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TRUCK ELECTRIFICATION IN BRAZIL: ECONOMIC, HEALTH AND ENVIRONMENTAL ANALYSIS OF ALTERNATIVE TECHNOLOGIES

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ABSTRACT

This article presents an economic, health and environmental analysis of the implementation of alternative technologies for heavy-duty trucks in Brazil, with a special focus on the state of São Paulo. The research evaluates different technological scenarios, including electrification, hybridization, and alternative fuels, quantifying their impacts in terms of reducing pollutant emissions and greenhouse gases, as well as the associated economic costs and benefits. The results demonstrate that electric technologies offer the greatest environmental and economic benefits in the long term, while fossil fuel-based alternatives present significant limitations. The study contributes to the debate on public policies and corporate strategies for decarbonizing freight transport in Brazil, highlighting the role of major manufacturers in accelerating this transition.

Keywords: Truck electrification; Sustainable transport; Economic analysis; Air quality; Public policies.

INTRODUCTION

The freight transport sector in Brazil represents a fundamental component of the national economy, being responsible for moving approximately 65% of all goods in the country. However, this sector is also one of the main contributors to greenhouse gas (GHG) and air pollutants emissions, generating significant impacts on air quality, public health, and climate change. The Brazilian heavy-duty truck fleet, predominantly powered by diesel, faces considerable challenges in terms of energy efficiency and emissions control, especially when compared to more advanced international standards (Araujo, 2021).

A significant environmental and health concern associated with heavy-duty trucks is the emission of fine particulate matter ($PM_{2.5}$). Diesel exhaust produces these microscopic particles, which can penetrate deep into the lungs and enter the bloodstream, leading to cardiovascular and respiratory diseases. The impact of PM emissions is particularly severe in densely populated cities, where freight corridors often intersect with residential and commercial zones (De Miranda et al., 2012).

Emissions from heavy-duty trucks have well-documented health impacts, particularly in urban areas and along major freight corridors. Exposure to fine particulate matter ($PM_{2.5}$) and nitrogen oxides (NO_x) from diesel-powered trucks is strongly linked to chronic respiratory conditions such as asthma, bronchitis, and impaired lung function. Children and the elderly are particularly vulnerable to these effects due to their higher susceptibility to air pollution.

A study conducted across six Brazilian cities identified vehicle emissions as a major contributor to urban $PM_{2.5}$ concentrations, correlating with increased respiratory illnesses. In addition to respiratory diseases, prolonged exposure to diesel exhaust has been associated with a higher risk of cardiovascular conditions, including hypertension, stroke, and heart attacks. $PM_{2.5}$ plays a key role in triggering systemic inflammation and vascular dysfunction, exacerbating cardiovascular health risks. Research indicates that individuals living near highways, industrial zones, and logistics hubs face disproportionately higher exposure to these pollutants, increasing their likelihood of developing severe health complications (Andrade et al., 2012).

Given this scenario, the transition to cleaner and more efficient technologies in freight transport becomes essential, not only to meet climate and environmental goals but also to reduce the social and economic costs associated with pollution. This article offers an in-depth examination of technological alternatives for decarbonizing the heavy-duty truck sector in Brazil, with a special focus on the state of São Paulo, evaluating their environmental, economic, and social impacts.

The research uses original data from an economic analysis performed in the state of São Paulo, which compares different technological scenarios, including electrification, hybridization, and alternative fuels. The results offer significant understanding for policymakers, vehicle manufacturers, and fleet operators on the most effective pathways for decarbonizing freight transport in the Brazilian context.

HEALTH, ENVIRONMENTAL AND SOCIOECONOMIC IMPACTS OF FREIGHT TRANSPORT IN BRAZIL

Freight transport in Brazil, dominated by diesel-powered trucks, generates significant health, environmental and socioeconomic impacts. The Brazilian heavy-duty truck fleet is responsible for a considerable portion of greenhouse gas emissions and air pollutants, such as particulate matter (PM), nitrogen oxides (NOx), and volatile organic compounds (VOCs). These pollutants contribute to the degradation of air quality, especially in urban areas and along transport corridors, resulting in negative impacts on public health. The economic impacts related to public health caused by air pollution from freight transport are substantial. According to World Bank data (2022), the global health costs associated with $PM_{2.5}$ pollution alone represent a significant economic burden on healthcare systems.

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In addition to respiratory diseases, prolonged exposure to diesel exhaust has been associated with a higher risk of cardiovascular conditions, including hypertension, stroke, and heart attacks. $PM_{2.5}$ plays a key role in triggering systemic inflammation and vascular dysfunction, exacerbating cardiovascular health risks. Research indicates that individuals living near highways, industrial zones, and logistics hubs face disproportionately higher exposure to these pollutants, increasing their likelihood of developing severe health complications (Andrade et al., 2012).

