Considerations about vehicle electrification in Brazil: Facts and concerns

Considerações sobre a eletrificação veicular no Brasil: fatos e preocupações

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ABSTRACT

Research Purpose: To present a discussion on the main challenges, perspectives, and concerns associated with the implementation of a new transportation paradigm in Brazil: electric vehicles (EVs). Additionally, to conduct a comparative analysis between EVs and internal combustion engine vehicles powered by biofuels.

Methodology: Bibliographic research, official databases (number of registered EVs), tax incentives, and government planning policies related to vehicle electrification were employed to assess the impacts and challenges of this emerging urban mobility solution. Furthermore, based on the estimated electricity consumption of a utility-type EV, under Brazilian usage patterns and from the perspective of carbon footprint, a comparative evaluation was conducted between electric vehicle technologies and biofuel-powered vehicles, considering a projected fleet by 2030.

Findings: The findings reveal that there are additional concerns beyond those already observed in countries where EVs are widely adopted. These include infrastructural limitations, both in terms of accommodating the increasing electricity demand and ensuring a genuine reduction in atmospheric emissions. The study suggests that although electrification offers clear advantages, technological diversification—such as hybrid vehicles powered by both electricity and biofuels—may represent a promising solution. Consequently, the state of vehicle electrification in Brazil is highlighted, considering its status as a developing country with significant agricultural potential.

Originality/Value: EVs, due to their zero tailpipe emissions, have been strongly promoted by governments worldwide, including Brazil. However, Brazil has a long-standing tradition in agricultural production and operates a considerable fleet of vehicles powered by biofuels, which also constitute a sustainable alternative, particularly given the carbon offset through biomass regrowth. This study explores the key challenges of vehicle electrification in Brazil, in light of the specific context of a developing country where agribusiness accounts for over 20% of the Gross Domestic Product.

Keywords: Electric vehicles; Electrical infrastructure; Biofuels; Sustainability.

RESUMO

Objetivo da Investigação: Apresentar uma discussão sobre os principais desafios, perspectivas e apreensões associados à implementação de um novo paradigma de transporte no Brasil: os veículos elétricos (EVs) e, realizar uma análise comparativa entre os EVs e os veículos de combustão movidos a biocombustíveis.

Metodologia: Pesquisas bibliográficas, base de dados (quantidade de EVs licenciados), incentivos fiscais e políticas de planejamento governamentais voltadas à eletrificação veicular foram utilizadas para avaliar os impactos e desafios dessa nova solução de mobilidade urbana. A partir do cálculo do consumo de um modelo utilitário de EV, com base no perfil de uso brasileiro e sobre a perspectiva da pegada de carbono, foi realizada uma avaliação comparativa entre as soluções de eletrificação veícular e os veículos movidos a biocombustível, para uma frota projetada até 2030.

Resultados: Os resultados demonstram que existem preocupações adicionais às já recorrentes em países cujos EVs são uma realidade, incluindo as deficiências infraestruturais tanto para acomodar a crescente demanda por eletricidade, quanto para garantir a real diminuição nos níveis de emissões atmosféricas. O estudo indica que, apesar da eletrificação possuir vantagens, a diversificação tecnológica, como veículos híbridos movidos a eletricidade e biocombustíveis, pode se configurar como uma solução promissora. Consequentemente, o estado da eletrificação veicular no Brasil, como nação em desenvolvimento e de forte potencial agrícola, é ressaltado.

Originalidade/Valor: Os EVs, por não emitirem poluentes atmosféricos durante a operação, vêm sendo fortemente incentivados por governos, inclusive o brasileiro. No entanto, o Brasil, por ser um país com forte tradição agrícola, tem uma relevante frota de veículos movidos a biocombustíveis, também uma solução sustentável, dada a compensação do carbono através do replantio. Assim, a pesquisa explora os principais desafios da eletrificação veicular no Brasil, diante das perspectivas peculiares a um país em desenvolvimento cujo agronegócio representa mais de 20% de seu Produto Interno Bruto.

Palavras-chave: Veículos elétricos; Infraestrutura elétrica; Biocombustíveis; Sustentabilidade.

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1. Introduction

The transportation sector is responsible for approximately 14% of global greenhouse gas (GHG) emissions (IPCC, 2022). Around 60% of these emissions are attributed to passenger cars (Perujo et al., 2011). According to data from the Greenhouse Gas Emissions Estimation System (SEEG), Brazil emitted approximately 2 billion tons of CO_2 in 2017 alone. Of this total, about 21% was attributed to the transportation and energy sectors (WRI BRAZIL, 2018).

The production and consumption of energy from clean sources are extremely important for environmental protection and the maintenance of people's quality of life. Unlike fossil fuels, clean energy sources emit little or no greenhouse gases, thus helping to curb global warming. Clean energy is also a key factor in ensuring the planet's sustainable development. In this regard, electricity generated from renewable sources has been gaining increasing attention (Cabral-Neto et al., 2021). Similarly, biofuels have emerged as a prominent alternative to fossil fuels. Although they constitute a renewable energy source that is not entirely clean—given the emissions associated with their combustion—they still represent a viable sustainable transport solution. This is primarily due to the potential for carbon offsetting through the replanting of feedstock used in their production. Moreover, biofuels can be derived from a wide range of raw materials, many of which are highly adaptable to different climatic and soil conditions, thereby enabling production across diverse regions (Huang, 2024).

In the transportation segment, electric vehicles (EVs) have emerged as key actors in combating pollution. These vehicles are seen as viable alternatives for reducing GHG emissions, especially since they produce no emissions during operation. It is important to emphasize, however, that neither electric vehicles nor biofuel-powered vehicles are entirely free from environmental impact. A range of factors must be considered, from the production chains of these fuels to the efficiency levels of the vehicles themselves.

2. Electric Vehicles

Globally, China was responsible for half of all EV sales worldwide. Norway stood out as the largest EV consumer market, where 39% of newly sold cars are electric (BNEF, 2018). In this expansion scenario, experts predict that by 2040, 33% of the global fleet and 55% of new vehicles sold will be electric (BNEF, 2018). Public policy strategies aim to promote efficiency in the automotive market through regulation, encouraging manufacturers to produce, and consumers to adopt, more EVs (FGV, 2020).

