

THE IMPACT OF ELECTRIC VEHICLES ON HEAVY DUTY VEHICLES IN SÃO PAULO

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Abstract

This work analyzed the potential impact of electrifying the heavy-duty vehicle fleet in the State of São Paulo, replacing diesel internal combustion engines with electric vehicles. Using updated data on the state's energy mix provided by the Secretaria de Meio Ambiente Infraestrutura e Logística (2024) and information on the mileage driven by vehicle type, the total electric energy consumption needed for the electrified fleet, current diesel consumption, and associated CO₂ emissions for each scenario were estimated. The analysis showed that electrification could reduce CO₂ emissions by up to 88.4%, saving approximately 43.79 million tons of CO₂ per year. However, the transition would result in a significant increase in the state's electricity demand, requiring substantial investments in energy and highway infrastructure. The study also explored the implications for the oil and gas sector, which would experience a sharp decline in diesel demand, and the opportunities for new business models, such as Vehicle-to-Grid (V2G) technology integration and the Energy-as-a-Service (EaaS) model. We concluded that the electrification of São Paulo's heavy-duty vehicle fleet is a viable path towards decarbonization and alignment with global sustainability goals.

Keywords: electrification, heavy-duty vehicles, CO₂, infrastructure, decarbonization

1 Introduction

The transition to electric vehicles (EVs) is widely recognized as a critical pathway for reducing greenhouse gas emissions and dependence on petroleum-based fuels. The transportation sector alone accounts for more than 60% of global oil consumption, making it a key target for policies to reduce fossil fuel use and climate mitigation strategies. Within this sector, heavy-duty vehicles (HDVs) play a central role, as their operation is still largely based on diesel-powered internal combustion engines (ICEs), which generate high levels of CO₂ and other pollutants. Replacing ICE-based vehicles with electric vehicles, especially in the HDV segment, is therefore considered one of the most promising strategies for reducing fossil fuel consumption and mitigating emissions.

In Brazil, the relevance of this transition is evident. According to the National Association for Public Transportation, vehicles in the country emitted 31 million tons of CO₂eq (CO₂, CH₄, and N₂O) in 2018, of which 70% came from cars and motorcycles, while 30% came from buses, most of which operated in public transportation systems. In the State of São Paulo, the transportation sector accounts for 21.3% of total energy consumption, with diesel accounting for 40% of total energy use, followed by gasoline and ethanol at 24% each. Other fuels—such as aviation kerosene, natural gas, electricity, and fuel oil—collectively account for less than 2% of the state's energy matrix. These numbers indicate the dominance of fossil fuels and highlight the strategic importance of transitioning the transport sector toward electrification.

A full-scale migration of São Paulo's HDV fleet to electric propulsion would drastically reshape this energy balance. While electrification would eliminate diesel consumption in the transport sector, it would simultaneously impose significant additional demand on the state's electricity generation and distribution infrastructure. This shift would require not only grid reinforcement and new network capacity but also coordinated planning of charging logistics, charging strategies, and renewable energy integration.

The global EV market is already undergoing rapid growth, including in the HDV segment. According to the International Energy Agency (IEA, 2023), approximately 66,000 electric buses and 60,000 medium- and heavy-duty trucks were sold worldwide in 2022, representing 4.5% of global bus sales and 1.2% of truck sales. China leads this transition, accounting for 80% of global electric bus sales and 85% of electric HDV sales. Many of the vehicles circulating in Europe, Latin America, and North America are also manufactured by Chinese suppliers, evidencing the internationalization of the electric HDV market.

In Brazil, adoption is still in its early stages, but industrial and logistics leaders have already begun electrifying their fleets. In June 2024, Grupo Boticário announced the incorporation of 14 electric vehicles into its logistics operations in São Paulo and its metropolitan region, covering 50% of last-mile deliveries. Other companies, such as AMBEV and JBS, have made similar commitments. These initiatives demonstrate both the feasibility and the growing momentum of HDV electrification, but they also raise concerns about the impacts on energy demand and the resilience of electricity distribution systems.

Studies such as Borlaug et al. (2021) have already shown that electric trucks significantly affect grid load profiles. Their findings indicate that each vehicle requires between 137 and 235 kWh/day and adds a peak load of 10–74 kW, depending on charging strategy and fleet size. Under unmanaged charging, distribution components may exceed capacity limits, triggering costly upgrades. Other studies (Salah et al., 2015; Romo & Micheloud, 2015; Dogan et al., 2016) show similar results in different geographic and infrastructure contexts, confirming that electrification of vehicle fleets—when not strategically planned—can lead to feeder overloads, transformer saturation, and voltage imbalance.

Despite their relevance, these findings are mostly based on international case studies and focus primarily on passenger EVs or isolated HDV use cases. There remains a lack of large-scale, regional studies evaluating the systemic consequences of fully electrifying HDV fleets, particularly in emerging economies with heterogeneous infrastructure, such as Brazil. While the country has one of the world's cleanest electricity matrices—over 87% renewable in 2023 (EPE, 2023)—it

still faces structural challenges in distribution networks, investment planning, and transport electrification policy.