The International Council on Clean Transportation (ICCT) estimated that emissions from diesel vehicles, including heavy-duty trucks, are responsible for thousands of premature deaths annually in Brazil. A one-year delay in adopting the P-8 emission standards was projected to result in an additional 6,000 premature deaths between 2023 and 2050. Delays in implementing cleaner diesel technologies are expected to escalate health expenditures by nearly USD 11.5 billion by 2040 (International Council of Clean Transportation (ICCT), 2022).

The study by the International Council on Clean Transportation (ICCT) highlights the substantial economic burden that diesel truck emissions impose on Brazil’s healthcare system. The treatment of respiratory and cardiovascular diseases costs billions of reais annually, diverting critical resources from other public health priorities.

To quantify these financial impacts, this research conducted an updated assessment of hospitalization expenses within the Brazilian Unified Health System (SUS) for conditions with well-documented associations with air pollution. Our analysis estimates that between 2013 and 2023, approximately 24.5 billion reais were spent on hospitalizations related to these diseases. The conditions examined in this study include malignant neoplasms of the trachea, bronchi, and lungs; diabetes mellitus; acute myocardial infarction; other acute ischemic heart diseases; intracerebral hemorrhage; cerebral infarction; unspecified strokes; influenza; pneumonia; chronic obstructive pulmonary disease (COPD), including emphysematous bronchitis; and asthma. To refine the assessment, the analysis was stratified by age groups: cardiovascular and oncological diseases were analyzed in individuals over 40 years old, influenza and pneumonia in those over 60, pneumonia in children under five, and asthma in individuals under 15.

These findings underscore the severe economic and public health consequences of air pollution-related diseases, reinforcing the need for stringent air quality policies and emission control measures. Without effective intervention, diesel truck emissions will continue to strain Brazil’s healthcare system, leading to escalating costs and worsening health outcomes for vulnerable populations.

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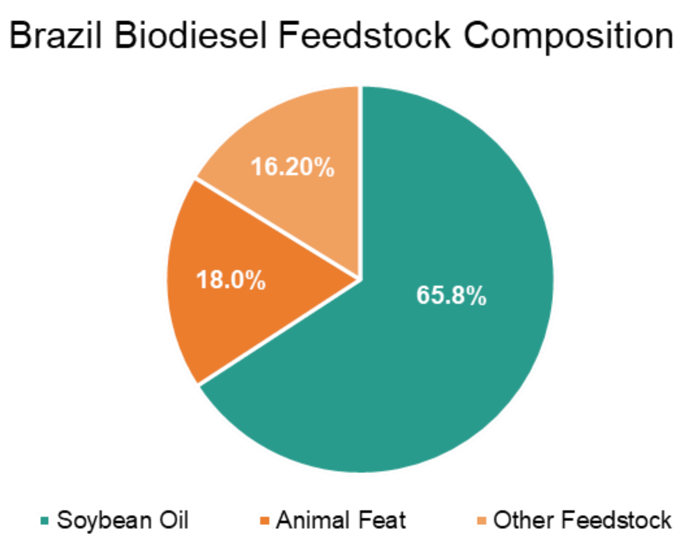
Problems of biodiesel as an alternative fuel

In addition to direct health impacts, the freight transport sector also faces challenges related to the energy matrix. Brazil has long promoted biodiesel, biomethane and ethanol to diversify its energy mix and lessen its dependence on fossil fuels (IEA Bioenergy, 2023). The country's abundant agricultural resources, coupled with robust government policies, have historically positioned biofuels at the forefront of efforts to achieve fuel diversification and lower emissions.

Biodiesel, in particular, has been widely adopted in Brazil through mandatory blending policies. By 2021, the biodiesel blend mandate had reached 13% (B13), with the government's initial plans to increase to 15% (B15) (Ministry of Mines and Energy, 2021). The current blend mandate is 14% in 2025. Brazil's National Biodiesel Production and Use Program (PNPB), established in 2004, has significantly advanced the biodiesel industry, leading to reduced petroleum imports and bolstering domestic agriculture. Over two decades, the program facilitated the production of 77 billion litres of biodiesel, preventing the emission of 240 million tons of CO_2 and saving approximately USD 38 billion in diesel imports. However, challenges persist regarding feedstock dependency and environmental impacts, necessitating ongoing evaluation and adaptation of the program (Government of Brazil, 2025). For instance, according to the National Agency of Petroleum, Natural Gas, and Biofuels (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP)), soybean oil constituted approximately 65.8% of Brazil's biodiesel production in 2022, followed by animal fats (16.2%) and other feedstocks (18%) (Brazil National Agency of Petroleum, Natural Gas, and Biofuels, 2022), as shown in Figure 1.

