiveness. *Environmental Science & Technology*. 2013;47(14):8022–8030. DOI: [10.1021/es400179w](https://doi.org/10.1021/es400179w).
- [82] Schmid F, Taube L, Rieck J, Behrendt F. Electrification of waste collection vehicles: Technoeconomic analysis based on an energy demand simulation using real-life operational data. *IEEE Transactions on Transportation Electrification*. 2021;7(2):604–615. DOI: [10.1109/tte.2020.3031072](https://doi.org/10.1109/tte.2020.3031072).
- [83] Wolfram P, Wiedmann T. Electrifying Australian transport: Hybrid life cycle analysis of a transition to electric light-duty vehicles and renewable electricity. *Applied Energy*. 2017;206:531–540. DOI: [10.1016/j.apenergy.2017.08.219](https://doi.org/10.1016/j.apenergy.2017.08.219).
- [84] Özlü L, Çelebi D. Electrifying freight: Modeling the decision-making process for battery electric truck procurement. *Sustainability*. 2024;16(9):3801. DOI: [10.3390/su16093801](https://doi.org/10.3390/su16093801).
- [85] Lebeau P, Macharis C, Van Mierlo J, Lebeau K. Electrifying light commercial vehicles for city logistics? A total cost of ownership analysis. *European Journal of Transport and Infrastructure Research*. 2015;15(4). DOI: [10.18757/ejtir.2015.15.4.3097](https://doi.org/10.18757/ejtir.2015.15.4.3097).
- [86] Lal A, et al. Electrifying light commercial vehicles for last-mile deliveries: Environmental and economic perspectives. *Journal of Cleaner Production*. 2023;416:137933. DOI: [10.1016/j.jclepro.2023.137933](https://doi.org/10.1016/j.jclepro.2023.137933).
- [87] Lyu Z, Pons D, Zhang Y. Emissions and total cost of ownership for diesel and battery electric freight pickup and delivery trucks in New Zealand: Implications for transition. *Sustainability*. 2023;15(10):7902. DOI: [10.3390/su15107902](https://doi.org/10.3390/su15107902).
- [88] Song H, et al. Energy consumption and greenhouse gas emissions of diesel/LNG heavy-duty vehicle fleets in China based on a bottom-up model analysis. *Energy*. 2017;140:966–978. DOI: [10.1016/j.energy.2017.09.011](https://doi.org/10.1016/j.energy.2017.09.011).
- [89] Mareev I, Sauer D. Energy consumption and life cycle costs of overhead catenary heavy-duty trucks for long-haul transportation. *Energies*. 2018;11(12):3446. DOI: [10.3390/en11123446](https://doi.org/10.3390/en11123446).
- [90] Sun D, Zheng Y, Duan R. Energy consumption simulation and economic benefit analysis for urban electric commercial-vehicles. *Transportation Research Part D: Transport and Environment*. 2021;101:103083. DOI: [10.1016/j.trd.2021.103083](https://doi.org/10.1016/j.trd.2021.103083).

- [91] Qiu Y, Dobbelaere C, Song S. Energy cost analysis and operational range prediction based on medium- and heavy-duty electric vehicle real-world deployments across the United States. *World Electric Vehicle Journal*. 2023;14(12):330. DOI: [10.3390/wevj14120330](https://doi.org/10.3390/wevj14120330).
- [92] Serrano-Guevara OS, Huertas JI, Quirama LF, Mogro EA. Energy efficiency of heavy-duty vehicles in Mexico. *Energies*. 2022;16(1):459. DOI: [10.3390/en16010459](https://doi.org/10.3390/en16010459).
- [93] Oke D, et al. Energy, economic, and environmental impacts assessment of co-optimized on-road heavy-duty engines and bio-blendstocks. *Sustainable Energy & Fuels*. 2023;7(18):4580–4601. DOI: [10.1039/d3se00381g](https://doi.org/10.1039/d3se00381g).
- [94] Langshaw L, et al. Environmental and economic analysis of liquefied natural gas (LNG) for heavy goods vehicles in the UK: A well-to-wheel and total cost of ownership evaluation. *Energy Policy*. 2020;137:111161. DOI: [10.1016/j.enpol.2019.111161](https://doi.org/10.1016/j.enpol.2019.111161).
- [95] Giordano A, Fischbeck P, Matthews HS. Environmental and economic comparison of diesel and battery electric delivery vans to inform city logistics fleet replacement strategies. *Transportation Research Part D: Transport and Environment*. 2018;64:216–229. DOI: [10.1016/j.trd.2017.10.003](https://doi.org/10.1016/j.trd.2017.10.003).
- [96] González-García S, García-Rey D, Hospido A. Environmental life cycle assessment for rapeseed-derived biodiesel. *The International Journal of Life Cycle Assessment*. 2012;18(1):61–76. DOI: [10.1007/s11367-012-0444-5](https://doi.org/10.1007/s11367-012-0444-5).
- [97] Rial M, Pérez J. Environmental performance of four different heavy-duty propulsion technologies using life cycle assessment. *Transportation Research Interdisciplinary Perspectives*. 2021;11:100428. DOI: [10.1016/j.trip.2021.100428](https://doi.org/10.1016/j.trip.2021.100428).