In São Paulo, this gap becomes especially relevant. The state not only hosts the country's largest vehicle fleet and industrial park but also concentrates the highest freight activity and road logistics flows. Electrifying the HDV fleet would therefore have a dual impact: (1) reducing emissions at a scale that meaningfully contributes to national climate goals and (2) significantly reshaping electricity demand curves and infrastructure needs.

Given this context, the need for structured analysis becomes evident. Before large-scale electrification is promoted through incentives or regulation, it is essential to quantify energy demand, estimate CO₂ emission reductions, and assess the implications for electricity distribution planning. A premature, uncoordinated transition, especially in a country with infrastructure bottlenecks, could lead to failures not only in transportation but also in the electrical supply chain.

Therefore, this research aims to simulate the full electrification of the heavy-duty vehicle fleet in the State of São Paulo and estimate the resulting electricity demand and expected reduction in CO₂-equivalent emissions. The study focuses exclusively on operational emissions, excluding those from vehicle or battery manufacturing, to isolate the energy and environmental effects directly attributable to fuel replacement.

The contribution of this work is twofold: (1) to provide quantitative evidence for public and private decision-making regarding the electrification of logistics and transportation systems, and (2) to demonstrate the environmental and infrastructural impacts of an electrified HDV fleet in one of the world's largest metropolitan and industrial regions. The findings are relevant for policymakers, energy distributors, transport planners, and stakeholders involved in Brazil's transition toward low-carbon mobility.

The remainder of this paper is organized as follows: Section 2 presents a detailed literature review on EV adoption, grid impacts, and Brazilian studies on electric mobility. Section 3 describes the methodology applied to estimate energy demand and emissions. Section 4 presents the results. Section 5 discusses implications, and Section 6 concludes the study and proposes directions for future work.

2 Literature Review

Research on electric vehicles has developed along different directions, with early studies focusing mainly on light-duty passenger vehicles and more recent work beginning to address the implications of electrifying heavy-duty fleets. Initial contributions focused on charging behavior, energy consumption patterns, and distribution grid impacts associated with passenger EVs, often under small-scale adoption or controlled simulation conditions. As electrification expanded, the scope of analysis shifted toward the technical feasibility and operational consequences of greater electric vehicle penetration, including buses and trucks.

A significant portion of the literature has examined how EVs affect electricity distribution systems. Salah et al. (2015) investigated EV integration in the Swiss power grid and observed that substations were not overloaded until penetration reached 50%, while at 100% penetration, six substations exceeded their capacity. The study also showed that dynamic pricing alone does not prevent infrastructure overload. Romo and Micheloud (2015) analyzed the impact of EV charging on a local grid in Austin, Texas, demonstrating that unmanaged charging caused voltage imbalances due to residential single-phase connections, whereas coordinated charging strategies reduced peak demand. Dogan et al. (2016) compared unmanaged and optimized charging strategies using GridLab-D simulations and concluded that even 30% EV penetration can cause grid stress when charging is uncontrolled. In contrast, time-shifted charging enables higher adoption without infrastructure reinforcement.

Some studies have analyzed behavioral and temporal charging patterns. Marmaras, Xydas, and Cipcigan (2017) developed a multi-agent model that distinguishes “aware” and “unaware” EV users and found that most owners plug in immediately upon arriving home, typically around 17:30–18:00, thereby increasing the evening peak load. Castro et al. (2022) provided one of the few real-world applications in an isolated system, evaluating EV integration in the Fernando de Noronha Island microgrid, where diesel generators and solar systems coexist. Their results showed that even moderate EV adoption requires charging coordination and supply planning under limited generation resources.

While many of these studies address light-duty vehicles, more recent work has focused specifically on electric heavy-duty trucks. Borlaug et al. (2021) evaluated energy demand for short-haul electric trucks. They estimated that each HDV requires 137–235 kWh/day, adding 10–74 kW of peak load depending on charging strategy and duty cycle. The authors concluded that uncontrolled fleet charging can overload local grid infrastructure, requiring upgrades to feeders and transformers unless managed charging is adopted. These findings highlight the importance of charging strategies. Still, they are based on case studies in the United States and do not assess the effects of large-scale HDV electrification at the regional or national level.

In Brazil, research on electric mobility has focused primarily on adoption scenarios, economic barriers, regulatory frameworks, and environmental assessments rather than on grid and energy demand modeling. Costa et al. (2021) examined socio-economic and political factors influencing EV adoption and emphasized the lack of incentives and charging infrastructure. Grangeia et al. (2023) analyzed the evolution of EV pricing and public policies in Brazil and concluded that large-scale deployment depends on fiscal measures and industrial stimulus. De Souza et al. (2018) performed a life-cycle environmental comparison of different vehicle types in the Brazilian context. They found that EVs have the lowest environmental impact when charged from the national electricity mix. Choma and Ugaya (2017) reinforced these findings by analyzing emissions reductions under different EV penetration scenarios. Ruoso and Ribeiro (2022) evaluated diffusion barriers to EVs and recommended policies to overcome infrastructure and cost limitations, while de Oliveira Gonçalves et al. (2022) compared electric, hybrid, and flex vehicles in economic, social, and environmental dimensions.