Figure 1. Feedstock composition of Biodiesel in Brazil in 2022.



Note: Data for the year 2022.
Source: Brazil National Agency of Petroleum, Natural Gas, and Biofuels, 2022.

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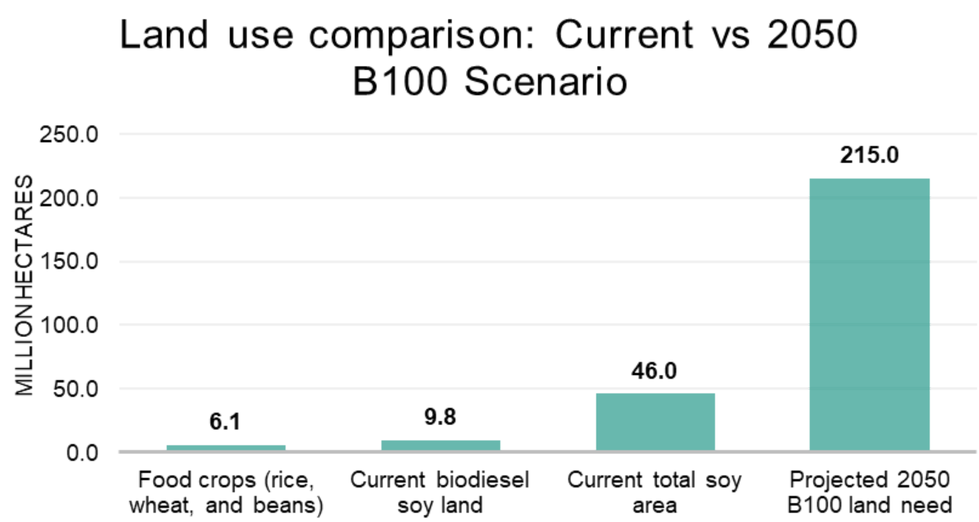
Brazil currently consumes approximately 40 billion liters of diesel annually (Brazil Ministry of Mines and Energy, 2024). Under the current 14% biodiesel blend mandate, this translates to roughly 5.6 billion liters of biodiesel produced each year. However, because only about 70% of Brazil's biodiesel is derived from soybean oil, the actual volume of soybean-based biodiesel is approximately 3.92 billion liters per year. With an average yield of 400 liters of biodiesel per hectare from soybean-based feedstocks, this level of production requires around 9.8 million hectares of soy. This area accounts for about 26.5% of Brazil's total soybean cultivation area, which is estimated at 46 million hectares (EMBRAPA, 2024). For context, staple food crops such as rice, wheat, and beans are grown on a combined area of about 6.1 million hectares, meaning that the land used for soybean-based biodiesel production is nearly 7.5 times larger than that used for these key food crops.

Looking ahead to a future scenario in which Brazil fully transitions to B100 biodiesel by 2050, it is assumed that diesel consumption will grow at an annual rate of 3.9% (Machado et al., 2020) from 2030 to 2050. Under this growth rate, the annual diesel consumption is projected to increase from 40 billion liters to approximately 86 billion liters by 2050. In a full B100 transition scenario, this entire 86 billion liters of diesel would be replaced by biodiesel. At the same yield of 400 liters per hectare, producing 86 billion liters of biodiesel would require about 215 million hectares of land. This represents an increase of roughly 205 million hectares compared to current soybean-based biodiesel production. To put this in perspective, 215 million hectares is about 4.7 times the current total soybean cultivation area of 46 million hectares and constitutes approximately 25.3% of Brazil's total land area of 850 million hectares. The bar graph in Figure 2 presents these disparities.

Figure 2. Land use comparison



Note: B100 refers to a blend of 100% biodiesel, meaning it's pure, unblended biodiesel.
Source: EMBRAPA. (2024).