- [98] Xu F, et al. Environment-economic analysis of diesel, hybrid electric, plug-in hybrid electric trucks in China. *Transportation Research Part D: Transport and Environment*. 2023;117:103661. DOI: [10.1016/j.trd.2023.103661](https://doi.org/10.1016/j.trd.2023.103661).
- [99] Mu Z, et al. Evaluating fuel cell vs. battery electric trucks: Economic perspectives in alignment with China's carbon neutrality target. *Sustainability*. 2024;16(6):2427. DOI: [10.3390/su16062427](https://doi.org/10.3390/su16062427).
- [100] Hao X, et al. Evaluating the current perceived cost of ownership for buses and trucks in China. *Energy*. 2022;254:124383. DOI: [10.1016/j.energy.2022.124383](https://doi.org/10.1016/j.energy.2022.124383).
- [101] Richter S, Braun-Unkhoff M, Hasselwander S, Haas S. Evaluation of the applicability of synthetic fuels and their life cycle analyses. *Energies*. 2024;17(5):981. DOI: [10.3390/en17050981](https://doi.org/10.3390/en17050981).
- [102] Hovi IB, Pinchasik DR, Figenbaum E, Thorne RJ. Experiences from battery-electric truck users in Norway. *World Electric Vehicle Journal*. 2019;11(1):5. DOI: [10.3390/wevj11010005](https://doi.org/10.3390/wevj11010005).
- [103] Yaïci W, Ribberink H. Feasibility study of medium- and heavy-duty compressed renewable/natural gas vehicles in Canada. *Journal of Energy Resources Technology*. 2020;143(9):090902. DOI: [10.1115/1.4049455](https://doi.org/10.1115/1.4049455).
- [104] Meinrenken CJ, Lackner KS. Fleet view of electrified transportation reveals smaller potential to reduce GHG emissions. *Applied Energy*. 2015;138:393–403. DOI: [10.1016/j.apenergy.2014.10.082](https://doi.org/10.1016/j.apenergy.2014.10.082).
- [105] Anselma PG, Belingardi G. Fuel cell electrified propulsion systems for long-haul heavy-duty trucks: present and future cost-oriented sizing. *Applied Energy*. 2022;321:119354. DOI: [10.1016/j.apenergy.2022.119354](https://doi.org/10.1016/j.apenergy.2022.119354).
- [106] Sengupta S, Cohan DS. Fuel cycle emissions and life cycle costs of alternative fuel vehicle policy options for the city of Houston municipal fleet. *Transportation Research Part D: Transport and Environment*. 2017;54:160–171. DOI: [10.1016/j.trd.2017.04.039](https://doi.org/10.1016/j.trd.2017.04.039).
- [107] Samet MJ, Liimatainen H, Van Vliet OPR. GHG emission reduction potential of road freight transport by using battery electric trucks in Finland and Switzerland. *Applied Energy*. 2023;347:121361. DOI: [10.1016/j.apenergy.2023.121361](https://doi.org/10.1016/j.apenergy.2023.121361).
- [108] Smit R, et al. Greenhouse gas emissions performance of electric, hydrogen and fossil-fuelled freight trucks with uncertainty estimates using a probabilistic life-cycle assessment (pLCA). *Sustainability*. 2024;16(2):762. DOI: [10.3390/su16020762](https://doi.org/10.3390/su16020762).
- [109] Shamsi H, et al. Health cost estimation of traffic-related air pollution and assessing the pollution reduction potential of zero-emission vehicles in Toronto, Canada. *Energies*. 2021;14(16):4956. DOI: [10.3390/en14164956](https://doi.org/10.3390/en14164956).
- [110] Allwright J, Rahman A, Coleman M, Kulkarni A. Heavy multi-articulated vehicles with electric and hybrid power trains for road freight activity: An Australian context. *Energies*. 2022;15(17):6237. DOI: [10.3390/en15176237](https://doi.org/10.3390/en15176237).
- [111] Antonini C, et al. Hydrogen from wood gasification with CCS – A techno-environmental analysis of production and use as transport fuel. *Sustainable Energy & Fuels*. 2021;5(10):2602–2621. DOI: [10.1039/d0se01637c](https://doi.org/10.1039/d0se01637c).
- [112] Yan J, Jing J, Li Y. Hydrogen fuel cell commercial vehicles in China: Evaluation of carbon emission reduction and its economic value. *International Journal of Hydrogen Energy*. 2024;52:734–749. DOI: [10.1016/j.ijhydene.2023.04.164](https://doi.org/10.1016/j.ijhydene.2023.04.164).

- [113] Wanniarachchi S, et al. Hydrogen fuel supply chains for vehicular emissions mitigation: A feasibility assessment for North American freight transport sector. *International Journal of Sustainable Transportation*. 2022;17(8):855–869. DOI: [10.1080/15568318.2022.2116739](https://doi.org/10.1080/15568318.2022.2116739).
- [114] Jones J, Genovese A, Tob-Ogu A. Hydrogen vehicles in urban logistics: A total cost of ownership analysis and some policy implications. *Renewable and Sustainable Energy Reviews*. 2020;119:109595. DOI: [10.1016/j.rser.2019.109595](https://doi.org/10.1016/j.rser.2019.109595).
- [115] Jiang Z, Yan R, Gong Z, Guan G. Impact assessment of crude oil mix, electricity generation mix, and vehicle technology on road freight emission reduction in China. *Environmental Science and Pollution Research*. 2022;30(10):27763–27781. DOI: [10.1007/s11356-022-24150-x](https://doi.org/10.1007/s11356-022-24150-x).
