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AVOID-SHIFT-IMPROVE POLICIES FOR REDUCING POLLUTING EMISSIONS AND GREENHOUSE GASES FROM ROAD FREIGHT TRANSPORT IN ITALY

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Abstract— The decarbonization of road freight transport is essential to achieve sustainability goals and meet the main climate and decarbonization targets. The freight sector, characterized by complex supply chains and fierce cost-based competition, faces challenges as a "hard-to-abate" domain. This study explores the Italian road freight transport decarbonizing trajectory, also proposing some Avoid-Shift-Improve (ASI) strategies to reduce greenhouse gas (GHG) emissions. The research is based on two main aims: i) estimating current (2023) and reference (2005) freight demand and their corresponding GHG inventories; ii) defining ASI-based "business-as-usual" scenario for 2030 and assessing the related GHG emissions. A forecasting scenario — "optimistic"— is developed to estimate GHG emission trajectories and assess the feasibility of achieving EU climate goals. Findings indicate that without additional policy interventions and comprehensive ASI measures, Italy is unlikely to meet the ambitious targets set by the European Commission. The study emphasizes the need for a coordinated, data-driven approach to ensure a sustainable transition for the road freight sector.
Keywords—Avoid-Shift-Improve (ASI) framework, decarbonization, greenhouse gas emissions, road freight transport, transportation planning.

I. INTRODUCTION

Global warming represents one of the most pressing challenges of our time, with far-reaching environmental, economic, and social consequences. Among the various sectors contributing to climate change, transport plays a pivotal role, accounting for nearly one-third of global energy-related greenhouse gas (GHG) emissions [1]. Road transport, in particular, is the largest contributor within the sector, driven by the growing demand for freight and passenger mobility, urban expansion, and continued reliance on fossil fuels.

To address these issues, numerous countries and regions worldwide have introduced ambitious decarbonization strategies. For instance, Japan launched its "Green Growth Strategy through Achieving Carbon Neutrality in 2050," focusing on hydrogen technologies and carbon-neutral logistics [2]. The United States rejoined the Paris Agreement and in 2023 released its "National Blueprint for Transportation Decarbonization", which outlines an integrated pathway to net-zero emissions [3]. China committed to peak carbon emissions before 2030 and reach carbon neutrality by 2060, with extensive efforts to promote electric mobility and invest in rail freight [4]. In India, the "National Electric Mobility Mission Plan" and the "FAME" scheme aim to accelerate EV deployment [5]. Brazil promotes advanced biofuels through its "National Energy Plan 2050" [6], while Australia recently adopted its "National Electric Vehicle Strategy" to guide the transition to zero-emission mobility [7]. These international initiatives reflect a growing global consensus on the urgency of decarbonizing the transport sector.

Within this global context, the European Union (EU) has also developed a comprehensive climate strategy. The European Green Deal and the "Fit for 55" package, adopted in July 2021 by the European Commission, aim to reduce net GHG emissions by at least 55% by 2030 compared to 1990 levels, and achieve the carbon neutrality by 2050. At the European level, a debate is underway on which policies and actions are the most effective and should therefore be prioritized to achieve these goals [8].

According to the European Environment Agency (EEA), the transport sector accounts for approximately one-quarter of total GHG emissions in the EU, with road transport responsible for nearly three-quarters of these emissions [9]. As a matter of fact, while total EU emissions decreased by approximately 20% between 1990 and 2019, road transport emissions increased by more than 25% [10]. In Italy, this sector accounts for over 90% of transport-related emissions [12]. Road freight transport represents one of the most challenging areas for decarbonization, due to several structural and operational constraints. These include the highly complex nature of supply chains, cost-driven competition among operators, and predominantly short-haul demand, which makes modal shift to more sustainable alternatives (e.g., rail transport) particularly difficult [13]. For these reasons, road transport is widely recognized as a "hard-to-abate" sector (e.g., [14]-[16]).

Already during the 26th UN Climate Change Conference of the Parties (COP26) at the Scottish Event Campus (SEC) in Glasgow in November 2021, road freight transport was identified as a key sector for reducing greenhouse gas emissions. Moreover, it was highlighted that, although progress has been made in key commitments and initiatives to address climate change, achieving these goals solely through currently available technologies is extremely ambitious [17]. If not accompanied by demand reduction strategies and modal shift policies, technological advancements alone are insufficient to achieve significant GHG emission reductions in the short term (e.g., [18]-[21]). Given these challenges, a holistic strategy is needed to reduce road freight emissions, one that goes beyond technological improvements to include demand management policies and incentives for modal shift. The "Avoid-Shift-Improve" (ASI) framework provides a structured approach to facilitating this transition (e.g., [22]-[24]).