CASE STUDY: ECONOMIC ANALYSIS OF THE IMPLEMENTATION OF NEW TECHNOLOGIES IN THE STATE OF SÃO PAULO

Researchers from Imperial College London and the University of São Paulo (Machado et al., 2020) conducted a comprehensive assessment of greenhouse gas (GHG) and pollutant emissions in São Paulo's road freight transport sector under different scenarios. The study, using the Low Emissions Analysis Platform (LEAP) model (Stockholm Environment Institute, 2025) to estimate emissions from fuel combustion in vehicles (demand-side emissions), fuel production and processing (transformation emissions), and imported fuel emissions, particularly for scenarios dependent on external fuel sources. The model integrates multiple inputs, including fleet composition and transitions across scenarios, emission factors for each vehicle type, and the energy source mix for electricity-based alternatives. Additionally, it accounts for vehicle survival rates and degradation factors over time to ensure an accurate representation of realworld emissions.

The analysis contrasts a Baseline Scenario, where diesel trucks remain dominant until 2050 without significant investment in alternative fuel infrastructure, against Alternative Technology Scenarios, in which cleaner technologies progressively replace diesel vehicles from 2030 onwards. These alternatives include Liquified Natural Gas (LNG), Compressed Natural Gas (CNG), biodiesel, hybrid diesel, hydrogen fuel cell electric, and battery electric trucks, with the assumption of infrastructure expansion to support fuel supply.

The study models Brazil's truck fleet evolution and emissions by incorporating projections for energy system evolution and economic growth. Fleet growth follows GDP trends, while São Paulo's electricity mix remains predominantly renewable (~60% hydropower). The study assumes crude oil refining capacity will remain unchanged until 2050. Additionally, it includes an annual 3.9% increase in biodiesel production capacity and a steady expansion of renewable electricity generation from hydropower, wind, and solar sources.

Scenario-Specific Assumptions

The baseline scenario assumes a diesel-dominated fleet until 2050, whereas alternative pathways introduce battery electric (BEV), hydrogen fuel-cell (FCEV), hybrid diesel-electric, liquefied natural gas (LNG), compressed natural gas (CNG), and biodiesel as substitutes. Each scenario accounts for fuel infrastructure expansion, shifts in energy production, and reductions in crude oil refining demand, as seen in Table 1.

Table 1. Summary of the main assumptions for each scenario

Scenario	Fleet sales	Crude Oil Refining	Biodiesel Share	Electricity Generation	Natural Gas Infrastructure
Diesel Baseline	100% diesel until 2050	No increase	Gradual B20 by 2050 (+3.9% per year)	No change	No change

Battery Electric (BEV)	100% electric by 2030	Large decrease	No change	Electricity demand increases significantly, requiring grid expansion and investment in charging infrastructure	No change
Hydrogen Fuel-Cell (FCEV)	100% hydrogen fuel-cell by 2030	Decrease	No change	Minor increase for hydrogen production	Hydrogen plants added in São Paulo from 2030
Hybrid Diesel-Electric	50% hybrid, 50% diesel by 2030	Moderate decrease	B30 by 2050 (+3.9% per year)	No change	No change
Liquefied Natural Gas (LNG)	100% LNG by 2030	Moderate decrease	No change	No change	LNG plants built from 2030
Compressed Natural Gas (CNG)	100% CNG by 2030	Moderate decrease	No change	No change	CNG processing expands by 2040 (+10 million m^3/day)
Biodiesel	100% biodiesel (B100 by 2050)	No decrease	B100 by 2050 (+3.9% per year)	No change	No change

This framework provides a strategic basis for evaluating emissions reductions, infrastructure needs, and policy interventions required for freight decarbonisation in São Paulo.

The transition to low-emission truck technologies in São Paulo's freight sector can have significant implications for air quality and climate change mitigation. Tables 2 and 3 summarize the expected pollutant reductions for different fuel and powertrain options compared to a diesel baseline, providing insights into both short-term (2030) and long-term (2050) effects. The pollutants considered in the study are GHG, NO_x, $PM_{2.5}$, CO, HCs.

Table 2. Percent Reduction in pollutants in 2030 and 2050 per scenario. Negative values represent reductions in emissions, while positive values represent increases

Scenario	Year	GHG (%)[1]	NO_x (%)	$PM_{2.5}$ (%)	CO (%)	HCs (%)
Battery Electric	2030	-30%	-15%	-30%	-11%	-70%
	2050	-46%	-30%	-43%	-21%	-89%
Fuel-Cell Electric	2030	-15%	-5%	-15%	-10%	-65%

[1] The GHG emissions reported in this study follow a well-to-wheel approach, covering both fuel production and vehicle use. In São Paulo, where biodiesel is mostly produced from soybeans using energy- and resource-intensive methods, the emissions from farming, processing, and distribution are high enough that the total GHG emissions of biodiesel can match or exceed those of fossil diesel, despite its biogenic tailpipe CO_2 being considered neutral.