According to data from the National Association of Motor Vehicle Manufacturers (ANFAVEA), the number of licensed cars by fuel type in Brazil shows the evolution of the national automobile market (Tables 1 and 2). It is important to note that until 2020, both fully electric and hybrid vehicles were classified as “electric” for licensing purposes. From 2021 onwards, classifications were separated into “electric” (100% electric propulsion) and “hybrid” (mixed propulsion – electric and combustion). Therefore, for comparative purposes and to preserve the time series basis, the study sums both categories under “Elect + Hyb”. It is interesting to observe that, even amid the economic crisis caused by the COVID-19 pandemic (2020–2021), the EV segment, along with diesel vehicles, was the only one to record positive growth, with 77.2% and 25.11%, respectively. From 2020 to 2024, with the exception of electric vehicles—which showed notable growth—other segments experienced some market share decline (ANFAVEA, 2025). These indicators reflect the impact of public policies aimed at promoting vehicle electrification.

Table 1

Licensed cars by fuel category, in Brazil

Fuel	**Licensed cars**				
	2020	**2021**	**2022**	**2023**	**2024**
Gasoline	58,930	53,587	48,804	60,569	102,388
Electric	*19,745*	*2,860*	*8,440*	*19,277*	*61,325*
Hybrid	-	*32,130*	*40,822*	*42,440*	*56,193*
Elect+Hyb	19,745	34,990	49,262	61,717	117,518
Flex Fuel	1,664,999	1,624,348	1,633,282	1,809,864	1,967,353
Diesel	211,154	264,185	229,114	215,889	240,458

Source: Adapted from Anfavea (2025).

Table 2

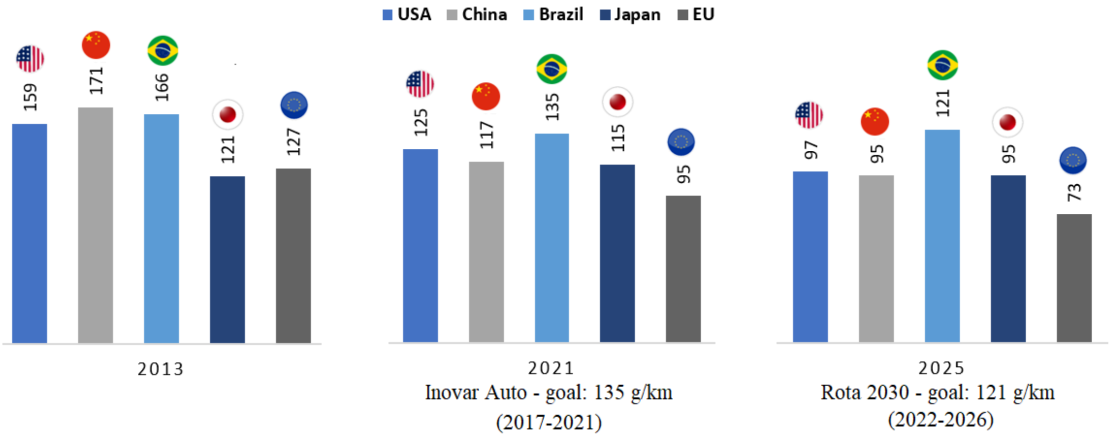
Growth of licensed cars by fuel category, in Brazil

Fuel	**Growth (%)**			
	2020/2021	**2021/2022**	**2022/2023**	**2023/2024**
Gasoline	-9.07	-8.92	19.39	40.84
Electric	*-85.51*	*195.01*	*128.40*	*218.12*
Hybrid	-	*27.05*	*3.96*	*32.40*
Elect + Hyb	77.20	40.78	25.28	90.41
Flex-Fuel	-2.44	0.5	10.81	8.70
Diesel	25.11	-13.28	-5.77	11.38

Most electric vehicle models available in Brazil are imported and benefit from import tax exemptions. However, to reverse this scenario and stimulate national production, the government has implemented policies with emission reduction targets in CO_2/km, as practiced in other countries. Two key public initiatives in this context are the Inovar-Auto Program and the Mobility Program – Rota 2030 (Figure 1).

Figure 1

Global targets (United States, China, Brazil, Japan, and European Union) for vehicle emissions, in grams of CO_2 per kilometer driven, for the years 2013, 2021, and 2025



Source: Adapted from Neto (2023).

The most recent incentive program in Brazil, Rota 2030, established by Law No. 13.755 (Brazil, 2018), replaced the previous Inovar-Auto Program (Brazil, 2012) and aimed to tighten greenhouse gas (GHG) emission targets.

Under this policy, the excise tax (IPI) on electric vehicles, initially set at 25%, was reduced to between 7% and 18%, depending on the vehicle's energy efficiency. The higher the energy efficiency, the lower the IPI rate applied to the EV. Manufacturers of conventional internal combustion engine vehicles that meet efficiency targets without transitioning to electrification are eligible for only a one percentage point discount on the 25% IPI (Brazil, 2018). In addition, under the Rota 2030 program, aside from the estimated annual tax relief of BRL 1.5 billion granted by the federal government, automotive companies that participate and invest in innovation may generate tax credits equivalent to up to 30% of the vehicle value. These credits can be applied against income tax (IR) or social contribution on net profit (CSLL). If investments are made in strategic areas defined by the government—such as the development of EV batteries—this tax benefit can increase to 40%. Failure to meet the program's established targets may result in fines of up to 20% of the sales value, applicable to both manufacturers and importers (Brazil, 2018).

Among national policies, which include the major initiatives, there are also several regional and local programs promoted by state and municipal governments to foster the EV market. For example, in the city of São Paulo, electric vehicles are exempt from the vehicle rotation restriction policy. In Campinas, plans are underway to create a "White Zone," free of internal combustion engine (ICE) vehicles, in the city center (FGV, 2020).

However, whether these are national or local initiatives, when drawing on international experience to design domestic policies, it is critical not only to support the production and commercialization of EVs, but also to address the infrastructure necessary to sustain such a market (Harrison & Thiel, 2017). According to Lesser (2024), despite the relatively simplified mechanical structure of fully electric vehicles, their deployment demands significant investments in infrastructure. This includes energy generation systems, refueling stations, and a prepared charging network. Since most EVs are recharged via the electric grid, they require long charging times—typically between 6 and 12 hours—and a more robust distribution system than conventional setups. Vidhi & Shrivastava (2018) argue that the lack of governmental support for infrastructure development has resulted in slow EV deployment, especially in emerging markets. In Brazil, this limitation remains a major bottleneck to the sector's expansion.