- [116] Dos Reis JCG. Implementing electric vehicles in public services: A case study research. *International Journal of Electric and Hybrid Vehicles*. 2019;11(3):205. DOI: [10.1504/ijehv.2019.101297](https://doi.org/10.1504/ijehv.2019.101297).
- [117] Esteban B, et al. Is it environmentally advantageous to use vegetable oil directly as biofuel instead of converting it to biodiesel? *Biomass and Bioenergy*. 2011;35(3):1317–1328. DOI: [10.1016/j.biombioe.2010.12.025](https://doi.org/10.1016/j.biombioe.2010.12.025).
- [118] Samet MJ, Liimatainen H, Pihlatie M, Van Vliet OPR. Levelized cost of driving for medium and heavy-duty battery electric trucks. *Applied Energy*. 2024;361:122976. DOI: [10.1016/j.apenergy.2024.122976](https://doi.org/10.1016/j.apenergy.2024.122976).
- [119] Sun S, Ertz M. Life cycle assessment and Monte Carlo simulation to evaluate the environmental impact of promoting LNG vehicles. *MethodsX*. 2020;7:101046. DOI: [10.1016/j.mex.2020.101046](https://doi.org/10.1016/j.mex.2020.101046).
- [120] Hanesch S, Schöpp F, Göllner-Völker L, Schebek L. Life cycle assessment of an emerging overhead line hybrid truck in short-haul pilot operation. *Journal of Cleaner Production*. 2022;338:130600. DOI: [10.1016/j.jclepro.2022.130600](https://doi.org/10.1016/j.jclepro.2022.130600).
- [121] Yang L, Hao C, Chai Y. Life cycle assessment of commercial delivery trucks: Diesel, plug-in electric, and battery-swap electric. *Sustainability*. 2018;10(12):4547. DOI: [10.3390/su10124547](https://doi.org/10.3390/su10124547).
- [122] Drawer C, Rödl A, Kaltschmitt M. Life cycle assessment of construction and driving operation of a hydrogen-powered truck built from a used diesel truck. *Transportation Research Interdisciplinary Perspectives*. 2024;24:101020. DOI: [10.1016/j.trip.2024.101020](https://doi.org/10.1016/j.trip.2024.101020).
- [123] El Hannach M, et al. Life cycle assessment of hydrogen and diesel dual-fuel class 8 heavy duty trucks. *International Journal of Hydrogen Energy*. 2019;44(16):8575–8584. DOI: [10.1016/j.ijhydene.2019.02.027](https://doi.org/10.1016/j.ijhydene.2019.02.027).
- [124] Arvidsson R, Persson S, Fröling M, Svanström M. Life cycle assessment of hydrotreated vegetable oil from rape, oil palm and Jatropha. *Journal of Cleaner Production*. 2011;19(2–3):129–137. DOI: [10.1016/j.jclepro.2010.02.008](https://doi.org/10.1016/j.jclepro.2010.02.008).
- [125] Yu R, et al. Life cycle CO₂ emissions for the new energy vehicles in China drawing on the reshaped survival pattern. *The Science of the Total Environment*. 2022;826:154102. DOI: [10.1016/j.scitotenv.2022.154102](https://doi.org/10.1016/j.scitotenv.2022.154102).
- [126] Shahraeeni M, et al. Life cycle emissions and cost of transportation systems: Case study on diesel and natural gas for light duty trucks in municipal fleet operations. *Journal of Natural Gas Science and Engineering*. 2015;24:26–34. DOI: [10.1016/j.jngse.2015.03.009](https://doi.org/10.1016/j.jngse.2015.03.009).
- [127] Cooper J, Hawkes A, Balcombe P. Life cycle environmental impacts of natural gas drivetrains used in UK road freighting and impacts to UK emission targets. *The Science of the Total Environment*. 2019;674: 482–493. DOI: [10.1016/j.scitotenv.2019.04.091](https://doi.org/10.1016/j.scitotenv.2019.04.091).
- [128] Zhou T, Roorda M, MacLean H, Luk JM. Life cycle GHG emissions and lifetime costs of medium-duty diesel and battery electric trucks in Toronto, Canada. *Transportation Research Part D: Transport and Environment*. 2017;55: 91–98. DOI: [10.1016/j.trd.2017.06.019](https://doi.org/10.1016/j.trd.2017.06.019).
- [129] Yeow LW, Yan Y, Cheah L. Life cycle greenhouse gas emissions of alternative fuels and powertrains for medium-duty trucks: A Singapore case study. *Transportation Research Part D: Transport and Environment*. 2022;105:103258. DOI: [10.1016/j.trd.2022.103258](https://doi.org/10.1016/j.trd.2022.103258).
- [130] Yuan Z, Ou X, Peng T, Yan X. Life cycle greenhouse gas emissions of multi-pathways natural gas vehicles in China considering methane leakage. *Applied Energy*. 2019;253:113472. DOI: [10.1016/j.apenergy.2019.113472](https://doi.org/10.1016/j.apenergy.2019.113472).
- [131] Lave L, MacLean H, Hendrickson C, Lankey R. Life-cycle analysis of alternative automobile fuel/propulsion technologies. *Environmental Science & Technology*. 2000;34(17):3598–3605. DOI: [10.1021/es991322](https://doi.org/10.1021/es991322).