	2050	-27%	-10%	-26%	-19%	-80%
Hybrid Diesel	2030	-4%	-12%	-20%	-9%	-15%
	2050	-8%	-23%	-30%	-18%	-30%
LNG	2030	-1%	5%	-20%	15%	10%
	2050	-1%	10%	-30%	30%	20%
CNG	2030	20%	2%	-8%	38%	5%
	2050	35%	5%	-15%	76%	10%
Biodiesel	2030	1%	5%	10%	500%	25%
	2050	2%	10%	20%	1000%	50%

Table 3. Absolute changes in 2030 and 2050 (in tons). Negative values represent reductions in emissions, while positive values represent increases

Scenario	Year	GHG (tons)	NO_x (tons)	$PM_{2.5}$ (tons)	CO (tons)	HCs (tons)
Battery Electric	2030	-3,584,400.0	-1,647.6	-29.1	-122.5	-67.9
	2050	-5,496,080.0	-3,295.2	-41.7	-245.0	-86.4
Fuel-Cell Electric	2030	-1,792,200.0	-549.2	-14.6	-116.7	-63.1
	2050	-3,224,000.0	-1,098.4	-25.2	-221.6	-77.7
Hybrid Diesel	2030	-477,920.0	-1,318.1	-19.4	-105.0	-14.6
	2050	-955,840.0	-2,525.3	-29.1	-210.0	-29.1
LNG	2030	-59,740.0	549.2	-19.4	175.0	9.7
	2050	-119,480.0	1,098.4	-29.1	350.0	19.4
CNG	2030	2,389,600.0	219.7	-7.8	443.3	4.9
	2050	4,181,800.0	549.2	-14.6	886.0	9.7
Biodiesel	2030	119,480.0	549.2	9.7	5,832.6	24.3
	2050	238,960.0	1,098.4	19.4	11,665.2	48.5

Economic Analysis of Alternative Scenarios

Methodology for Monetized Damage Costs in Brazil

To accurately estimate the economic benefits of emissions reductions in São Paulo's road freight sector, this study adjusts internationally recognised damage cost functions to reflect Brazil's economic, environmental, and public health conditions. The analysis incorporates income elasticity, urban exposure, healthcare costs, currency conversion, and economic growth projections to ensure reliable valuations for 2024, 2030, and 2050.

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Economic willingness to pay (WTP) for pollution reduction is linked to GDP per capita. Since Brazil's GDP per capita is lower than the OECD average, an adjustment must be made. In 2023, Brazil's GDP per capita was estimated at $9,032 (World Bank, 2024a), while the OECD average GDP per capita was $30,490 (World Bank, 2024b). The difference in income levels requires a correction factor to align damage cost estimates with Brazil's economic reality.

Income elasticity assumptions for environmental valuation were derived from existing literature. The income elasticity factor varies by pollutant, with carbon dioxide (CO_2) assigned a factor of 1.50, nitrogen oxides (NO_x) at 1.10, particulate matter ($PM_{2.5}$) at 1.30, carbon monoxide (CO) at 1.20, and hydrocarbons (HCs) at 1.10. These factors ensure that damage cost estimates scale appropriately based on income differences between Brazil and higher-income countries where original damage cost functions were developed.

Since economic conditions, willingness to pay, and healthcare costs evolve over time, the values were further adjusted to account for projected economic and inflationary trends. Brazil's GDP is expected to grow at an annual rate of 2.3% between 2024 and 2050, reflecting economic expansion. Simultaneously, inflation is projected at 3.8% per year over the same period, requiring adjustments to maintain the real value of estimated costs in future years.

The adjustment formula:

$$\text{Damage Cost}_{BR} = \text{Damage Cost}_{OECD} \times \left(\frac{\text{GDP}_{pc,BR}}{\text{GDP}_{pc,OECD}}\right)^{\text{Income Elasticity}} \times \left[(1 + GDP_{Growth})(1 + Inflation)\right]^{tt}$$

where:

- tt, years from 2024 (6 years for 2030, 26 years for 2050)
- GDP_{Growth} Rate = 2.3%
- $Inflation$ Rate = 3.8%

Table 4 presents the damage functions calculated for Brazil in 2030 and 2050, expressed in 2024 R$ values. These functions quantify the economic cost per ton of each pollutant emitted, allowing a direct comparison between different technological scenarios.