Rosato et al. (2017) point out that the widespread adoption of EVs would create radically different electricity demand patterns in households, potentially threatening the stability of the power grid. In response to this challenge, the European Union has prioritized microgeneration and distributed generation as some of the most effective strategies for saving primary energy, reducing emissions, and mitigating the impact of EVs on electrical systems. Moriarty & Wang (2017) and Van Mierlo et al. (2017) further emphasize that EVs can still be polluting if powered by electricity generated from non-renewable sources, such as coal, natural gas, or oil. In Brazil, both microgeneration and distributed generation remain at an incipient stage, which limits the environmental advantages of EVs in some scenarios.

These combined deficits explain why, despite the growing adoption of electric vehicles in recent years, their absolute share of the Brazilian vehicle fleet remains low. According to ANFAVEA (2025), EVs accounted for only 1.0%, 1.8%, 2.5%, 2.8%, and 4.8% of all vehicles licensed from 2020 to 2024, respectively.

3. Biofuels

In the current context of growing concern over climate change and the urgent need to reduce greenhouse gas emissions, biofuels constitute a category of fuels derived from organic sources—such as plants, vegetable oils, and agricultural residues—that play a significant role in the pursuit of more sustainable alternatives to conventional fossil fuels (Neto et al., 2023).

The wide variety of raw materials makes biofuels a versatile and adaptable option. According to Mercado et al. (2023), biofuels represent a promising alternative to reduce petroleum dependency and mitigate the environmental impacts caused by fossil fuel combustion, which results in the massive release of pollutants such as CO_2, CH_4, and nitrogen oxides.

Brazil stands out as one of the global leaders in the production and consumption of biofuels, with a rich and successful history in the sector. In recent years, biofuels have become a fundamental component of the Brazilian energy matrix. The country’s tropical climate, vast expanses of arable land, and longstanding agricultural expertise provide favorable conditions for large-scale biofuel production. The main crops used for this purpose in Brazil include sugarcane, soybeans, corn, and oil palm.

Sugarcane is the most prominent crop for biofuel production in Brazil, with ethanol being its primary product (Antunes et al., 2019). Leite & Leal (2007) emphasize that although the use of ethanol as a fuel in Brazil dates back to the 1920s, it was with the launch of the Proálcool program in November 1975 that ethanol’s long-term strategic role became clearly defined. This enabled significant private sector investment in expanding ethanol production.

In the 1970s, the Brazilian government, motivated by the negative impact of rising oil import costs on the country's trade balance—at a time when Brazil imported over 80% of the oil it consumed—launched Proálcool as a strategy to reduce the nation’s dependence on oil (Leite & Leal, 2007). Proálcool became a milestone in the promotion of biofuels, incentivizing the production and use of ethanol, particularly for vehicular fuel. Since then, Brazil has become one of the largest producers and exporters of ethanol worldwide.

Currently, Brazil continues to be a global leader in biofuel production and use. Today’s global biofuel production is still largely based on first-generation technologies, which involve the manufacture of ethanol from sugars or starches—such as sugarcane, beet, corn, wheat, and cassava—and biodiesel from vegetable oils or animal fats, such as soybean, castor, palm oil, tallow, and used cooking oil. Sugarcane ethanol remains a popular alternative to fossil fuels, especially in flex-fuel vehicles that can operate on ethanol, gasoline, or a mixture of both (Neto et al., 2023).

The growing global demand for cleaner and renewable energy sources continues to drive the expansion of the biofuel market. This is due to the essential role that biofuels play in offering sustainable solutions to increasing environmental and energy challenges worldwide. According to Leite & Leal (2007), biofuels must fulfill at least a dual responsibility: to help reduce greenhouse gas emissions and to partially substitute petroleum, thereby extending its lifespan.

In this context, energy balance and greenhouse gas emissions are key parameters for evaluating biofuel sustainability, along with the challenge of natural resource availability (Pérez-Almada et al., 2023). These authors point out that sugarcane ethanol performs well on these metrics, offering high energy yield and low carbon footprint across its production chain, especially when compared to other biofuels such as corn or wheat ethanol and palm oil biodiesel.

One of the main advantages of biofuels is their carbon compensation capability. During the growth phase of plants used to produce biofuels, these plants absorb carbon dioxide (CO_2) from the atmosphere. When the biofuels are burned in vehicle engines or power plants, the amount of CO_2 released is approximately equal to what was absorbed during plant growth. This creates a closed carbon cycle, reducing net CO_2 emissions and helping to mitigate climate change. Additionally, biofuel use contributes to the reduction of solid waste and the environmental impacts associated with its disposal. These characteristics can support the development of Clean Development Mechanism (CDM) projects, which aim to reduce greenhouse gas emissions and promote sustainable development (Schirmer et al., 2015).

Biodiesel is another type of biofuel with the advantage of having a shorter carbon cycle compared to its fossil counterpart, conventional diesel. Thus, the CO_2 fixation time resulting from biodiesel combustion is shorter than that of fossil diesel. Biodiesel production primarily relies on raw materials such as soybean oil, cottonseed oil, beef tallow, palm oil, and sunflower oil. In addition to these, several other oilseeds—including babassu, canola, sesame, macaúba, jatropha, and crambe—have demonstrated significant potential for biodiesel production (Silva et al., 2017).

In today’s market, biofuels offer several advantages. First, they can be produced locally, reducing dependency on oil imports. Furthermore, biofuel production often stimulates rural economies by creating jobs and fostering sustainable development, including opportunities for small-scale production for self-consumption by rural producers (Silveira et al., 2017). Moreover, biofuels such as ethanol and biodiesel can be used in existing engines with minimal modifications, making the transition to cleaner energy sources more accessible and practical.