This approach is based on three pillars:

1) Avoid: reducing the need for transport by improving logistics efficiency, land-use planning, and digitalization (e.g., optimizing supply chains and promoting teleworking);
2) Shift: promoting a modal shift towards more sustainable transport options, such as rail and inland waterways for freight, or public transport and active mobility for passengers;
3) Improve: enhancing vehicle efficiency through technological advancements, such as electrification, alternative fuels (e.g., biofuels and hydrogen), and improved fuel economy.

This approach recognizes that no single solution can achieve deep decarbonization and that a combination of demand management, modal reallocation, and technological improvements is necessary. While previous policies have primarily focused on the "Improve" dimensions, such as promoting electric vehicles, recent research indicates that a more integrated ASI approach is required to meet ambitious climate targets (e.g., [25],[26]).

In this context, the present study aims to analyze the decarbonization trajectory of road freight transport in Italy, evaluating future scenarios up to 2030 and assessing the impact of ASI policies on emission reduction. By defining "business-as-usual" scenario, the study estimates the effectiveness of current and potential measures in meeting European emission reduction targets.

This work incorporates the ASI FOR FREIGHT research project – supported by Italy's National Recovery and Resilience Plan through the National Center for Sustainable Mobility (MOST), Spoke 10 – as a practical case study to examine the real-world implementation of EU decarbonization policies.

The paper is organized as follows. Section II describes the methodology and data sources, outlining the methodological approach adopted and providing an overview of the available datasets. Section III introduces the ASI framework, detailing its key concepts and applications to the freight transport sector. It then examines the three ASI pillars: Avoid, Shift and Improve strategies focusing on vehicle technology advancements and operational efficiency and it then defines decarbonization scenario for 2030, also measuring the main impact on emissions and energy consumption. Section IV presents the results and discussion, evaluating the effectiveness of ASI policies in reducing GHG emissions and comparing the scenarios to assess the feasibility of meeting EU 2030 climate targets. Finally, the conclusion summarizes the key findings, highlighting policy implications and future research directions.

II. METHODOLOGY AND DATA SOURCES

A. Methodological approach adopted

This study adopts a detailed analytical approach to estimate road mobility demand, energy consumption, and greenhouse gas (GHG) emissions. The main objective is to provide an accurate assessment of the environmental impact of road transport in Italy. A bottom-up analysis method is followed, which involves a detailed estimation of transport demand categorized by vehicle type (light and heavy commercial vehicles for freight transport), environmental category (Euro class), and road type. This approach, which builds estimates from individual data points to form a comprehensive assessment, enables a more precise evaluation of emissions by considering fuel consumption and vehicle characteristics.

To achieve these objectives, the analysis unfolds through several key phases:

1) estimating mobility demand by collecting and integrating data from various official Italian sources (e.g. ISPRA, ISTAT, Ministry of Transport). This allows for a comprehensive understanding of national travel patterns, considering the distances covered by vehicles across different road categories. A segmentation of freight transport demand is applied to distinguish between short-haul and long-haul operations, as this impacts fuel consumption and emissions;
2) energy consumption and emissions are estimated. This step involves multiplying mobility demand by the specific consumption rates of different vehicle and fuel categories. The analysis employs direct vehicle emissions (Tank-to-Wheel, TtW). The study uses emission factors from the Joint Research Centre (JRC) and the European Environment Agency (EEA) to estimate TtW emissions;
3) finally, to ensure the reliability of the findings, the results are validated by comparing the estimated data with official fuel sales records from the Italian Ministry of Ecological Transition and national energy reports. This validation process helps verify the accuracy of the calculations and refine the methodology where necessary.

To enhance the accuracy of the analysis, the vehicle fleet is categorized based on:

- vehicle type (Light Commercial Vehicles - LCVs, Heavy-Duty Vehicles - HDVs).
- environmental category (Euro 3 to Euro 6, zero-emission vehicles).

- fuel type (Diesel, LNG, biofuels, hydrogen, electric).