Table 4. Damage functions calculated for Brazil in 2030 and 2050, expressed in 2024 R$ value

Pollutant	**Original Cost (USD/ton)**	**Adjusted Cost (BRL/ton, 2030)**	**Adjusted Cost (BRL/ton, 2050)**	**Source**
CO_2	190	R$266.36	R$884.96	(EPA, 2023)
CH_4	2,800	R$3,925.24	R$13,041.46	(EPA, 2023)
N_2O	55,000	R$77,102.98	R$256,258.46	(EPA, 2023)
NO_x	7,000	R$11,887.58	R$37,878.97	(Dang &

				Mourougane, 2014)
$PM_{2.5}$	30,000	R$43,512.69	R$146,509.09	(World Bank, 2022)
CO	1,050	R$6,456.32	R$20,569.98	Scaled from NO_x
HCs	4,500	R$6,188.30	R$19,723.63	Scaled from $PM_{2.5}$

Table 5 complements this analysis by presenting the damage costs with weighted greenhouse gas (GHG) function, also expressed in 2024 R$ values. This weighting reflects the relative importance of different greenhouse gases in terms of their global warming potential.

Table 5. Damage Costs with Weighted GHG Function, expressed in 2024 R$ value

Pollutant	Original Cost (USD/ton)	Adjusted Cost (BRL/ton, 2030)	Adjusted Cost (BRL/ton, 2050)	Source
GHG (CO_2 + CH_4 + N_2O)	Composite	R$267.86	R$889.36	(EPA, 2023) and emission shares in (Machado et al., 2020)
NO_x	7,000	R$11,887.58	R$37,878.97	(Dang & Mourougane, 2014)
$PM_{2.5}$	30,000	R$43,512.69	R$146,509.09	(World Bank, 2022)
CO	1,050	R$6,456.32	R$20,569.98	Scaled from NO_x
HCs	4,500	R$6,188.30	R$19,723.63	Scaled from $PM_{2.5}$

Table 6 details the economic cost avoided or added by pollutants in 2030 and 2050, expressed in 2024 R$ values, excluding GHGs. This analysis allows the identification of which technologies offer the greatest economic benefits in terms of air pollution reduction.

Table 6. Economic avoided or added cost by Pollutant in 2030 and 2050 expressed in 2024 R$ value, excluding GHGs

Scenario	Year	Total Impact (million R$)	Total Avoided Pollutant Emissions (tons)	Impact per Ton (million R$/ton)
Battery Electric	2030	-22.06	1,867.10	-11.82
	2050	-137.67	3,668.30	-37.53
Fuel-Cell Electric	2030	-8.31	743.6	-11.17
	2050	-51.39	1,422.90	-36.12
Hybrid Diesel	2030	-17.28	1,457.10	-11.86
	2050	-103.23	2,793.50	-36.96

LNG	2030	8.27	714.5	11.57
	2050	49.87	1,438.70	34.67
CNG	2030	5.19	660.1	7.86
	2050	37.04	1,430.30	25.91
Biodiesel	2030	44.72	6,415.80	6.97
	2050	285.32	12,831.50	22.23

Electric Technologies: Strong Long-Term Benefits

The economic analysis reveals that electric technologies, particularly battery electric trucks (BEV), offer the greatest long-term economic benefits. Although the initial acquisition costs are higher, the lower operating costs and significant reduction in pollutant emissions result in a competitive total cost of ownership (TCO) over the vehicle's lifetime.

The joint policy paper "Décarboner le transport routier de marchandises", published in March 2025 by France's Conseil d'Analyse Économique (CAE) and Germany's Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung (GCEE), presents a clear position on the future of freight decarbonization in Europe. The report recommends prioritizing battery-electric trucks (BETs) as the main technological solution, citing their current cost-effectiveness, operational readiness, and alignment with the evolving structure of freight logistics. It emphasizes that BETs have already achieved total cost of ownership parity with diesel trucks in France and Germany, and that public investment should focus on rapidly deploying megawatt-scale charging infrastructure along major corridors. In contrast, hydrogen fuel cell trucks receive notably less support in the report, not because they are without potential, but because their deployment faces significant hurdles related to cost, energy efficiency, and infrastructure feasibility.

Hybrid Diesel: Limited Economic Benefit

Diesel-electric hybrid trucks present limited economic benefits compared to fully electric technologies. While they offer some reduction in pollutant emissions compared to conventional diesel trucks, this reduction is not sufficient to offset the additional costs of hybrid technology. Furthermore, as they still partially depend on fossil fuels, they do not provide a complete solution for decarbonizing freight transport.

Fossil-Based Alternatives: Increased Economic Costs

Fossil fuel-based alternatives, such as LNG and CNG, present an increase in economic costs when environmental and health impacts are considered. Although they may offer some reductions in certain pollutant emissions compared to conventional diesel, these technologies still contribute significantly to greenhouse gas emissions and other air pollutants. Consequently, the total economic costs, including environmental and health externalities, are higher than those of electric technologies.