However, several other variables must be taken into account. Large-scale biofuel production can compete with food production for land and resources, raising concerns about food security and potential increases in food prices. Additionally, the energy efficiency of biofuel production varies significantly depending on the feedstock and production methods used, which can impact the economic viability of biofuels (MME, 2017). Furthermore, certain types of biofuels—such as palm oil biodiesel—are associated with environmental issues like deforestation and habitat loss. Biofuel production requires extensive land use for feedstock cultivation and, therefore, demands the implementation of sustainable agricultural and processing technologies to minimize environmental and social impacts (Bauer et al., 2019). In this regard, it is important to note the lack of robust regulations in Brazil to ensure best practices throughout the biofuel production and utilization chain. After the initial momentum brought by Proálcool, the development of new incentive policies in this sector has remained limited.

Therefore, the efficiency and sustainability of biofuels depend on a wide range of factors, including the technologies used, agricultural practices, and production processes. As such, it is essential to address the implications of biofuel use through sound regulation and sustainable practices. As society continues to search for solutions to pressing energy and climate challenges, biofuels must be considered as a component of a broader strategy for transitioning to a greener and more sustainable economy.

Despite the aforementioned advantages and disadvantages, investment in this energy segment is viewed as necessary to contribute to the diversification of the energy matrix. In addition to the environmental benefits, fossil resources are finite and, as they become scarcer, may lead to significant economic disruptions.

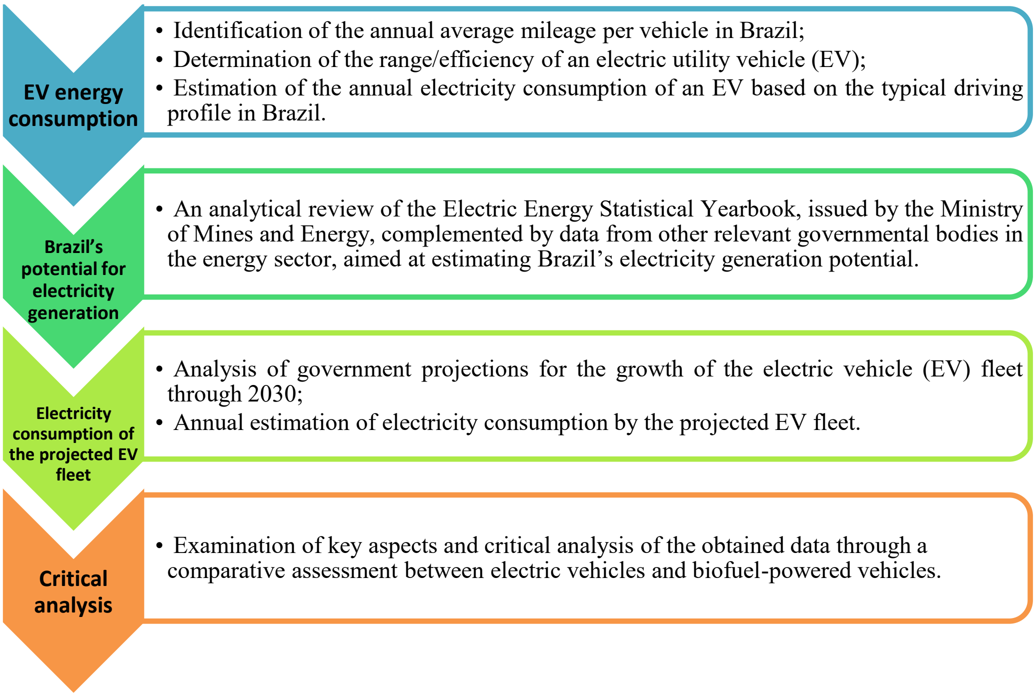
4. Methodology

Based on the electricity consumption data of an electric vehicle (EV) model and the average distance traveled annually by Brazilian drivers, the total electricity consumption of a projected EV fleet was estimated. Subsequently, a comparative analysis was conducted between Brazil's current electricity generation capacity and the new projected consumption. Lastly, a comparative emission analysis was performed, assuming that the projected EV fleet would be powered by biofuels.

The flowchart in Figure 2 outlines the methodological steps applied in the study.

Figure 2

Methodological flowchart



- Identification of the annual average mileage per vehicle in Brazil;
- Determination of the range/efficiency of an electric utility vehicle (EV);
- Estimation of the annual electricity consumption of an EV based on the typical driving profile in Brazil.

- An analytical review of the Electric Energy Statistical Yearbook, issued by the Ministry of Mines and Energy, complemented by data from other relevant governmental bodies in the energy sector, aimed at estimating Brazil's electricity generation potential.

- Analysis of government projections for the growth of the electric vehicle (EV) fleet through 2030;
- Annual estimation of electricity consumption by the projected EV fleet.

- Examination of key aspects and critical analysis of the obtained data through a comparative assessment between electric vehicles and biofuel-powered vehicles.

4.1. Estimated Electricity Consumption of an EV in Brazil

Considering the average vehicle mileage (in kilometers) per state in Brazil, the national driving profile was calculated based on the average of the state-level results.

Based on a sensitivity analysis, and observing the fact that the electrified vehicle market in Brazil is predominantly composed of light passenger vehicles (more than 99% of the fleet, according to ABVE, 2025), to simplify the calculations and minimize uncertainty—particularly due to the lack of reliable data on the extent to which larger vehicles will transition to electrification—this study assumed that the entire future electric vehicle (EV) fleet would be composed exclusively of passenger cars. To determine the average electricity consumption of an EV, efficiency data published by the National Institute of Metrology, Quality and Technology (INMETRO) were analyzed for the most sold EV model in Brazil.

To estimate the annual electricity consumption of an EV under Brazilian usage conditions, vehicle efficiency data were combined with the average annual mileage of a utility vehicle in Brazil.

4.2. Electricity Generation Potential in Brazil

Based on the Statistical Yearbook of Electric Energy, published by the Energy Research Company (EPE), and on data from the National Electric Energy Agency (ANEEL)—both agencies under the Ministry of Mines and Energy (MME)—the various electricity generation sources in Brazil were identified and classified as either renewable or non-renewable. Additionally, the study identified both the installed and effective power generation capacities, highlighting the share of imported electricity used to meet domestic demand.

4.3. Electricity Consumption of the Projected EV Fleet

Based on market growth projections for electric vehicles in Brazil through 2030—driven by governmental incentive policies—and on the previous calculation of electricity consumption by a single utility EV, the overall consumption estimate was recalculated for a projected national fleet rather than a single vehicle.