Although these studies make relevant contributions, most address light-duty vehicles, policy analysis, or environmental assessments rather than technical and quantitative modeling of heavy-duty vehicle electrification. Moreover, none of the Brazilian studies evaluate the effects of fully replacing diesel-powered HDVs with electric vehicles in a real regional context, nor do they simulate the resulting electricity demand, peak load implications, or CO₂-equivalent emission reductions. This gap is particularly relevant given the logistical and economic importance of HDVs, especially in regions with high freight intensity and renewable energy supply.

3 Materials and Methods

This study assesses the impact of electric vehicles (EVs) on the heavy-duty vehicle fleet in the state of São Paulo, Brazil. The data analysis was based on a dataset from DENATRAN-CGIE, which contains detailed information on vehicle registrations by municipality as of April 2024. The steps below outline the methodology, assumptions, and calculations used in this study.

The analysis began by importing the vehicle fleet data from an Excel file. The dataset included columns such as state (UF), municipality, and various vehicle types. Initial data cleaning steps involved:

- a) Removing the first row of metadata from the dataset.
- b) Dropping the 'TOTAL' column to focus on specific vehicle types.
- c) Converting all relevant columns to numeric values to ensure consistency in calculations.

The total number of vehicles was calculated for each state to understand the vehicle distribution. The state of São Paulo accounts for approximately 30% of the total national vehicle fleet — nearly 33,645,466 vehicles — as shown in Figure 1. Further analysis detailed the breakdown of vehicle types in São Paulo (Figure 2) and identified the top 10 municipalities by vehicle count, with São Paulo city accounting for nearly 30% of the state's vehicles (Table 1).