- [132] Bachmann C, Chingcuanco F, MacLean HL, Roorda MJ. Life-cycle assessment of diesel-electric hybrid and conventional diesel trucks for deliveries. *Journal of Transportation Engineering*. 2015;141(4). DOI: [10.1061/\(asce\)te.1943-5436.0000761](https://doi.org/10.1061/(asce)te.1943-5436.0000761).
- [133] Wang K, et al. Life-cycle CO₂ mitigation of China’s class-8 heavy-duty trucks requires hybrid strategies. *One Earth*. 2022;5(6):709–723. DOI: [10.1016/j.oneear.2022.05.013](https://doi.org/10.1016/j.oneear.2022.05.013).
- [134] Arteconi A, Brandoni C, Evangelista D, Polonara F. Life-cycle greenhouse gas analysis of LNG as a heavy vehicle fuel in Europe. *Applied Energy*. 2010;87(6):2005–2013. DOI: [10.1016/j.apenergy.2009.11.012](https://doi.org/10.1016/j.apenergy.2009.11.012).

- [135] He X, et al. Life-cycle greenhouse gas emission benefits of natural gas vehicles. *ACS Sustainable Chemistry & Engineering*. 2021;9(23):7813–7823. DOI: [10.1021/acssuschemeng.1c01324](https://doi.org/10.1021/acssuschemeng.1c01324).
- [136] Lee D-Y, et al. Life-cycle implications of hydrogen fuel cell electric vehicle technology for medium- and heavy-duty trucks. *Journal of Power Sources*. 2018;393:217–229. DOI: [10.1016/j.jpowsour.2018.05.012](https://doi.org/10.1016/j.jpowsour.2018.05.012).
- [137] Qasim M, Csiszar C. Major barriers in adoption of electric trucks in logistics system. *PROMET - Traffic & Transportation*. 2021;33(6):833–846. DOI: [10.7307/ptt.v33i6.3922](https://doi.org/10.7307/ptt.v33i6.3922).
- [138] Cabrera-Jiménez R, et al. Microalgae biofuel for a heavy-duty transport sector within planetary boundaries. *ACS Sustainable Chemistry & Engineering*. 2023;11(25):9359–9371. DOI: [10.1021/acssuschemeng.3c00750](https://doi.org/10.1021/acssuschemeng.3c00750).
- [139] Casolari BL, et al. Model study of a fuel cell range extender for a neighborhood electric vehicle (NEV). *International Journal of Hydrogen Energy*. 2014;39(20):10757–10787. DOI: [10.1016/j.ijhydene.2014.05.001](https://doi.org/10.1016/j.ijhydene.2014.05.001).
- [140] Vojtišek-Lom M, et al. On-road and laboratory emissions of NO, NO₂, NH₃, N₂O and CH₄ from late-model EU light utility vehicles: Comparison of diesel and CNG. *The Science of the Total Environment*. 2018;616–617:774–784. DOI: [10.1016/j.scitotenv.2017.10.248](https://doi.org/10.1016/j.scitotenv.2017.10.248).
- [141] Ghandriz T, Jacobson B, Laine L, Hellgren J. Optimization data on total cost of ownership for conventional and battery electric heavy vehicles driven by humans and by automated driving systems. *Data in Brief*. 2020;30:105566. DOI: [10.1016/j.dib.2020.105566](https://doi.org/10.1016/j.dib.2020.105566).
- [142] Lee D-Y, Thomas VM. Parametric modeling approach for economic and environmental life cycle assessment of medium-duty truck electrification. *Journal of Cleaner Production*. 2017;142:3300–3321. DOI: [10.1016/j.jclepro.2016.10.139](https://doi.org/10.1016/j.jclepro.2016.10.139).
- [143] Ahluwalia R, Wang X, Papadias D, Star G. Performance and total cost of ownership of a fuel cell hybrid mining truck. *Energies*. 2022;16(1):286. DOI: [10.3390/en16010286](https://doi.org/10.3390/en16010286).
- [144] Huo H, et al. Projection of energy use and greenhouse gas emissions by motor vehicles in China: Policy options and impacts. *Energy Policy*. 2012;43:37–48. DOI: [10.1016/j.enpol.2011.09.065](https://doi.org/10.1016/j.enpol.2011.09.065).
- [145] Zhao J. Projections of the costs of medium- and heavy-duty battery-electric and fuel cell vehicles (2020–2040) and related economic issues. *Energy for Sustainable Development*. 2023;77:101343. DOI: [10.1016/j.esd.2023.101343](https://doi.org/10.1016/j.esd.2023.101343).
- [146] Van Den Oever AEM, Costa D, Messagie M. Prospective life cycle assessment of alternatively fueled heavy-duty trucks. *Applied Energy*. 2023;336:120834. DOI: [10.1016/j.apenergy.2023.120834](https://doi.org/10.1016/j.apenergy.2023.120834).
- [147] Navas-Anguita Z, García-Gusano D, Dufour J, Iribarren D. Prospective techno-economic and environmental assessment of a national hydrogen production mix for road transport. *Applied Energy*. 2020;259:114121. DOI: [10.1016/j.apenergy.2019.114121](https://doi.org/10.1016/j.apenergy.2019.114121).