The results were presented cumulatively for each year from 2025 to 2030. The additional electricity demand resulting from EVs was compared with Brazil’s current effective electricity generation capacity.

4.4. Critical Analysis

Taking into account the emission levels of Brazil’s vehicle fleet by fuel type (gasoline, electricity, and ethanol), and the average mileage of a passenger car in the country, the avoided CO_2 emissions resulting from the projected EV fleet by 2030 were calculated. Based on the carbon credit market price, the amount of non-emitted CO_2 (in metric tons) was monetized. For comparative purposes and critical evaluation, the same economic value was estimated for an equivalent fleet of flex-fuel vehicles, considering that such vehicles can run on ethanol—the most widely used biofuel in the Brazilian market (Hoeckel & Alvim, 2023).

Based on the results obtained, a critical analysis was conducted regarding the infrastructure required to support the growth of the EV market in Brazil, as well as the technical and economic viability of electric vehicles compared to other technologies, as a solution for mitigating greenhouse gas (GHG) emissions.

5. Results and discussions

In general, the data collected enabled the characterization of current EV electricity consumption and the projected size of the future fleet. Based on these findings, a diagnostic overview was developed, considering the expansion of electric vehicles within the Brazilian scenario.

5.1. Electricity Consumption of an EV

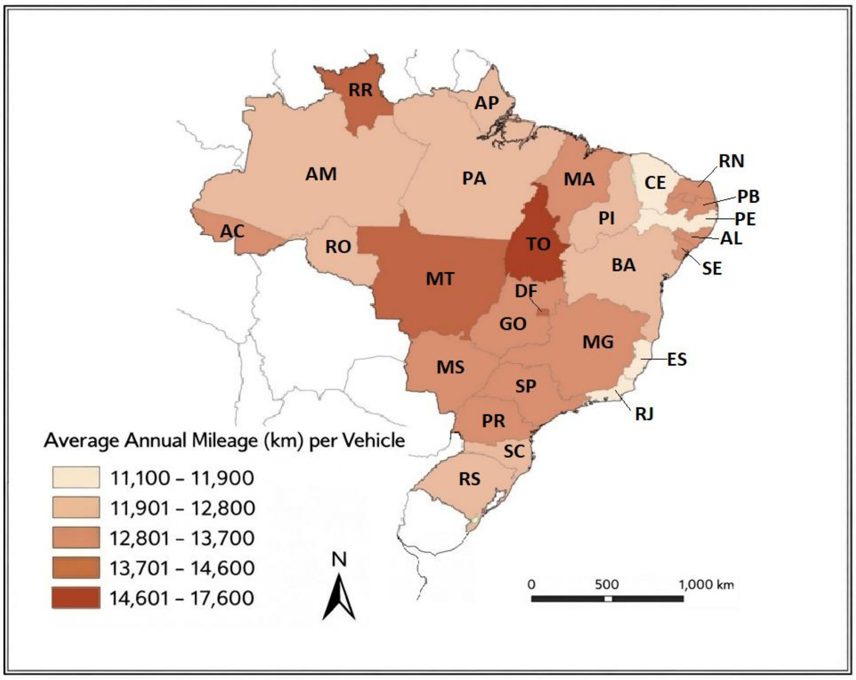
According to a study conducted by Kelley Blue Book, based on the analysis of big data from over one million vehicles across Brazil, the average annual vehicle mileage by state was reported (KBB BRAZIL, 2019), as shown in Box 1, and with territorial distribution represented by the map in Figure 3.

Box 1
Average Annual Mileage (km) per Vehicle by State in Brazil (2019)

State	Avg. mileage (km)	State	Avg. mileage (km)	State	Avg. mileage (km)
TO	17,600	**PR**	13,100	**AP**	12,500
DF	14,600	**SE**	13,100	**BA**	12,500
MT	14,600	**MA**	13,000	**RO**	12,500
RR	14,300	**SP**	13,000	**RS**	12,200
GO	13,700	**AL**	12,900	**PA**	12,100
MS	13,700	**MG**	12,900	**CE**	11,900
RN	13,400	**AM**	12,800	**ES**	11,700
AC	13,300	**SC**	12,800	**RJ**	11,600
PB	13,100	**PI**	12,600	**PE**	11,100

Source: Adapted from KBB BRAZIL (2019).

Figure 3
Average Annual Mileage (km) per Vehicle by State in Brazil (2019)



Source: Adapted from KBB BRAZIL (2019).

The national average annual mileage per vehicle was calculated as the mean of the values across all states, resulting in approximately 12,900 km/year.

To determine electricity consumption for an EV, the Volvo XC40 model was selected as it is, according to the Brazilian Electric Vehicle Association (ABVE), the most sold fully electric utility vehicle in the country. In addition to leading sales in 2022, the ABVE (2023) reports that out of 3.77 thousand EVs registered in the first half of 2023, 903 units were the Volvo XC40—accounting for nearly 24% of total EV sales.

According to the vehicle's technical specifications published by INMETRO (2023), the Volvo XC40 has a battery capacity of 67 kWh and an estimated range of approximately 348 km.

Thus, the following parameters were defined:

- CE_{AM}: Electricity consumption for maximum vehicle range, in kWh ($CE_{AM} = 67$)
- AM: Maximum vehicle range, in km ($AM = 348$)
- KA_{BRA}: Average annual mileage driven by a Brazilian driver, in km ($KA_{BRA} = 12{,}900$)
- CEA_{BRA}: Estimated annual electricity consumption for an EV in Brazil, in kWh ($CEA_{BRA} = ?$)

Using a simple proportionality (rule of three), the annual electricity consumption of an EV under Brazilian driving conditions was estimated (Equation 1):

$$CEA_{BRA} \times AM = CE_{AM} \times KA_{BRA} \quad \text{(Equation 1)}$$

$$CEA_{BRA} \times 348 = 67 \times 12{,}900$$

$$CEA_{BRA} = 2{,}483.6 \text{ kWh} \rightarrow CEA_{BRA} \approx 2.5 \text{ MWh}$$

Based on the assumptions above, it was estimated that the average annual electricity consumption for a utility-type EV model is approximately 2.5 MWh.

5.2. Electricity Generation Potential in Brazil

The electricity matrix is the set of power generation sources in a country responsible for meeting the electricity demand. The sum of the generation capacity of these various sources corresponds to the electricity generation potential.