The analysis also considers the expected fleet renewal by 2030, integrating assumptions about the penetration rate of electric and alternative-fuel trucks, based on EU regulatory targets and market trends.

The year 2005 is chosen as the reference point, as it represents the reference year for EU "Fit for 55" target, while the year 2023 is chosen as the base-line period.

Following the ASI framework, an optimistic forecasting for 2030 are developed based on current policies and planned investments, including higher adoption of electric and hydrogen-powered trucks, a greater share of biofuels, and a stronger modal shift from road transport to rail one.

This scenario was designed to evaluate whether current strategies (in an optimistic perspective) are sufficient to achieve the European Union's emission reduction targets and to identify potential improvements.

The adopted method enables a detailed estimation of road mobility, energy consumption, and GHG emissions, providing a solid foundation for assessing the effectiveness of sustainability policies in the Italian transport sector.

B. Overview of available data sources

Accurate data on freight transport demand are crucial for assessing current emission levels and evaluating the potential impact of decarbonization policies. In Italy, multiple official sources provide information on road transport activity, including:

- AISCAT (Italian Association of Motorway and Tunnel Concessionaires), which reports statistics on highway traffic volumes;
- the MIT National Transport Report, which offers periodic overviews of transport sector trends;
- ISPRA (Italian Institute for Environmental Protection and Research), which monitors emissions and environmental impacts of transport;
- ISTAT (Italian National Institute of Statistics), which provides mobility and economic data related to freight transport;
- PUMS (Sustainable Urban Mobility Plans) of major Italian cities, which outline long-term strategies for sustainable urban transport, integrating policies for emission reduction, modal shift, and infrastructure development.
- CNIT (Conto Nazionale delle Infrastrutture e dei Trasporti), which includes structured and disaggregated data on investments, infrastructure use, and mobility flows;
- ACI (Automobile Club d'Italia), which supplies detailed vehicle fleet data and statistics on motorization rates and road network usage;
- ACEA (European Automobile Manufacturers' Association), which offers insights into vehicle registrations, fuel types, and technological penetration across Italy and, more broadly, European countries;
- EUROSTAT (Statistical Office of the European Union), which provides harmonized data on freight transport at the EU level, enabling international comparisons;
- Fondazione Caracciolo, which publishes research and reports on transport trends, logistics performance, and policy implications for sustainable mobility.

However, despite the availability of these sources, several limitations persist in the reconstruction of road freight transport demand.

At the European level, only a few countries have recently begun to systematically assess the impact of planned policies and actions in terms of their ability to achieve the ambitious targets set by the European Commission. Nevertheless, among the most relevant studies available to date, several critical issues and limitations can be identified:

1) some studies rely on overly optimistic assumptions, making the proposed scenarios unrealistic, for instance, regarding the market penetration of electric vehicles;
2) the transition toward the desired low-emission future is often not structured into progressive, time-based milestones, making it difficult to track the feasibility of intermediate steps;
3) not all studies conclude that the "Fit for 55" targets will be achievable within the transport sector, raising concerns about the effectiveness of current policy frameworks.

Regarding Italy, aside from the recently published study titled "La rivoluzione della mobilità sostenibile parte dalle autostrade. Sicure, digitali, decarbonizzate" [27], published by Il Sole 24 Ore, there is no official ministerial report assessing the feasibility of achieving the EU's decarbonization goals. The only document that provides preliminary considerations on possible technological solutions, albeit without any quantitative analysis, is the 2022 report by the Italian Ministry of Infrastructure and Sustainable Mobility (MIMS), titled "Decarbonizzare i trasporti: Evidenze scientifiche e proposte di policy" [28].

Moreover, at the national level, there is still no comprehensive understanding of road freight transport demand. Current official data sources (e.g., [29]-0) do not allow for a complete and consistent reconstruction of freight mobility across the Italian territory. Instead, they provide partial estimates, conflicting figures, or data derived from different calculation methodologies. Additionally, none of these sources classify traffic by vehicle size or emission class, further limiting the accuracy of analyses.

Given these gaps, a detailed estimation of freight transport demand, disaggregated by vehicle type (e.g., weight, Euro class) and road category (e.g., highways, extra-urban roads, urban roads), is both a critical challenge and an urgent necessity to support evidence-based policymaking and ensure an effective transition towards sustainable freight mobility.