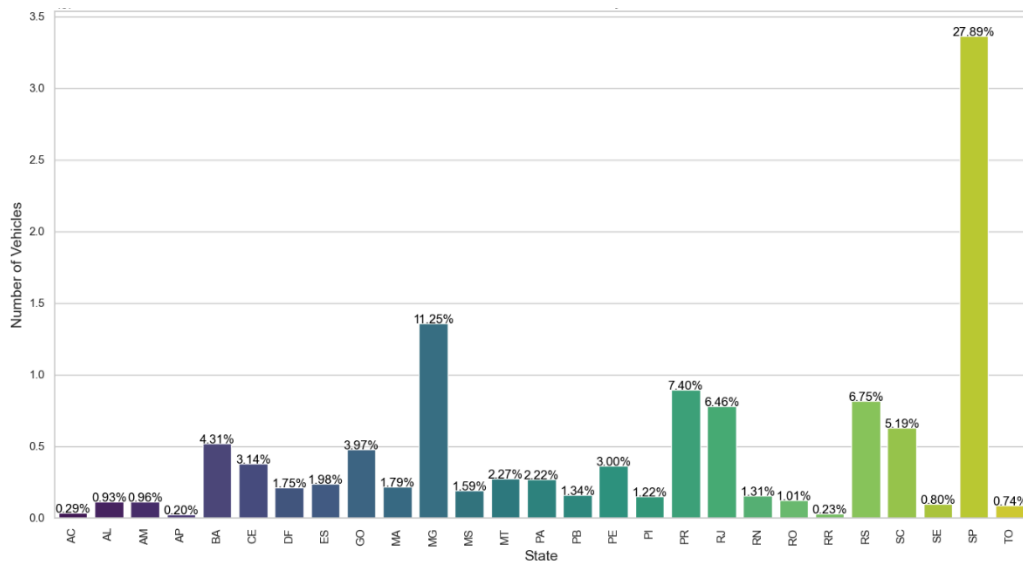


Figure 1 - Total number of Vehicles by State

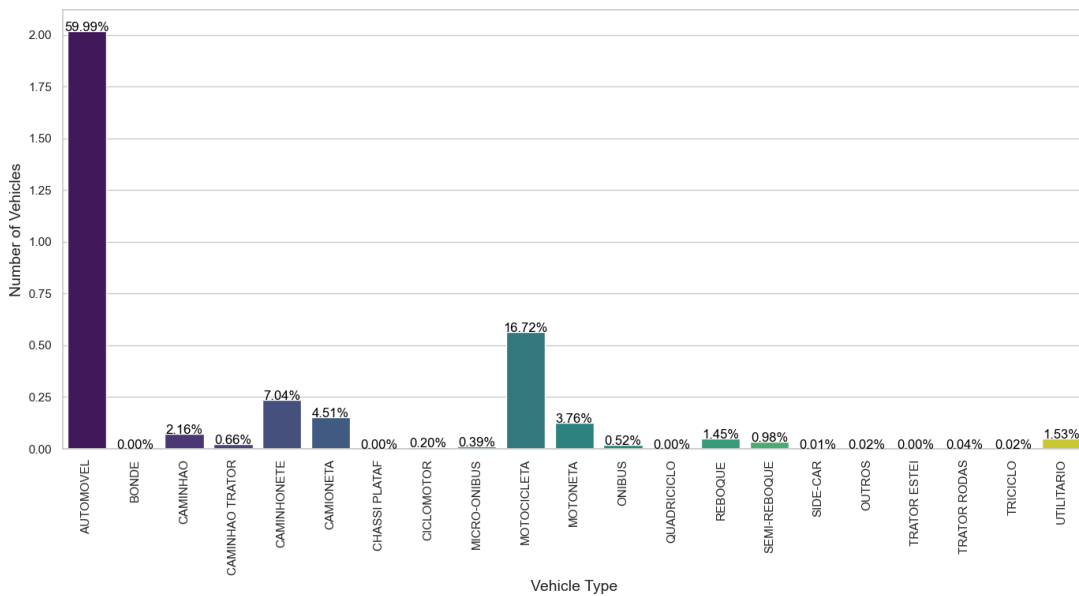


Figure 2 -Total number of each type of Vehicle in UF SP

Table 1 - Top 10 Municipalities per vehicle in the State of São Paulo

Municipality	Total Vehicles	Percentages [%]
São Paulo	9590536	28.50%
Campinas	975402	2.89%
Guarulhos	798376	2.37%
São Bernardo do Campo	647019	1.92%
Ribeirão Preto	589072	1.75%
Santo Andre	584530	1.73%
Sorocaba	542378	1.61%
São José dos Campos	488417	1.45%
Osasco	474304	1.40%
São José do Rio Preto	434863	1.29%

Source - Original research result

For the scope of this study, heavy-duty vehicles were defined as follows: ``vehicle_types_HD = [TRUCK, TRUCK TRACTOR, MICRO-ONIBUS, BUS, TRAILER, SEMI-TRAILER]`. We filtered out these vehicle types for further analysis. Figure 3 illustrates the total count and percentage of each heavy-duty vehicle type in São Paulo. Vehicles that contributed less than 1% were excluded from this analysis to focus on the most impactful categories.

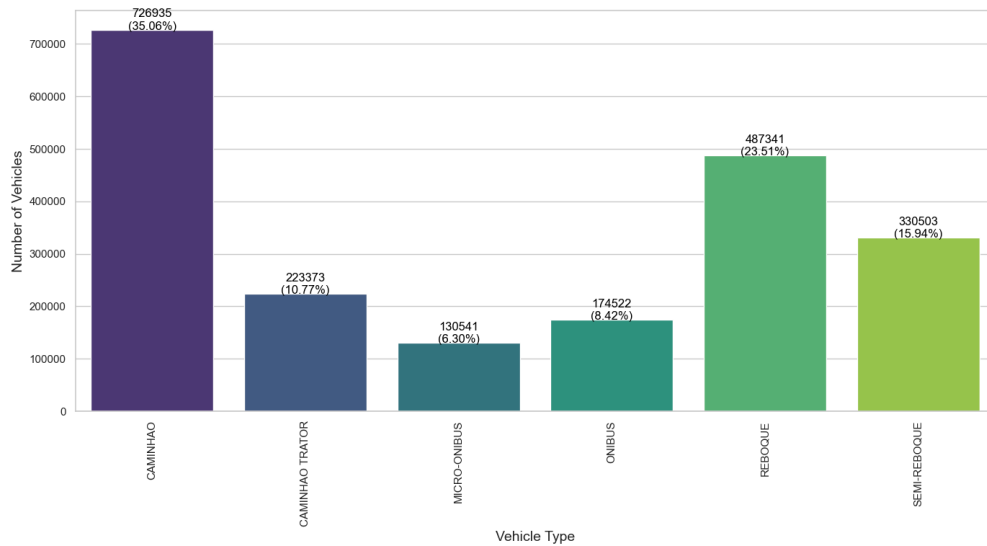


Figure 3 - Total Number of each type of Heavy-Duty Vehicle in São Paulo State

To estimate the energy demand and emissions, the study utilized average annual kilometers driven for each heavy-duty vehicle type, based on data from the report "Usage Intensity Curves by Type of Motor Vehicle in the Fleet of the City of São Paulo", table 2 (COMPANHIA AMBIENTAL DO ESTADO DE SÃO PAULO, 2013). The study assumed an average vehicle age of 10.1 years across all types, reflecting typical industry usage patterns. The average kilometers driven per year per vehicle type were:

Table 2 - Usage Intensity curves by type of motor vehicle in the fleet of São Paulo

Vehicle type	Fuel	Usage Intensity Curves [Km vs. Average Year]
TRUCK	Diesel	$y = 0,0774x^4 - 7,3952x^3 + 249,38x^2 - 3664x + 44505$
TRUCK TRACTOR	Diesel	$Y = -8,8551x^3 + 263,41x^2 - 4219,4x + 66435$
BUS /MICROBUS	Diesel	$y = -5661\ln(x) + 35578$
TRAILER/SEMI-TRAILER	Diesel	$y = -1023,7x + 57247$

Source – Companhia Ambiental do Estado de São Paulo

Using the usage intensity curves, we calculate the total kilometers driven by each type of heavy-duty vehicle (HDV) in the State of São Paulo. These curves provided insights into the average usage patterns and frequency of operation for each vehicle

category, allowing us to estimate the total annual distance covered by the entire fleet with precision:

The total distance traveled by heavy-duty vehicles in the State of São Paulo is projected to reach approximately 6.10×10^{10} km in 2024 (Figure 4).