According to the Energy Research Company – EPE (2022), Brazil's current matrix is predominantly renewable, with a significant portion of electricity generated from hydroelectric plants (61.9%). The remaining sources are wind (11.8%), biomass (7.2%), natural gas (6.1%), solar (4.4%), nuclear (2.1%), coal (1.2%), diesel oil (0.9%), other non-renewables (1.8%), other renewables (0.8%), and imports (1.9%).

Despite having over 178 GW of installed capacity—which would correspond to a generation of 1,537 TWh—Brazil is not self-sufficient in electricity production, still importing 1.9% of its demand from countries such as Paraguay, Argentina, Venezuela, and Uruguay. It is also important to note that not all installed capacity is converted into actual electricity generation due to the intermittency of some renewable sources subject to climate variation, and the varying efficiency of each technology. According to the 2022 Statistical Yearbook of Electric Energy published by EPE, only 677 TWh of the total installed capacity was effectively converted into electricity (EPE, 2022).

When comparing Brazil's electricity matrix to China’s—where electric vehicles (EVs) have been widely adopted—we find that in 2021, Brazil had a predominantly renewable matrix (83%) (EPE, 2022), while China’s was mostly fossil-based (80.2%) in the same year (Cabral-Neto et al., 2022). China is one of the world’s largest greenhouse gas (GHG) emitters and was responsible for approximately 25% of global emissions in 2018 (Zheng et al., 2019). According to Li et al. (2016), the implementation of EVs in China essentially shifts gasoline consumption to coal-based electricity generation, leading to higher coal use and, consequently, increased CO_2 emissions. Thus, Li et al. (2016) concluded that China's strategy is not to reduce GHG emissions but to relocate pollution from major urban centers to more remote areas where power plants are located.

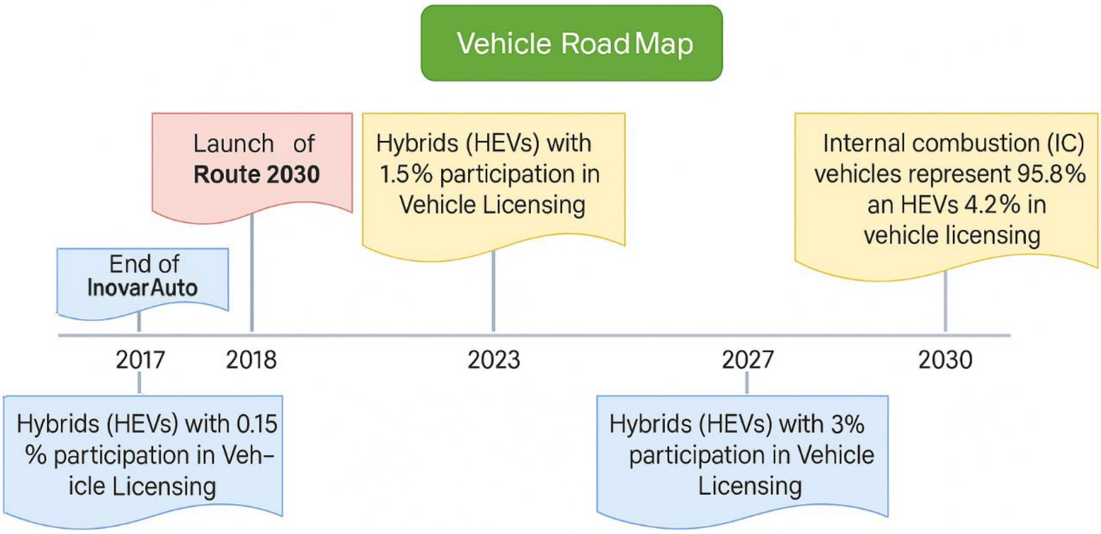
Therefore, although Brazil has a largely clean electricity matrix, any increase in demand due to EVs must be supported by an expansion of renewable generation capacity; otherwise, there may simply be a geographic shift in pollution, as observed in China.

5.3. Projected Electricity Consumption of the EV Fleet

Although electric vehicles (EVs) currently represent less than 5% of the national fleet, their adoption rate in Brazil has been increasing year by year. One of the main drivers of this growth has been the involvement of Brazilian government agencies. Based on increasingly assertive incentives targeting the electric transportation sector, both public and private institutions have developed projections for the EV fleet in Brazil by 2030. In one of the more optimistic projections, it is estimated that EVs will account for 5% of the national vehicle fleet by 2030, totaling approximately 2 million electric vehicles, with an annual licensing target of 180,000 new EVs (BCG, 2019). On the other hand, a more conservative forecast by the Brazilian Energy Research Office (EPE, 2019) estimates a fleet of approximately 1 million EVs by 2030.

Considering factors such as the economic downturn during the COVID-19 pandemic—particularly in the automotive sector (Nóbrega et al., 2021)—this study adopts EPE’s projection of 1 million EVs by 2030, as it is deemed more realistic given current economic conditions.

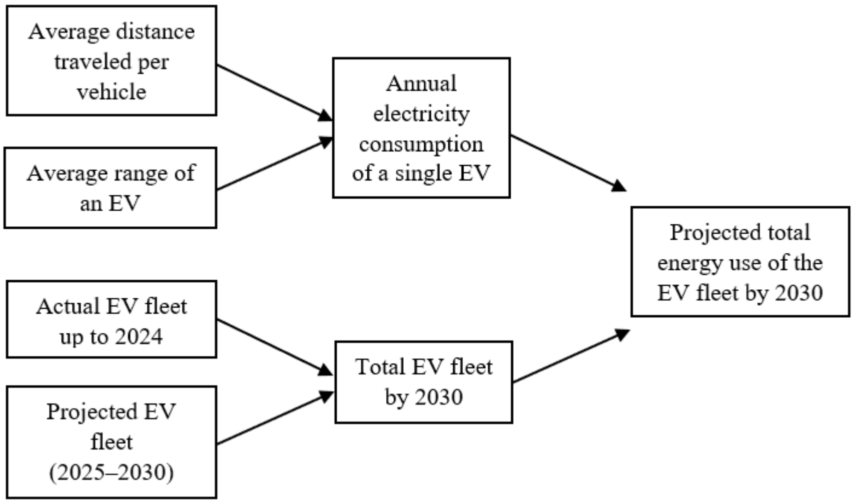
Figure 4
Vehicle roadmap in Brazil



Source: Adapted from EPE (2018).