III. THE AVOID-SHIFT-IMPROVE (ASI) FRAMEWORK

A. Key concepts and applications to the freight transport sector

The Avoid–Shift–Improve (ASI) framework provides a structured approach for reducing greenhouse gas (GHG) emissions in the transport sector. Applied to freight, the ASI paradigm recognizes the limitations of relying solely on technological improvements and emphasizes the importance of integrated strategies targeting demand, modal choice, and technological advancements. [13] adopt the ASI framework to develop scenario-based analyses for the decarbonization of Italy's road freight transport by 2030, offering insight into the differentiated impact of policy actions across the avoid, shift, and improve dimensions.

The ASI approach is increasingly used in transport decarbonization scenario-building due to its comprehensiveness and adaptability. In the freight sector, this paradigm helps conceptualize three interconnected strategies: (1) Avoid strategies focus on reducing freight transport demand or avoiding unnecessary travel; (2) Shift strategies promote the use of more sustainable modes, such as rail and intermodal systems; and (3) Improve strategies enhance vehicle and fuel efficiency. This framework supports the definition of a future scenario, highlighting the potential impacts of ASI-aligned policies on emissions and energy consumption for the Italian freight transport context.

B. Avoid strategies: reducing transport demand and improving logistics efficiency

Avoid strategies in the freight sector aim to reduce overall vehicle-kilometres travelled by increasing logistical efficiency and minimizing unnecessary freight movements. In the proposed 2030 scenario, freight transport demand is partially offset by the increased use of high-load strategies such as co-loading, reduction of empty mileage, and crowdsourced urban delivery. These logistics enhancements lead to significant reduction in vehicle-kilometres for light commercial vehicles (LCVs) and for heavy commercial vehicles (HCVs), compared to the baseline.

C. Shift strategies: modal shift towards rail and intermodal transport

Shift strategies in the freight sector aim to reduce greenhouse gas emissions by encouraging a modal reallocation from road to more sustainable transport modes, such as rail and short-sea shipping. In the proposed 2030 scenario, modal shift policies are assumed to be strengthened through the continuation and enhancement of national incentives like Marebonus and Ferrobonus. These incentives, combined with infrastructure investments and regulatory support, are projected to increase the share of rail for long-distance freight movements (i.e., over 300 km), reaching the European Commission's target of 30% modal share by 2030. Despite their lower national-level impact—given rail's current marginal share in the Italian freight sector—shift strategies are still important for decarbonizing specific market segments, such as international corridor freight and Alpine crossings. These targeted effects, although limited in overall magnitude, contribute meaningfully to a diversified decarbonization pathway.

D. Improve strategies: vehicle technology advancements and operational efficiency

Improve strategies focus on enhancing vehicle efficiency and reducing emissions through technological innovation, fleet renewal, and cleaner fuels. In the proposed 2030 scenario, aggressive assumptions are made regarding the renewal of the light and heavy commercial vehicle (LCV and HCV) fleets. These include higher annual replacement rates, accelerated penetration of battery electric vehicles (BEVs), and initial deployment of hydrogen-powered trucks (both fuel cell and combustion-based). By 2030, BEVs are projected to reach a significant percentage of the LCV and HCV fleets, while a low fraction of the HCV will also be hydrogen-fueled trucks.

In addition to electrification, the proposed scenario assumes a substantial use of second-generation biofuels, particularly Hydrotreated Vegetable Oil (HVO) and Compressed Bio-Methane (CBM), replacing fossil diesel and CNG in compatible fleets. These fuels, classified as part of the circular carbon cycle, allow for significant Well-to-Wheel (WtW) GHG reductions and complement the benefits of fleet electrification.

IV. RESULS AND DISCUSSION

A. Estimated demand for road freight mobility in 2023

By applying the described methodology and integrating official statistical data with industry studies and research, the total road freight transport demand for the year 2023 has been estimated.

The resulting value amounts to more than 85,000 million vehicle-kilometres, representing the sum of the contributions from Light Commercial Vehicles (LCVs) and Heavy Commercial Vehicles (HCVs).

Specifically:

- approximately 65% of the total demand is attributable to LCVs, corresponding to over 55,000 million vehicle-kilometres;
- the remaining 35% is associated with HCVs, with an estimated value of about 30,000 million vehicle-kilometres.