THE CASE FOR ELECTRIFICATION: BRAZIL'S HEAVY-DUTY TRANSPORT SECTOR

The economic and environmental analysis presented in this study provides compelling evidence for the electrification of Brazil's heavy-duty transport sector. Battery electric trucks offer the most favorable combination of environmental and economic benefits, especially when considering the total costs over the vehicle's lifetime and the externalities associated with air pollution and climate change.

In the Brazilian context, the electrification of freight transport presents additional advantages due to the country's predominantly renewable electricity matrix. With approximately 60% of electricity coming from hydroelectric sources and a growing share of wind and solar energy, electric trucks in Brazil can operate with a significantly lower carbon footprint than in countries with electricity matrices more dependent on fossil fuels (IEA, 2023).

Furthermore, the electrification of freight transport can contribute to reducing dependence on oil and derivative imports, improving the country's energy security and reducing exposure to the volatility of international fuel prices.

GLOBAL TRENDS AND SUCCESS STORIES IN HEAVY-DUTY TRUCK ELECTRIFICATION

The electrification of heavy-duty trucks is gaining momentum globally, with various countries and regions implementing policies and incentives to accelerate this transition. In Europe, the Clean Vehicles Directive establishes ambitious targets for the adoption of low and zero-emission vehicles in public and commercial transport (European Commission, 2024). In the United States, California leads with its Advanced Clean Trucks Regulation, which requires an increasing percentage of truck sales to be zero-emission vehicles starting in 2024 (California Air Resources Board, 2020).

Several cities around the world are implementing low or zero-emission zones, where only vehicles that meet certain emission standards can operate. These policies are creating a strong incentive for the adoption of electric trucks, especially for urban logistics operations.

In the private sector, logistics and transport companies are increasingly committed to decarbonization goals, driving demand for zero-emission trucks. Companies such as Amazon have established ambitious targets to reduce emissions in their supply chains, including the transition to zero-emission transport fleets (Chris Roe, 2024).

KEY MANUFACTURER CONTRIBUTIONS

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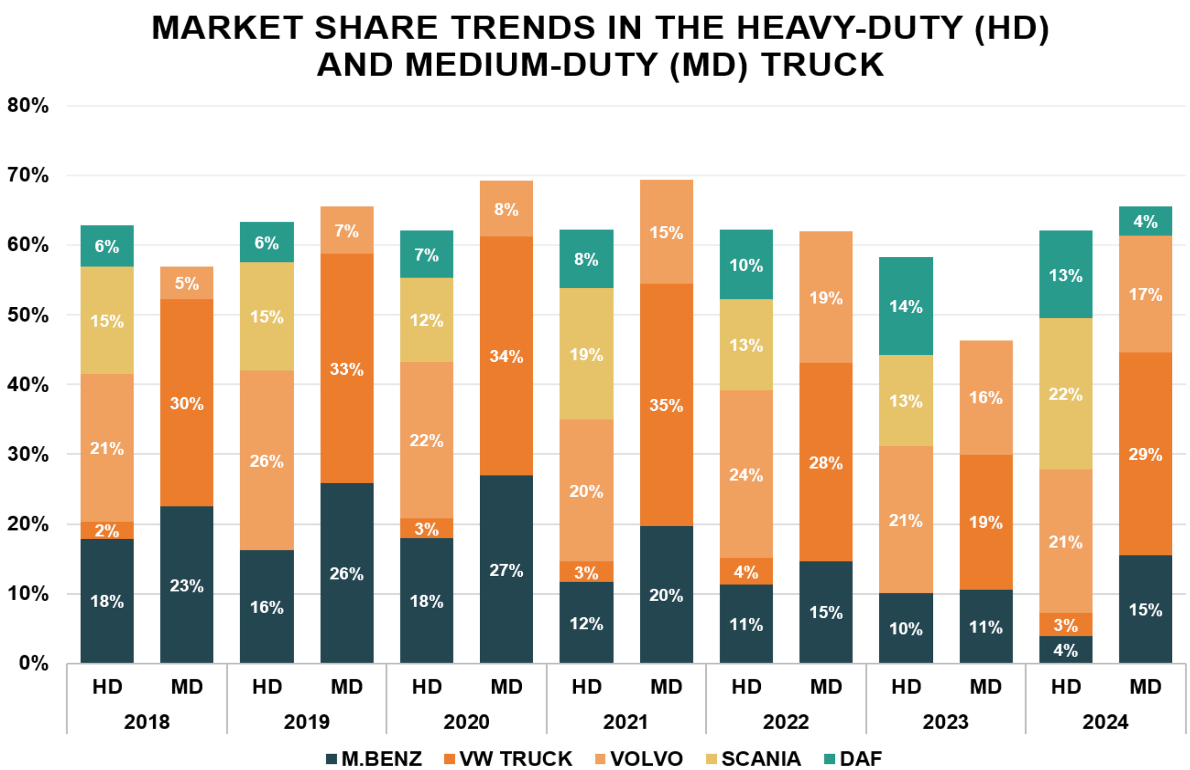
Major truck manufacturers are playing a crucial role in the transition to zero-emission freight transport. Table 9 presents a summary of commitments to zero-emission targets for the truck sector by the main manufacturers, demonstrating the industry's growing alignment with decarbonization objectives.