- [148] Üçok MD. Prospects for hydrogen fuel cell vehicles to decarbonize road transport. *Discover Sustainability*. 2023;4(42). DOI: [10.1007/s43621-023-00159-1](https://doi.org/10.1007/s43621-023-00159-1).
- [149] Sripad S, Viswanathan V. Quantifying the economic case for electric semi-trucks. *ACS Energy Letters*. 2018;4(1):149–155. DOI: [HTTPS://DOI.ORG/10.1021/acsenenergylett.8b02146](https://doi.org/10.1021/acsenenergylett.8b02146).
- [150] Shen X, et al. Real-world exhaust emissions and fuel consumption for diesel vehicles fueled by waste cooking oil biodiesel blends. *Atmospheric Environment*. 2018;191:249–257. DOI: [10.1016/j.atmosenv.2018.08.004](https://doi.org/10.1016/j.atmosenv.2018.08.004).
- [151] Martin J, Neumann A, Ødegård A. Renewable hydrogen and synthetic fuels versus fossil fuels for trucking, shipping and aviation: A holistic cost model. *Renewable and Sustainable Energy Reviews*. 2023;186:113637. DOI: [10.1016/j.rser.2023.113637](https://doi.org/10.1016/j.rser.2023.113637).
- [152] Lao J, Song H, Wang C, Zhou Y. Research on atmospheric pollutant and greenhouse gas emission reductions of trucks by substituting fuel oil with green hydrogen: A case study. *International Journal of Hydrogen Energy*. 2023;48(30):11555–11566. DOI: [10.1016/j.ijhydene.2022.02.230](https://doi.org/10.1016/j.ijhydene.2022.02.230).
- [153] Brynolf S, et al. Review of electrofuel feasibility – Prospects for road, ocean, and air transport. *Progress in Energy*. 2022;4(4):042007. DOI: [10.1088/2516-1083/ac8097](https://doi.org/10.1088/2516-1083/ac8097).
- [154] Guo Y, Kelly JA, Clinch JP. Road transport electrification – Is timing everything? Implications of emissions analysis’ outcomes for climate and air policy. *Transportation Research Interdisciplinary Perspectives*. 2021;12:100478. DOI: [10.1016/j.trip.2021.100478](https://doi.org/10.1016/j.trip.2021.100478).
- [155] Ou X, Zhang X, Chang S. Scenario analysis on alternative fuel/vehicle for China’s future road transport: Life-cycle energy demand and GHG emissions. *Energy Policy*. 2010;38(8):3943–3956. DOI: [10.1016/j.enpol.2010.03.018](https://doi.org/10.1016/j.enpol.2010.03.018).
- [156] Ramshankar AT, Desai AG, De La Villarmois JA, Bozeman J. Sustainability analysis of overhead cable line powered freight trucks: A life cycle impact and techno-economic assessment toward transport electrification. *Environmental Research: Infrastructure and Sustainability*. 2023;3(1):015010. DOI: [10.1088/2634-4505/acc273](https://doi.org/10.1088/2634-4505/acc273).
- [157] Liu J, et al. Synergistic air pollutants and GHG reduction effect of commercial vehicle electrification in Guangdong’s public service sector. *Sustainability*. 2021;13(19):11098. DOI: [10.3390/su131911098](https://doi.org/10.3390/su131911098).

- [158] Alonso-Villar A, et al. Technical, economic, and environmental feasibility of alternative fuel heavy-duty vehicles in Iceland. *Journal of Cleaner Production*. 2022;369:133249. DOI: [10.1016/j.jclepro.2022.133249](https://doi.org/10.1016/j.jclepro.2022.133249).
- [159] Gunawan TA, Monaghan RFD. Techno-econo-environmental comparisons of zero- and low-emission heavy-duty trucks. *Applied Energy*. 2022;308:118327. DOI: [10.1016/j.apenergy.2021.118327](https://doi.org/10.1016/j.apenergy.2021.118327).
- [160] Wang B, et al. Technological-economic assessment and optimization of hydrogen-based transportation systems in China: A life cycle perspective. *International Journal of Hydrogen Energy*. 2023;48(33):12155–12167. DOI: [10.1016/j.ijhydene.2022.12.189](https://doi.org/10.1016/j.ijhydene.2022.12.189).
- [161] Ma Y, Ke R-Y, Han R, Tang B-J. The analysis of the battery electric vehicle's potentiality of environmental effect: A case study of Beijing from 2016 to 2020. *Journal of Cleaner Production*. 2017;145:395–406. DOI: [10.1016/j.jclepro.2016.12.131](https://doi.org/10.1016/j.jclepro.2016.12.131).
- [162] Li Y, Taghizadeh-Hesary F. The economic feasibility of green hydrogen and fuel cell electric vehicles for road transport in China. *Energy Policy*. 2022;160:112703. DOI: [10.1016/j.enpol.2021.112703](https://doi.org/10.1016/j.enpol.2021.112703).
- [163] Liu F, Zhao F, Liu Z, Hao H. The impact of fuel cell vehicle deployment on road transport greenhouse gas emissions: The China case. *International Journal of Hydrogen Energy*. 2018;43(50):22604–22621. DOI: [10.1016/j.ijhydene.2018.10.088](https://doi.org/10.1016/j.ijhydene.2018.10.088).