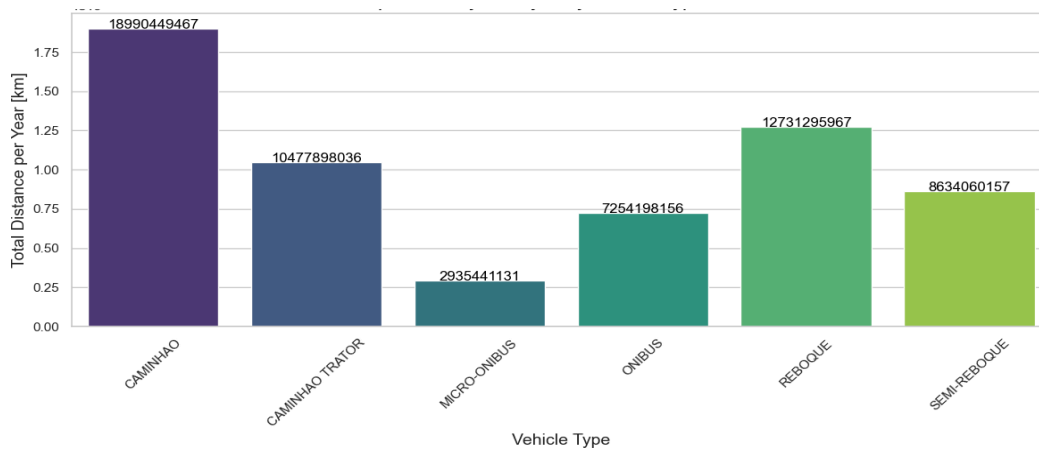


Figure 4 - Total Distance per Year by Heavy Duty Vehicle type in São Paulo State

Diesel consumption volume (V_D) was estimated using an average engine efficiency of 3.3 km/L. We calculated total diesel consumption using the total kilometers driven (D_T) and the average fuel efficiency of heavy-duty vehicles (f_{eff}) (Equation 1). This value provided the basis for estimating current energy use and CO₂ emissions for São Paulo's HDV fleet. The HDV internal combustion engine fleet in São Paulo consumes approximately 18.49 billion liters of diesel per year, with trucks accounting for the largest share of fuel use.

$$V_D (L) = \frac{D_T (km)}{f_{eff} \left(\frac{km}{L} \right)} \quad (1)$$

Subsequently, the energy demand in gigawatt-hours (GWh) was calculated using the specific energy content of diesel (9.8 kWh per liter). Based on this conversion, the São Paulo ICE HDV fleet would require approximately 181,220.83 GWh of electric energy per year if fully electrified.

To estimate the environmental impact, Equation (2) was applied to calculate CO₂-equivalent emissions (TE_{CO_2}). Emissions were computed using an emission factor (Ef_{CO_2}) of 2.68 kg CO₂ per liter of diesel for all heavy-duty vehicle categories, in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

$$TE_{CO_2} (Tons) = V_D (L) \times Ef_{CO_2} \left(\frac{kg}{L}\right) \quad (2)$$

The total CO₂-equivalent emissions were converted from kilograms to metric tons to provide a clearer representation of the environmental impact, as shown in figure 5. The heavy-duty vehicle fleet in São Paulo is estimated to emit approximately 49.56 million tons of CO₂eq per year in 2024.

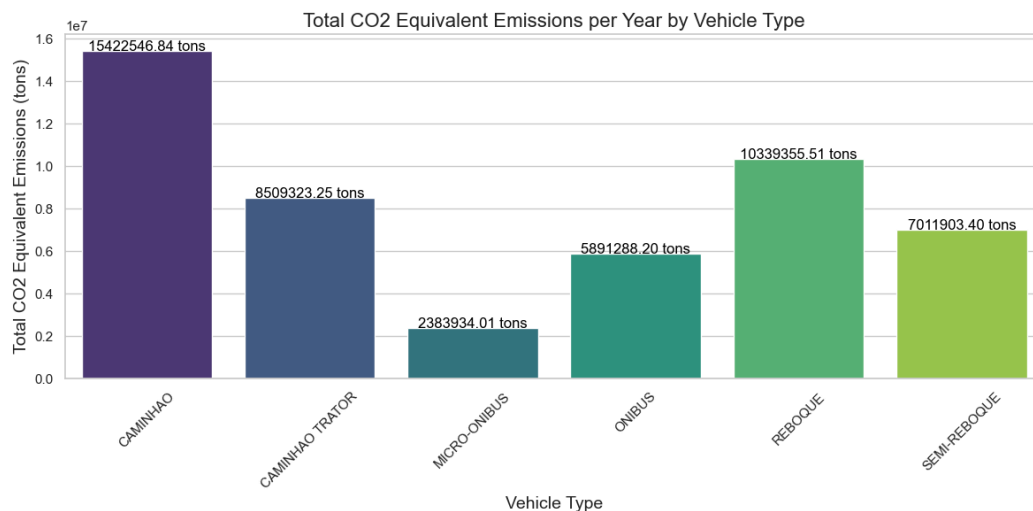


Figure 5 - Total CO₂ Equivalent Emissions per Year by Vehicle Type

By quantifying diesel consumption, energy demand, and CO₂ emissions, this methodology provides a detailed assessment of the current impact of heavy-duty vehicles in São Paulo and the potential benefits and challenges of transitioning to an all-electric fleet.