Based on the projection shown in Figure 4 and the electricity consumption model —which assumes an annual consumption of 2.5 MWh for a utility-type EV—it was possible to estimate the increase in electricity demand resulting from the projected EV fleet by 2030 (Figure 5 and Table 3).

Figure 5
Flowchart of the projected electricity consumption model for Brazil's electric vehicle fleet through 2030



As of 2024, 304,293 EVs had been registered in Brazil. To reach the projected target of 1 million EVs by 2030, an average of 115,951 new electric vehicles would need to be added to the fleet each year.

Table 3

Projected electricity consumption of the electric vehicle fleet in Brazil through 2030

Year	Cumulative fleet (units)	Incremental consumption (MWh)
Until 2024	304,293	760,733
2025	420,244	1,050,610
2026	536,195	1,340,488
2027	652,147	1,630,366
2028	768,098	1,920,244
2029	884,049	2,210,122
2030	1,000,000	2,500,000

Thus, the projected increase in electricity demand required to support the introduction of EVs into the Brazilian transportation sector by 2030 is estimated at 2.5 TWh.

By way of estimate, considering an expansion of generation from photovoltaic energy sources, with an annual solar incidence of 8,760 hours (Brazilian average – Silva et al. (2020)), a capacity factor (average efficiency of use of installed power over time) of approximately 22% (reference value for Brazilian power plants by the National Electric System Operator – ONS (2021)), for an annual production of 2.5 TWh, it is estimated that an installed capacity of 1.3 GW is required, as shown in the calculations below (Equation 2):

$$\text{Installed Capacity (GW)} = \frac{\text{Annual Generation (TWh)}}{\text{Annual Solar Incidence (h) X Capacity Factor (\%)}} \qquad \text{(Equation 2)}$$

$$\text{Installed Capacity (GW)} = \frac{2.5}{8{,}760\ \text{X}\ 0.22} \approx 1.3\ \text{GW}$$

Considering exclusively the investment required for the deployment of energy generation capacity sufficient to supply an annual output of 2.5 TWh, and adopting the average cost range for the installation of large-scale solar photovoltaic plants in Brazil—estimated between 4 and 5 million Brazilian reais per MWp installed (CONFEA, 2024)—the total capital expenditure for a solar facility of this magnitude is projected to fall between approximately 5.19 and 6.48 billion Brazilian reais.

6. Critical Analysis

To carry out a comparative analysis between electrification and biofuel-based mobility solutions, one of the metrics adopted is the generation of carbon credits. Carbon credits assign economic value to emissions reductions achieved through sustainable practices, while also contributing to economic growth, job creation, and income generation (OECD, 2011; Sheppard et al., 2011).

In the context of mobility solutions, carbon credit generation is linked to the displacement of fossil fuels and the reduction of associated emissions. These credits can be traded, enabling industries and countries to meet their emission reduction targets more flexibly and efficiently.

To quantify the emission reductions, it is first necessary to calculate the amount of CO_2 that would be emitted if the projected fleet were powered by gasoline. For this purpose, the vehicle fleet from Table 3 was used. Additionally, the average annual distance traveled by a vehicle in Brazil (12,900 km) was considered, along with efficiency data provided in a study conducted by Stellantis (2023), which evaluated emissions from a well-to-wheel perspective—considering the entire energy lifecycle. This is crucial, as even electric vehicles (EVs) are associated with indirect emissions due to the fact that Brazil's electricity matrix is not entirely renewable.

The Stellantis (2023) study tested a vehicle powered by different energy sources, comparing total CO_2 emissions under identical driving conditions. The vehicle was fueled with hydrated ethanol, gasoline, and electricity (supplied by the Brazilian energy grid). During a simulated trip of 240.49 km, the following emissions were recorded: gasoline – 252.15 gCO_2eq/km; ethanol – 107.24 gCO_2eq/km; battery-powered EV – 89.19 gCO_2eq/km.

Based on these values, total emissions from the gasoline-powered control fleet (Table 3) were calculated, as shown in Table 4.

Table 4

Emissions from the projected gasoline-powered vehicle fleet in Brazil by 2030

Year	Cumulative fleet (units)	CO_2 emissions (t CO_2)
Until 2024	304,293	989,784
2025	420,244	1,366,943
2026	536,195	1,744,101
2027	652,147	2,121,260
2028	768,098	2,498,418
2029	884,049	2,875,577
2030	1,000,000	3,252,735
Total		**14,848,818**

Given that carbon credits are treated as an environmental commodity subject to market volatility, the potential competitive advantage of EVs can be evidenced by quantifying and monetizing the emissions reductions achieved. For this purpose, a carbon credit value of €86.09 per ton was used, based on the closing value from the stock exchange on October 13, 2024 (INVESTING, 2024). The projection also took into account the estimated EV fleet by 2030, the indirect emissions of EVs, and the average annual distance of 12,900 km per vehicle. The results are presented in Table 5.

Table 5

Environmental and financial benefits from EV adoption in Brazil by 2030

Year	Cumulative fleet (units)	Carbon credits (t CO_2)	Economic gain (EUR bn)
Until 2024	304,293	639,680	55,070
2025	420,244	883,431	76,055
2026	536,195	1,127,181	97,039
2027	652,147	1,370,932	118,024
2028	768,098	1,614,683	139,008
2029	884,049	1,858,433	159,993
2030	1,000,000	2,102,184	180,977
Total		**10,352,225**	**891,223**

For comparison, and using the same assumptions, carbon credit gains were also calculated for a hypothetical ethanol-powered fleet, as shown in Table 6.

Table 6
Environmental and financial benefits from ethanol-powered vehicles in Brazil by 2030

Year	Cumulative fleet (units)	Carbon credits (t CO_2)	Economic gain (EUR bn)
Until 2024	304,293	568,827	48,970
2025	420,244	785,579	67,630
2026	536,195	1,002,331	86,291
2027	652,147	1,219,083	104,951
2028	768,098	1,435,835	123,611
2029	884,049	1,652,587	142,271
2030	1,000,000	1,869,339	160,931
Total		**8,533,580**	**734,656**

From this analysis, it is evident that, in the Brazilian context, EVs reduce the carbon footprint by 64.63%, while ethanol-powered vehicles achieve a 57.47% reduction compared to gasoline-powered vehicles. When comparing EVs to ethanol-powered vehicles, EVs offer a further 16.83% reduction in emissions. These results highlight the competitive advantage of Brazil’s predominantly renewable energy matrix (>83%), which enhances the ecological performance of EVs. Nevertheless, they also demonstrate the environmental relevance of biofuels, which approach EVs in emissions efficiency and remain a strong, competitive alternative.