- [164] Brand C, Tran M, Anable J. The UK transport carbon model: An integrated life cycle approach to explore low carbon futures. *Energy Policy*. 2012;41:107–124. DOI: [10.1016/j.enpol.2010.08.019](https://doi.org/10.1016/j.enpol.2010.08.019).
- [165] He L-Y, Chen Y. Thou shalt drive electric and hybrid vehicles: Scenario analysis on energy saving and emission mitigation for road transportation sector in China. *Transport Policy*. 2013;25:30–40. DOI: [10.1016/j.tranpol.2012.11.006](https://doi.org/10.1016/j.tranpol.2012.11.006).
- [166] Zhao Y, Noori M, Tatari O. Vehicle to grid regulation services of electric delivery trucks: Economic and environmental benefit analysis. *Applied Energy*. 2016;170:161–175. DOI: [10.1016/j.apenergy.2016.02.097](https://doi.org/10.1016/j.apenergy.2016.02.097).
- [167] Iyer RK, Kelly JC, Elgowainy A. Vehicle-cycle and life-cycle analysis of medium-duty and heavy-duty trucks in the United States. *The Science of the Total Environment*. 2023;891:164093. DOI: [10.1016/j.scitotenv.2023.164093](https://doi.org/10.1016/j.scitotenv.2023.164093).
- [168] Taefi TT. Viability of electric vehicles in combined day and night delivery: A total cost of ownership example in Germany. *European Journal of Transport and Infrastructure Research*. 2016;16(4):3160. DOI: [10.18757/ejtr.2016.16.4.3160](https://doi.org/10.18757/ejtr.2016.16.4.3160).
- [169] Zhang F, et al. Well-to-wheel analysis of natural gas fuel for hybrid truck applications. *Energy Conversion and Management*. 2021;240:114271. DOI: [10.1016/j.enconman.2021.114271](https://doi.org/10.1016/j.enconman.2021.114271).
- [170] Gustafsson M, et al. Well-to-wheel greenhouse gas emissions of heavy-duty transports: Influence of electricity carbon intensity. *Transportation Research Part D: Transport and Environment*. 2021;93:102757. DOI: [10.1016/j.trd.2021.102757](https://doi.org/10.1016/j.trd.2021.102757).
- [171] Jaller M, Pineda L, Ambrose H, Kendall A. Empirical analysis of the role of incentives in zero-emission last-mile deliveries in California. *Journal of Cleaner Production*. 2021;317:128353. DOI: [10.1016/j.jclepro.2021.128353](https://doi.org/10.1016/j.jclepro.2021.128353).

APPENDIX

Table 9 – Classification of selected documents

Reference	Geography	Perspective	Vehicle type	Drivetrain technology
[29]	Latin America	economic	LDT, MDT, HDT	BEV, ICEV
[30]	UK	economic	private car, bus, HDT, forklift	BEV, FCEV, ICEV
[18]	East Asia (China)	both	HDT	BEV, FCEV
[10]	not specified	both	LDV, HGV	BEV, FCEV
[21]	EU (Sweden)	both	HDT	ICEV
[11]	North America (US)	ecological	LCV	BEV, EREV
[31]	UK	both	HDT	BEV, ICEV
[32]	EU (Spain)	ecological	HDT	ICEV

Reference	Geography	Perspective	Vehicle type	Drivetrain technology
[33]	EU (Spain)	both	truck	ICEV
[34]	UK	economic	MDT, HDT	ICEV, HEV, BEV
[35]	not specified	ecological	HDT	ICEV
[36]	South Asia	both	motorcycle, private car, taxi, bus, goods vehicle	ICEV, FCEV, BEV
[37]	EU (Ireland)	both	HDT	ICEV
[38]	EU + UK	economic	LDT, MDT, HDT	ICEV, HEV, BEV, FCEV
[39]	East Asia (China)	both	MiDT, LDT, MDT, HDT	BEV, FCEV, ICEV
[40]	EU (Germany)	economic	HDT	BEV, ICEV
[41]	East Asia (China)	economic	private car, taxi, motorcycle, LDT, MDT, HDT	BEV, FCEV, ICEV
[42]	EU (Germany)	economic	MDT	ICEV, BEV
[43]	East Asia (China)	ecological	LDT	ICEV, BEV
[44]	EU	both	HDT	ICEV, BEV, FCEV
[45]	EU (Germany)	both	HDT	BEV, ICEV
[46]	EU (Germany)	ecological	HDT	ICEV, HEV
[47]	North America (US)	both	HDT	ICEV, FCHEV, BEV
[48]	EU (Greece)	ecological	MDT, HDT	ICEV
[49]	North America (US)	ecological	LDT, MDT	ICEV, HEV, BEV
[50]	North America (US)	ecological	HDT	ICEV, HEV, BEV
[51]	EU (Iceland)	both	LDV, HDV	BEV, PHEV, ICEV, HEV, FCEV