The following tables (Table 1, 2 and 3) present the estimated results.

Light Commercial Vehicles

TABLE I% DISTRIBUTION OF LCVS ROAD MOBILITY DEMAND BY 2023, BY ENVIRONMENTAL CLASS GROUPS

	Distribution %
Euro 0-I-II	11%
Euro III-IV	32%
Euro V-VI	57%
TOTAL	**100%**

Heavy Commercial Vehicles

TABLE II % DISTRIBUTION OF HCVS ROAD MOBILITY DEMAND BY 2023 BY SEGMENT, NORMALIZED FOR EACH ENVIRONMENTAL CLASS GROUP

	Distribution %			
	Euro 0-I-II	Euro III-IV	Euro V-VI	**Total**
< 14 tons	49%	34%	21%	24%
14,1 - 20 tons	15%	14%	10%	11%
20,1 - 28 tons	25%	20%	18%	19%
> 28 tons	11%	31%	51%	46%
TOTAL	**100%**	**100%**	**100%**	**100%**

TABLE III% DISTRIBUTION OF HCVS ROAD MOBILITY DEMAND IN 2023 BY EACH GROUP OF ENVIRONMENTAL CLASSES, NORMALIZED FOR SEGMENTS

	Distribution %			
	Euro 0-I-II	Euro III-IV	Euro V-VI	**Total**
< 14 tons	9%	22%	69%	**100%**
14,1 - 20 tons	6%	22%	72%	**100%**
20,1 - 28 tons	6%	17%	77%	**100%**
> 28 tons	1%	11%	88%	**100%**
TOTAL	4%	16%	80%	**100%**

B. Estimated greenhouse gas emissions attributable to road freight mobility in 2023

Subsequently, the tank-to-wheel (TTW) greenhouse gas emissions, expressed in tonnes of CO2 equivalent, related to road freight transport for the year 2023 were estimated.

The resulting total amounts to more than 30 million tonnes of CO2eq, representing the sum of emissions from Light Commercial Vehicles and Heavy Commercial Vehicles.

Specifically:

- approximately 40% of the total emissions are attributable to LCVs, with a total of about 12 million tonnes of CO2eq;
- the remaining 60% is attributable to HCVs, with an estimated value of more than 18 million tonnes of CO2eq.

The following tables (Table 4, 5 and 6) provide the main estimate results.

Light Commercial Vehicles

TABLE IV GREENHOUSE GAS EMISSIONS AND % DISTRIBUTION OF ROAD MOBILITY OF LCVS IN 2023, BY ENVIRONMENTAL CLASS GROUPS

	Distribution %
Euro 0-I-II	11%
Euro III-IV	33%
Euro V-VI	56%
TOTAL	**100%**

Heavy Commercial Vehicles

TABLE V % DISTRIBUTION OF HCVS GREENHOUSE GAS EMISSIONS BY 2023 BY SEGMENT, NORMALIZED FOR EACH ENVIRONMENTAL CLASS GROUP

	Distribution %			
	Euro 0-I-II	Euro III-IV	Euro V-VI	**Total**
< 14 tons	33%	20%	10%	13%
14,1 - 20 tons	16%	13%	7%	8%
20,1 - 28 tons	32%	23%	18%	19%
> 28 tons	18%	44%	65%	60%
TOTAL	**100%**	**100%**	**100%**	**100%**

TABLE VI % DISTRIBUTION OF HCVS GREENHOUSE GAS EMISSIONS BY 2023 BY EACH GROUP OF ENVIRONMENTAL CLASSES, NORMALIZED FOR SEGMENTS

	Distribution %			
	Euro 0-I-II	Euro III-IV	Euro V-VI	**Total**
< 14 tons	9%	24%	67%	**100%**
14,1 - 20 tons	7%	23%	70%	**100%**
20,1 - 28 tons	6%	18%	76%	**100%**
> 28 tons	1%	11%	88%	**100%**
TOTAL	4%	15%	81%	**100%**

C. The effects of trend scenarios on greenhouse gas emissions to 2030

Having consolidated the 2023 baseline estimates, the proposed optimistic 2030 scenario described in Section III were applied for the 2023-2030 horizon. The resulting TTW emission trajectories are shown in Figure 1.