In contexts such as China, where the energy matrix remains largely fossil-based (Cabral-Neto et al., 2022), outcomes would differ significantly. In such cases, large-scale EV adoption often results in "emission displacement," improving air quality in urban centers while increasing pollution in rural areas where power plants are located.

Another important aspect is the potential of carbon credits to act as a driver of green mobility. The economic gains presented in Tables 5 and 6, for both EVs and ethanol-powered vehicles, could be reinvested to consolidate these technologies, such as through the development of charging infrastructure—currently a significant gap for EVs.

However, the relationship between energy consumption, efficiency, and carbon credits presents several challenges, including ensuring project sustainability, assessing cost-effectiveness, establishing certification standards, regulating credit markets, and promoting responsible energy use across environmental, social, and economic dimensions (Tang et al., 2023).

In this regard, several issues must be considered when implementing carbon credit schemes. Clear and rigorous criteria must be established to certify projects—whether related to EVs or biofuels. Moreover, it is essential to ensure that the fuel used in these vehicles leads to actual reductions in greenhouse gas emissions, avoiding the so-called "emission displacement." It is also important to evaluate indirect impacts, such as land-use changes or biodiversity loss, to ensure the overall sustainability of the projects.

Accordingly, Box 2 outlines the main advantages and disadvantages associated with the carbon credit market.

Box 2

Advantages and Disadvantages of the Carbon Credit Market

Advantages	Disadvantages
Encourages reduction of greenhouse gas emissions	Risk of "emission displacement"—reductions in one region offset by increases elsewhere
Promotes adoption of cleaner, more sustainable technologies	Difficulties in accurately pricing carbon, leading to market distortions
Supports conservation and preservation of natural resources	Potential for fraud and lack of transparency in credit issuance and trading
Stimulates R&D in low-carbon solutions	Dependence on government regulations for efficient market operation
Facilitates transition to a low-carbon economy	Uneven socio-economic impacts, potentially harming vulnerable communities

Finally, while EVs exhibit a lower carbon footprint than biofuel-powered vehicles, several other factors must be considered—such as infrastructure.

Although EVs feature relatively simple mechanical structures, the same does not apply to the external infrastructure required to support them. As previously mentioned, for EVs to deliver real emissions reductions, they must be powered by renewable electricity. This makes it essential that the increased energy demand projected in Table 3 be matched by public policies that expand renewable generation. Furthermore, investment in charging stations and a robust charging network is vital, especially given Brazil’s continental size.

Conversely, biofuels can be used in existing internal combustion engines with minimal modifications, leveraging the already established refueling network. This makes the transition from fossil fuels to biofuels more practical and accessible.

On a global scale, both solutions present advantages and limitations, and both should be considered viable pathways toward more sustainable mobility. Ideally, investments should be made in both technologies to promote energy diversification. Hybrid solutions, such as vehicles that combine electrification and biofuel use, may also play a significant role in this transition.

7. Assumptions and sensitivity analysis

It is important to emphasize that the scenarios evaluated in this study consider specific characteristics of the Brazilian context, including: a predominantly renewable energy matrix (>83%) (EPE, 2022); a consolidated biofuel production culture, particularly regarding sugarcane-derived ethanol—a technology established since the 1920s (Leite & Leal, 2007); an EV fleet that represents more than 99% of the light passenger vehicle segment (ABVE, 2025); and, due to favorable climatic conditions, a substantial potential for further expansion of renewable energy generation, especially solar photovoltaic.

Despite these particularities, the structure of the proposed model remains broadly applicable and may serve as a reference for other contexts, provided appropriate adaptations are made.

In the current global landscape—where the expansion of electric vehicles featured prominently at the 30th United Nations Climate Change Conference (COP 30), held in 2025 in Belém do Pará, Brazil—this discussion aligns with broader debates on energy transition and sustainable mobility, aimed at the decarbonization of the economy and the mitigation of greenhouse gas emissions.

8. Final considerations

The present study found that both electric vehicles (EVs) and biofuel-powered vehicles play an increasingly promising role in the pursuit of more sustainable mobility solutions. In the context of growing concern over climate change and the urgent need to mitigate greenhouse gas (GHG) emissions, the diversification of energy sources emerges as a viable pathway, given that both alternatives exhibit advantages and limitations. Nevertheless, energy diversification contributes to reducing dependence on petroleum derivatives within the energy matrix, resulting in a more resilient and sustainable energy system.

In this regard, regardless of the energy source under consideration—whether electric or biofuel-based—it is essential to ensure that the production and use of energy are conducted sustainably, taking into account the associated environmental impacts and proper certification of the projects involved. Only under such conditions can these alternatives constitute effective solutions for climate change mitigation in the context of transitioning toward a low-carbon economy.

Another contribution of this study lies in the perspective that energy alternatives must not be analyzed in isolation, as if they lacked environmental, social, political, or economic repercussions. Instead, they must be approached as part of an interdependent chain influenced by a variety of driving factors, such as: the escalating global price of oil—currently the predominant energy source for transportation in Brazil—which renders EVs and biofuels increasingly attractive; the recognition of the socioeconomic benefits that the expansion of biofuel usage can bring to the national agricultural sector, fostering rural development and sustainable economic growth; and the awareness of the necessity to reduce carbon dioxide emissions, recognizing that such reductions generate not only environmental benefits but can also be monetized through carbon credit mechanisms. Additionally, the growing role of renewable energy generation is highlighted—not only for its environmental benefits, but also for enhancing energy security and enabling the integration of EVs into smart grid systems.

Therefore, a holistic approach is imperative—one that considers not only the environmental impacts of each strategy, but also the social and economic implications. From this perspective, it becomes clear that there is no universally ideal solution, but rather the most appropriate one for each specific context and reality.

Supplementary Information

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