Table 7. Summary of commitment to zero emission target for the truck sector by the main manufacturers

Manufacturer	Target for 2040	Target for 2050
Daimler Truck	100% ZEV sales in key markets in 2039	CO_2-neutral fleet in key markets
Volvo Trucks	50% of global sales to be ZEVs	100% fossil-free vehicle sales globally
Scania	50% of global sales to be ZEVs	100% fossil-free fleet globally
MAN	No specific commitment for 2040	100% ZEV sales globally
Iveco	No specific commitment for 2040	CO_2-neutral fleet in key markets
Ford Trucks	100% zero-emission vehicle sales in Europe	No specific commitment for 2050
Volta Trucks	100% ZEV sales	No specific commitment for 2050

Figure 3 illustrates market share trends in the heavy-duty and medium-duty truck segments in Brazil between 2018 and 2024, providing insights into the competitive dynamics of the market and the positioning of different manufacturers (FENABRAVE, 2018, 2019, 2020, 2021, 2022, 2023, 2024).

Figure 3. Market Share Trends in the Heavy-Duty and Medium-Duty Truck Segments in Brazil (2018–2024)



How Can Brazil's Largest Manufacturers Help Accelerate the Transition to Electric Heavy-Duty Trucks?

Battery Production and R&D Investment

Truck manufacturers can accelerate the transition to electric vehicles by investing in local battery production and research and development. Establishing battery production capacity in Brazil would not only reduce the costs of electric trucks but also create jobs and develop local expertise in this critical technology. R&D investments can focus on adapting battery technologies to Brazil's specific conditions, such as climate, topography, and usage patterns.

Public-Private Partnerships for Charging Infrastructure

Charging infrastructure is an essential component for the viability of electric trucks. Manufacturers can establish partnerships with the public sector and energy companies to develop charging networks along major transport corridors and in logistics centers. These partnerships can share the costs and risks of infrastructure investment, accelerating its implementation.

Policy Engagement and Supportive Regulation

Manufacturers can actively engage with policymakers to develop regulations that support the transition to zero-emission trucks. This may include stricter emission standards, fiscal incentives for low and zero-emission vehicles, and public procurement policies that prioritize clean technologies. A favorable regulatory environment is crucial for creating market demand and justifying investments in zero-emission technologies.

Industry-Led Carbon-Credit Programs

Manufacturers can develop carbon credit programs specific to the freight transport sector, allowing fleet operators to monetize the emission reductions achieved with the adoption of electric trucks. These programs can provide an additional revenue stream to offset the higher initial costs of electric vehicles, improving their economic viability.

CONCLUSIONS AND RECOMMENDATIONS

This study provides robust evidence that electrification can represent the most promising pathway for decarbonizing freight transport in Brazil, offering the greatest environmental and economic benefits in the long term. Based on the results of the economic analysis and global trends, we recommend the following actions to accelerate this transition:

1. Development of a national roadmap for the electrification of freight transport, with clear and measurable targets for the adoption of zero-emission trucks.

2. Implementation of fiscal and financial incentives to reduce the initial cost of electric trucks and make them more competitive with conventional alternatives.

3. Investment in charging infrastructure along major transport corridors and in logistics centers, removing a significant barrier to the adoption of electric trucks.

4. Establishment of low or zero-emission zones in urban areas, creating demand for cleaner transport technologies.

5. Support for research and development in battery technologies and electric vehicles adapted to Brazil's specific conditions.

6. Development of training programs to train technicians and engineers specialized in electric vehicle technologies.

The transition to electric trucks in Brazil will not only contribute to reducing greenhouse gas emissions and improving air quality but will also offer significant economic opportunities, including job creation in high-technology sectors and reducing

DECLARATION OF COMPETING INTEREST

The authors declare no conflict of interest.

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