To perform the data analysis and visualization effectively, several Python libraries were utilized, each serving a specific purpose in managing and interpreting the dataset related to São Paulo's heavy-duty vehicles and their emissions:

Pandas: this library was the backbone of our data analysis process. Pandas enabled us to efficiently import large datasets, manipulate them, and prepare them for analysis. It helped to handle missing values, convert data types, and perform calculations on large-scale vehicle datasets. With its powerful DataFrame structure, Pandas enables operations such as grouping by vehicle type, calculating emissions and energy consumption, and merging multiple data sources, making data manipulation both efficient and streamlined.

NumPy: used to perform numerical calculations and handle arrays, providing the mathematical foundation for our analysis. Its capabilities in managing numerical data and performing vectorized operations allowed us to compute energy consumption and emissions values quickly and accurately. NumPy's integration with Pandas also enabled the efficient execution of mathematical formulas directly on large datasets, enhancing our ability to model energy and emissions scenarios.

Matplotlib: This library was essential for creating visualizations that illustrated our findings. Matplotlib enabled the generation of a variety of plots, including bar charts, line graphs, and other figures, that displayed key metrics such as vehicle type distributions, energy consumption, and emissions. Its flexibility allowed us to customize these visualizations, adjusting axes, labels, and colors to communicate the patterns and insights uncovered during the analysis clearly. The library also supported the creation of interactive visualizations, making it easier to explore and interpret different aspects of the data.

Seaborn: Built on top of Matplotlib, Seaborn provided an enhanced, more aesthetically pleasing approach to visualizing our data. Seaborn was particularly effective at generating advanced statistical graphics that illustrated relationships among variables, such as the correlation between vehicle types, emissions, and energy consumption. Its built-in themes and color palettes made it easier to create professional, interpretable visuals that highlighted key patterns in the data, helping us convey insights in a clear, visually appealing manner.

By leveraging these libraries, we efficiently processed, analyzed, and visualized the data, resulting in a comprehensive and detailed exploration of São Paulo's heavy-duty vehicle fleet's energy and emissions profile.

4 Results

According to the most recent dataset from DENATRAN-CGIE, released in April 2024, the State of São Paulo had 2,073,215 heavy-duty vehicles. The fleet consisted of several types of vehicles, including trucks, truck, microbuses, buses, trailers, and semi-trailers. These vehicle types are responsible for a significant share of São Paulo's transportation energy consumption and CO₂ emissions.

The total annual diesel consumption of São Paulo's heavy-duty vehicle fleet is calculated based on the yearly kilometers driven per vehicle type and the average engine efficiency (3.3 km per liter of diesel). The results show that the total diesel consumption for these vehicles amounts to 18.49 billion liters per year. Using an emission factor of 2.68 kg CO₂ per liter of diesel, the total CO₂ emissions from these vehicles are estimated at 49.56 million tons of CO₂ per year, as we illustrate in Figure 06.

We estimated the total amount of electric energy required to charge the entire heavy-duty vehicle fleet of the State of São Paulo by analyzing the total kilometers driven for each vehicle type: ICE and electric. For a diesel-fueled vehicle, we used the specific energy density of diesel to estimate the total electric energy demand from the actual heavy-duty fleet in São Paulo in 2024.

A commonly referenced value for the energy consumption of electric heavy-duty vehicles (EHDVs) is approximately 1.2 to 2.0 kWh per kilometer, depending on the vehicle type, load, and driving conditions. For this article, we used the value of 1.575 kWh/km. In Figure 6, we can analyze the difference between the electricity demand from ICE versus Electric vehicles:

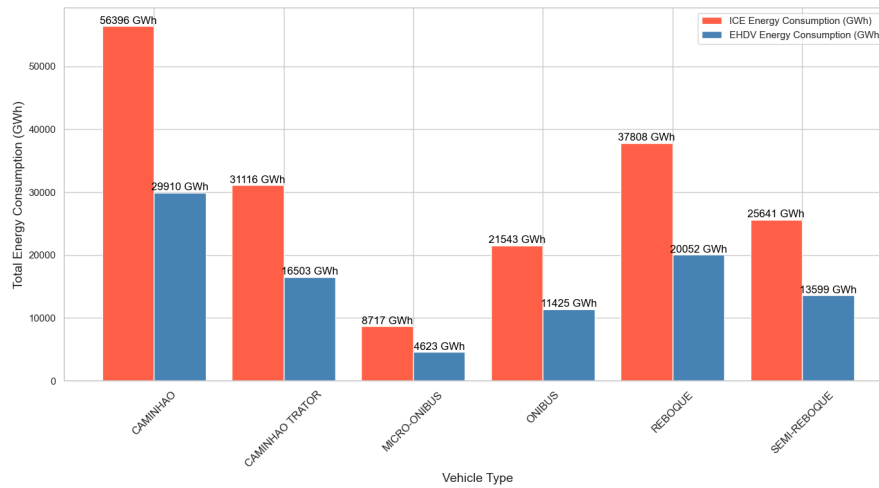


Figure 6 - Comparison of Energy Consumption

EHDVs are significantly more energy efficient than their diesel counterparts, requiring less energy to travel the same total fleet mileage projected for 2024. The estimated electricity demand for a fully electrified HDV fleet in São Paulo is 96,111 GWh per year.

This result provides a comprehensive estimate of the electric energy requirements associated with the large-scale transition from internal combustion engine vehicles to electric heavy-duty vehicles. Such information is essential for ensuring that the state can meet future transportation demands while supporting the shift toward low-carbon mobility. To assess the environmental benefits of this transition, the simulation used São Paulo's current electricity mix. The share of renewable energy in the grid plays a decisive role in determining the net CO₂ emissions from electric vehicles, since the carbon intensity of electricity generation directly affects the life-cycle emissions of EHDVs. The Figure 7 shows this effect.

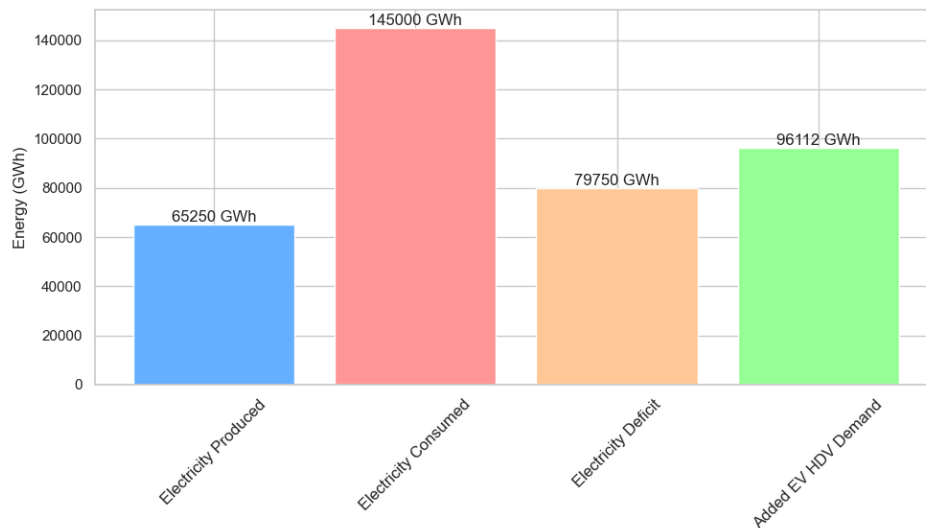


Figure 7 - Impact of EHDV Demand on São Paulo's Electric Energy Balance [GWh]

With more than 18.6 million consumer units, the electricity distributors operating in the State of São Paulo supply approximately 145,000 GWh of electricity per year. The industrial sector, which hosts the country's largest industrial park, accounts for 36.5% of this consumption. Although residential consumers represent more than 90% of all consumer units, they account for just over 30% of total electricity use, followed by the commercial sector at 22.2% and other sectors at 11.3%.

More than half of the state's electricity supply is generated from renewable sources. São Paulo has an installed generation capacity of 23 GW, equivalent to 15% of the national installed capacity. Hydropower represents 65% of this output, followed by biomass-based thermoelectric plants (25%) and fossil-fuel thermoelectric plants (10%). Although photovoltaic and wind generation facilities exist in the state, their contribution to the energy matrix is still marginal.

For this analysis, the carbon intensity of the fossil-fuel thermoelectric share of São Paulo's grid was assumed to be 600 g CO₂ per kWh. In contrast, the remaining 90% renewable share was considered to have zero operational emissions. Under current conditions, the ICE heavy-duty vehicle fleet emits approximately 49.56 million tons of CO₂eq per year. If the same fleet were fully electrified and powered by São Paulo's present electricity mix, annual emissions would fall to 5.77 million tons, representing

a substantial reduction. This comparison is illustrated in Figure 8, which highlights the difference between the diesel-based and electrified scenarios.