The proposed 2030 scenario, built on optimistic (ambitious) assumptions for logistics optimization, accelerated modal shift incentives and rapid penetration of zero- and low-carbon technologies, achieves an about -25% reduction relative to 2005, showing a considerable gap with respect to the EU "Fit-for-55" milestone.

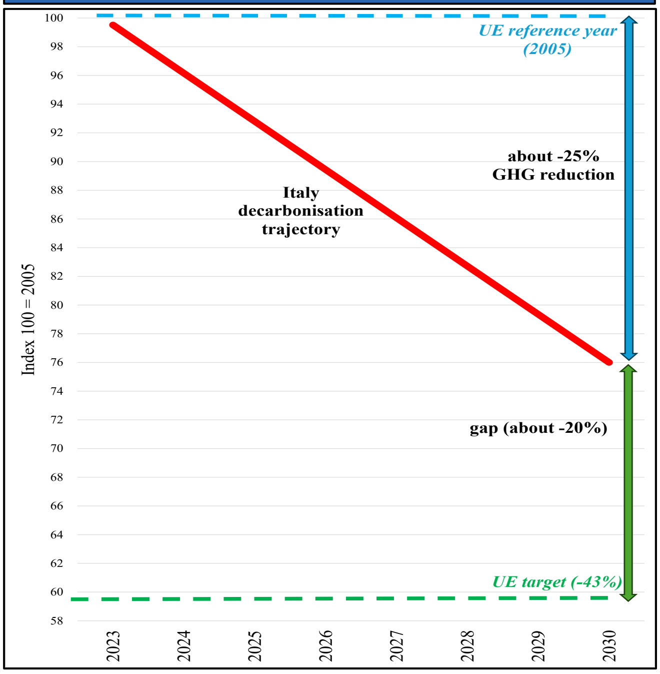

Fig. 1 Road freight greenhouse gas TTW emissions (GHG) (index 100 = 2005), decarbonization trajectory 2023-2030.

V. CONCLUSIONS

This study aimed to assess the decarbonization trajectory of road freight transport in Italy within the framework of the Avoid-Shift-Improve (ASI) paradigm, with particular focus on its application in forecasting scenarios developed within the ASI FOR FREIGHT project, part of the National Centre for Sustainable Mobility (MOST, Spoke 10). The core objective was to quantify greenhouse gas (GHG) emissions from freight transport and to evaluate the potential of ASI strategies to reduce them under the 2030 optimistic (accelerated decarbonization) scenario.

The main findings show that technological improvements alone are insufficient to achieve the EU 2030 climate targets. While "Improve" strategies—such as the electrification of fleets and the deployment of low-carbon fuels—play a crucial role, their impact remains limited if not accompanied by structural changes. Avoid strategies can reduce demand through logistics efficiency, while Shift strategies, though modest in total impact, are vital for long-haul and corridor freight. In the estimated 2030 scenario, the integrated application of all ASI pillars leads to a significant reduction in vehicle-kilometers and associated emissions, demonstrating that an ambitious but realistic combination of policies could enable Italy to align with EU decarbonization trajectories.

As a contribution to the ASI FOR FREIGHT research initiative, this work provides insights into how national freight decarbonization policies can be structured and assessed. The ASI framework proves particularly suitable for identifying policy synergies and trade-offs across demand management, modal reallocation, and technological innovation.

The findings highlight key policy implications:

- policy implications: there is an urgent need for coordinated, data-driven policies that promote a holistic approach to decarbonization. Governments must prioritize modal shift incentives, support the transition to cleaner technologies, and enhance logistics efficiency through regulation and subsidies;
- technological implications: the implementation of electric and hydrogen-powered freight vehicles, alongside the development of infrastructure for charging and refueling, is critical. Furthermore, adopting second-generation biofuels can complement the electrification of the fleet;
- decarbonization implications: achieving deep decarbonization in the freight sector will require a combination of demand-side measures (e.g., reducing the need for transport) and supply-side solutions (e.g., fleet improvements and infrastructure investments).

By utilizing the ASI framework, Italy fas an opportunity to significantly reduce transport-related emissions, aligning with the broader climate goals for 2030 and 2050. Future research should further develop disaggregated models of freight behavior, assess region-specific policy mixes and incorporate indirect emissions (Well-to-Wheel and life-cycle analysis), to ensure robust planning under uncertainty and support a just transition toward sustainable freight mobility.

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