[52]	South Asia	economic	LDT, MDT, HDT	ICEV, BEV
[53]	East Asia (China) + EU (Germany)	ecological	private car, HDT, bus	FCEV, BEV
[54]	Latin America	ecological	HDT	BEV, ICEV
[55]	EU (Norway)	ecological	HDT	ICEV, FCEV, BEV
[56]	East Asia (China)	both	LDT	ICEV, BEV, PHEV, FCEV
[7]	North America (Canada)	both	HDT	ICEV, BEV, PHEV, FCEV, PHFCEV, CV
[57]	EU (Germany)	both	HDT	BEV, CV, BSV
[58]	North America (US)	economic	MDT, bus	PHEV, ICEV
[59]	North America (US)	ecological	pick-up truck, LCV, MDT, HDT, bus	ICEV, HEV, BEV, FCEV
[60]	South Asia	ecological	motorcycle, LDT, MDT, HDT	ICEV, BEV
[61]	Latin America	both	LDT	ICEV, BEV

Reference	Geography	Perspective	Vehicle type	Drivetrain technology
[62]	EU (The Netherlands)	ecological	private car, van, truck, bus	ICEV, BEV, FCEV
[63]	EU (Sweden)	both	HDT	ICEV
[64]	East Asia (China)	both	private car, LDT, HDT	ICEV, BEV, HEV
[65]	North America (US)	economic	HDT	ICEV, BEV, FCEV
[66]	EU (Sweden)	both	private car, LDT, MDT	ICEV, HEV, FCEV, BEV
[67]	East Asia (China)	ecological	HDT	FCEV, ICEV
[68]	North America (US)	economic	MDT	PHEV, EREV
[66]	West Asia	ecological	HDT	ICEV
[70]	North America (Canada)	both	LDT, MDT, HDT, private car, van, pick-up truck, bus	FCEV, BEV, ICEV, PHEV, HEV
[6]	North America (US)	both	HDT	ICEV, HEV, BEV
[71]	EU	ecological	LDT, MDT, HDT	ICEV, HEV, PHEV, FCEV, BEV
[72]	EU (France)	both	HDT	ICEV
[73]	South East Asia	both	private car, bus, HDT	FCEV, BEV, PHEV, ICEV
[74]	North America (US)	both	pushback tractor, inter-terminal bus	ICEV, BEV, WPT EV
[75]	North America (US)	both	private car, LDT, MDT, HDT	WPT EV
[76]	North America (US)	both	LDV, HDT	WPT EV, ICEV
[77]	Eu (The Netherlands)	economic	LCV	ICEV, BEV, BSV
[78]	EU	economic	LCV	ICEV, BEV
[79]	EU	ecological	HDT	CV
[80]	North America (US)	economic	MDT, HDT	ICEV, BEV
[81]	North America (US)	both	private car, MDT, HDT	ICEV, BEV
[14]	EU (Spain)	both	LCV	ICEV, BEV, FCEREV, FCEV
[82]	EU (Germany)	both	HDT	ICEV, BEV
[83]	Oceania	ecological	private car, LDT	ICEV, HEV, PHEV, BEV
[84]	EU + West Asia	both	truck	ICEV, BEV
[85]	EU (Belgium)	economic	LCV	ICEV, BEV
[86]	EU (Germany) + North America (US)	both	LCV	ICEV, BEV, FCEV
[87]	Oceania	both	HDT	ICEV, BEV
[88]	East Asia (China)	both	HDT	ICEV
[89]	EU (Germany)	both	HDT	CV, BEV, ICEV

Reference	Geography	Perspective	Vehicle type	Drivetrain technology
[90]	East Asia (China)	both	LCV	BEV
[91]	North America (US)	both	MDT, HDT, bus	ICEV, BEV
[92]	Latin America	both	bus, HDT	BEV, ICEV
[93]	North America (US)	both	HDT	ICEV
[94]	UK	both	HGV	ICEV
[95]	EU	both	LCV	ICEV, BEV
[96]	EU + North America (Canada)	ecological	HDT	ICEV
[97]	EU (Spain)	both	MDT, HDT	ICEV, HEV
[98]	East Asia (China)	both	HDT	ICEV, HEV, PHEV
[99]	East Asia (China)	economic	HDT	FCEV, BEV
[24]	North America (US)	both	HDT	FCEV, ICEV
[100]	East Asia (China)	economic	bus, truck	BEV, FCEV, ICEV, HEV
[101]	EU (Germany)	ecological	HDT, private car	ICEV
[102]	EU (Norway)	both	LCV, HDT	ICEV, BEV, FCEV
[103]	North America (Canada)	both	MDT, HDT	ICEV
[104]	North America (US)	ecological	private car, van, bus, truck	HEV, BEV, PHEV
[105]	EU (Italy)	economic	HDT	FCEV, BEV
[106]	North America (US)	both	truck, private car	ICEV, HEV, PHEV, BEV
[107]	EU (Finland, Switzerland)	ecological	MDT, HDT	BEV, ICEV
[108]	Oceania	ecological	MDT, HDT	ICEV, BEV, FCEV
[109]	North America (Canada)	both	private car, HDT	BEV, FCEV, ICEV,
[110]	Oceania	ecological	HDT	ICEV, HEV, BEV
[111]	EU	ecological	private car, MDT	FCEV, BEV, ICEV
[112]	East Asia (China)	both	bus, HDT, private car	ICEV, BEV, FCEV
[113]	North America	both	HDT	BEV, FCEV
[114]	UK	economic	LCV	BEV, PHEV, ICEV, FCEV
[115]	East Asia (China)	ecological	LDT, MDT, HDT	ICEV, BEV, FCEV
[116]	EU (Portugal)	both	LDT	BEV, ICEV