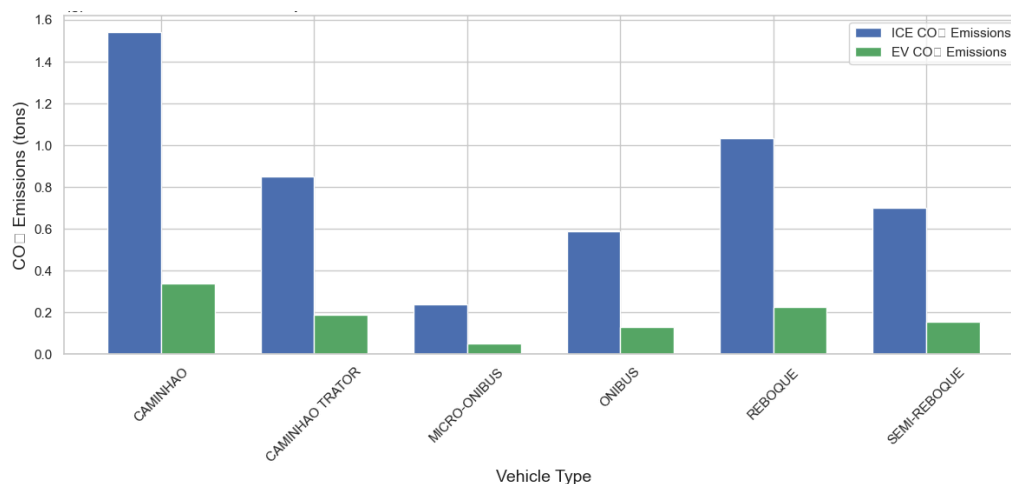


Figure 8 - Comparison of CO₂Eq. Emissions for ICE Vs. EV heavy-duty vehicles in São Paulo

The results clearly indicate that electrifying São Paulo’s HDV fleet would lead to a substantial reduction in CO₂ emissions. The current diesel-based HDV fleet emits approximately 49.56 million tons of CO₂eq per year. In comparison, an equivalent fully electric fleet—powered by the state’s present electricity mix—would emit only 5.77 million tons annually. This represents a net reduction of 43.79 million tons of CO₂eq, corresponding to an 88.4% decrease in total emissions. Such a reduction demonstrates the decisive impact that HDV electrification could have on São Paulo’s decarbonization strategy, reinforcing its potential contribution to the state’s long-term sustainability and climate goals.

5 Conclusion

This study has demonstrated the substantial potential of electrifying São Paulo’s HDV fleet to reduce greenhouse gas emissions and advance sustainable mobility. By integrating data on vehicle activity, fuel efficiency, diesel consumption, electricity demand, and the state’s energy matrix, we quantified both the current environmental impact of diesel-powered HDVs and the benefits achievable through full fleet electrification. The findings show that replacing internal combustion engine (ICE)

HDVs with electric HDVs (EHDVs) would not only dramatically reduce emissions but also support São Paulo's wider decarbonization and sustainability agenda.

Electrifying the heavy-duty vehicle (HDV) fleet would reduce annual CO₂ emissions from 49.56 million tons to 5.77 million tons, corresponding to an 88.4% decrease, or 43.79 million tons of avoided emissions. This reduction becomes even more significant when compared to the Vehicle Pollution Control Plan (published by CETESB – the Environmental Company of the State of São Paulo in 2023, which reported 46.1 million tons of transport-related CO₂ emissions in 2021, of which 56% (25.8 million tons) were attributed to HDVs. These results indicate that electrifying HDVs alone would effectively eliminate the majority of emissions from the transportation sector in São Paulo, with direct implications for air quality, public health, and achieving state-level climate mitigation targets.

However, the analysis also highlights the scale of the required infrastructural transformation. A fully electrified HDV fleet would demand 96,111 GWh per year, equivalent to a 66% increase over the state's current electricity consumption of 145,000 GWh. While São Paulo already benefits from a 90% renewable electricity mix, large-scale fleet electrification will require expanding power generation capacity, upgrading transmission and distribution networks, developing energy storage solutions, and deploying high-capacity charging infrastructure along logistics corridors. The transition also carries economic implications, as the current HDV fleet consumes 18.49 billion liters of diesel per year, meaning electrification would significantly reduce fossil fuel demand and restructure fuel supply chains, while simultaneously creating opportunities in energy services, charging infrastructure, battery manufacturing, and emerging business models such as Vehicle-to-Grid (V2G) and Energy-as-a-Service (EaaS).

São Paulo's transition to electric HDVs is aligned with Brazil's climate commitments and global decarbonization efforts under the Paris Agreement, positioning the state as a potential national and international reference for sustainable freight transport. The results of this research, therefore, contribute to the literature by providing a quantified, region-specific assessment of HDV electrification in a highly industrialized, logistically intensive region powered by a predominantly renewable grid.

Although the results are robust, the study presents limitations. It focuses solely on operational emissions, excluding life-cycle emissions related to vehicle and battery production, recycling, or disposal. The analysis assumes a static electricity mix and does not model hourly load curves, peak charging effects, or grid congestion. It also assumes full adoption of electric HDVs, without accounting for behavioral, regulatory, or financial constraints. Future research should expand the model to include life-cycle assessment, charging logistics, hourly energy modeling, renewable expansion pathways, comparisons of hydrogen and biofuel technologies, and policy frameworks for large-scale freight electrification. Scenario-based simulations incorporating smart charging, distributed energy resources, and tariff structures would offer further insight into grid impacts and investment needs.

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