[117]	EU (Spain)	ecological	HDT	ICEV
[118]	EU + North America (US)	economic	MDT, HDT	ICEV, BEV
[119]	North America (Canada)	ecological	HDT	ICEV
[120]	EU (Germany)	ecological	HDT	ICEV, HCV
[121]	East Asia (China)	both	LDT, MDT	ICEV, PHEV, BSV

Reference	Geography	Perspective	Vehicle type	Drivetrain technology
[122]	EU (Germany)	ecological	HDT	FCEV, ICEV
[123]	North America (Canada)	both	HDT	FCHEV, ICEV
[124]	EU (Germany, Sweden) + South Asia + South East Asia	ecological	HDT	ICEV
[125]	East Asia (China)	ecological	private car, bus, LDT, MDT, HDT	BEV, PHEV, ICEV
[126]	North America (Canada)	both	LDT	ICEV
[127]	UK	ecological	HGV	BEV, ICEV
[128]	North America (Canada)	both	MDT	BEV, ICEV
[129]	South East Asia	ecological	MDT	ICEV, BEV, FCEV
[130]	East Asia (China)	ecological	personal vehicle, bus, HDT	ICEV
[131]	North America (US)	both	private car, LDT	ICEV, BEV, HEV
[132]	North America (Canada)	both	MDT	HEV, ICEV
[133]	East Asia (China)	ecological	HDT	ICEV, FCEV, BEV
[134]	EU	ecological	HDT	ICEV
[135]	East Asia (China) + North America (US)	ecological	LDT, HDT	ICEV, BEV
[136]	North America (US)	both	LCV, LDT, MDT, HDT	FCEV, ICEV
[137]	EU (Hungary)	both	MDT	ICEV, BEV
[138]	not specified	ecological	HDT	ICEV
[139]	North America (US)	both	LDT	ICEV, FCEV
[140]	EU	ecological	private car, van	ICEV
[141]	EU (Sweden)	economic	HDT	ICEV, BEV
[142]	North America (US)	both	MDT	HEV, BEV, ICEV
[143]	not specified	both	HDT	ICEV, FCEV, FCHEV
[16]	EU (Poland)	both	private car, bus, truck	ICEV, HEV, FCEV
[15]	North America (US)	both	HDT	ICEV, HEV, BEV, FCEV
[144]	East Asia (China)	both	LDV, taxi, bus, HDT, LDT	ICEV, BEV
[145]	North America (US)	economic	MDT, HDT	ICEV, BEV, FCEV
[146]	EU	ecological	HDT	ICEV, PHEV, BEV
[147]	EU (Spain)	both	private car, bus, motorcycle, truck, van	ICEV, FCEV
[148]	Global	ecological	private car, bus, HDT	FCEV, BEV, ICEV
[149]	North America (US)	economic	HDT	ICEV, BEV
[150]	East Asia (China)	both	LDT, HDT	ICEV

Reference	Geography	Perspective	Vehicle type	Drivetrain technology
[151]	EU (Norway)	both	HDT	FCEV, ICEV
[152]	East Asia (China)	ecological	HDT, MDT, LDT, MiDT	ICEV, FCEV
[153]	EU (Denmark, Sweden) + North America (US)	both	private car, MDV, HDV	BEV, FCEV, ICEV
[154]	EU (Ireland)	ecological	private car, HDT, bus, LCV	ICEV, PHEV, BEV
[17]	North America (US)	both	HDT	ICEV, HEV
[155]	East Asia (China)	both	LDT, MDT, HDT, MiDT, bus, minivan, private car, motorcycle	ICEV, BEV, HEV
[156]	EU (Germany, Sweden) + North America (US)	both	HDT	CV, BEV, ICEV
[157]	East Asia (China)	ecological	bus, LDT, HDT	ICEV, BEV
[158]	EU (Iceland)	both	HDT	BEV, FCEV, HEV
[159]	EU (Ireland)	both	HDT	BEV, PHEV, ICEV, FCEV
[12]	EU (Germany)	both	HDT	ICEV, BEV
[2]	East Asia (China)	both	HDT	BEV, PHEV, FCEV, CV, ICEV
[160]	East Asia (China)	both	bus, HDT, private car, logistics vehicle	FCEV, BEV, ICEV
[161]	East Asia (China)	ecological	taxi, bus, HDT	BEV, ICEV
[162]	East Asia (China)	both	private car, bus, truck	FCEV, BEV, ICEV, PHEV, HEV
[163]	East Asia (China)	ecological	private car, bus, MiDT, LDT, MDT, HDT	ICEV, BEV, PHEV, FCEV
[164]	UK	both	motorcycle, private car, bus, LDT, MDT, HDT	ICEV, BEV, FCEV, HEV, PHEV
[165]	East Asia (China)	both	private car, LDT, bus, HDT, motorcycle	ICEV, BEV, HEV
[166]	North America (US)	both	LDT, LCV	ICEV, BEV, EREV
[167]	North America (US)	ecological	MDT, HDT	ICEV, HEV, BEV, FCEV
[168]	EU (Germany)	economic	MDT	ICEV, BEV
[169]	East Asia (China)+ EU + North America	ecological	Truck	ICEV, HEV
[170]	EU	ecological	bus, HDT	ICEV, BEV, FCEV
[13]	North America (US)	ecological	LCV, LDT, MDT, HDT	ICEV, BEV
[9]	EU (Finland)	both	HDT	BEV, FCEV, FCEREV
[171]	North America (US)	both	MDT, HDT	HEV, BEV, ICEV