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Comparative operational carbon footprints of a vehicle in Brazil: Electric, ethanol, and gasoline

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ABSTRACT

This study quantifies the operational carbon footprint of the Renault Kwid E-Tech (electric vehicle) and Renault Kwid Intense *flex* (gasoline and ethanol internal combustion engine vehicle) under a Well-to-Wheel approach within the Brazilian context. With a functional unit of 100,000 km, this analysis evaluates greenhouse gas (GHG) emissions associated with fuel consumption and considers different electric mixes across Brazilian regions, along with the periodic maintenance of each vehicle type. The results reveal significant environmental benefits in regions such as the Northeast, where renewable energy sources predominate, reducing the carbon footprint of the electric model, with a carbon footprint of 0.071 kg CO_2-eq/kWh. By contrast, the higher carbon intensity of the South's electricity mix reliant on coal, with a carbon footprint of 0.281 kg CO_2-eq/kWh, presents limitations in achieving emissions reductions with electric vehicles. Ethanol, a renewable biofuel in the Brazilian market, demonstrated a 46 % reduction in GHG emissions compared to gasoline. This study contributes to the sustainable mobility discourse, highlighting the critical role of regional energy sources, fuel choices, and sustainable production practices in emissions outcome. These insights support the development of policies encouraging cleaner energy matrices and biofuel use, contributing to Brazil's emissions reduction goals.

Introduction

Around 16 % of greenhouse gas (GHG) emissions are produced by the transport sector, which includes road transport, aviation, maritime transport, rail transport and pipeline transport (Ritchie, 2020). According to the Greenhouse Gas Emissions and Removals Estimating System (SEEG, 2023), emissions from Brazil's transportation sector accounted for 9.43 % of total Brazilian GHG emissions in 2022, totaling 2300 $MtCO_2$.

Road transportation constitutes a major anthropogenic source of worldwide carbon emissions due to its reliance on fossil fuels. Internal combustion engine vehicles using these fuels release pollutants such as particulate matter, carbon dioxide, nitrogen oxides and other harmful compounds, which are harmful to human health and the environment (Challa et al., 2022).

Vehicle electrification is the process of transitioning from internal combustion engines (ICEV) to electric propulsion systems (EVs). Charging networks, smart grids, energy storage systems, and smarter cities are among the supporting infrastructures and technologies included in this transition (İnci et al., 2024). Electrification represents a great leap toward the alignment of transport with energy transition targets by providing a more sustainable alternative to fossil fuel-powered vehicles (Elzinga et al., 2014). A more robust and flexible electrical infrastructure, on the other hand, is required, driving innovation in energy storage and distribution, the development of more efficient and sustainable technologies, and public policies for cleaner energy (Zhao et al., 2024).

In the Brazilian context, the electricity matrix stands out for its dependence on renewable energy sources. This characteristic is advantageous for Brazil due to the lower GHG emissions associated with renewables (Leiss, 2022). This approach has positive implications in both economic and environmental terms, contributing to reducing the emissions in the energy sector. Most of the Brazilian electricity system is interconnected by transmission networks, however 1 % of consumers are not connected to the national main grid (a section of the North region, encompassing around 250 cities) (Brazilian Energy Research Office, 2024).

Government incentives, technological advancements, and consumer

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interest in sustainable alternatives to ICEVs, as seen in Nordic countries (Sovacool et al., 2019), support the growing adoption of EVs. EVs offer an effective solution to curb air pollution in urban areas by reducing tailpipe emissions, which contribute to poor air quality and adverse public health outcomes (Dong et al., 2024).

Although EVs have the advantage of not emitting exhaust gases, the environmental impact of the life cycle of batteries is higher than that of ICEVs (Cox et al., 2018; Bautista, 2023), bringing the environmental burden forward from the use stage to the production stage.

Electrification of the transportation sector is critical to achieving global climate goals, as it helps reduce the reliance on fossil fuels and significantly cuts greenhouse gas emissions (Goedeking and Meckling, 2024). However, the environmental benefits of electric transport are directly associated with the source of electricity used for charging (Hawkins et al., 2013), which can vary significantly across regions. As the world moves toward low carbon energy sources, assessing the impact of different electricity mixes is essential for a full understanding of the potential environmental advantages of adopting electric transportation.

The energy source used to fuel or charge a vehicle plays a crucial role in determining the overall efficiency of the transportation system (Albatayneh et al., 2020). Systems powered by renewable energy sources, such as wind and solar, enhance overall efficiency throughout the energy chain. Feliciano et al. (2023) demonstrated the benefits of increased efficiency through electrification by comparing the efficiency of ICEVs and EVs. The potential of ethanol as a sustainable fuel alternative was highlighted, with significant environmental and efficiency benefits, justifying increased consideration in public policy frameworks and global incentive programs.

Moro and Lonza (2017) examined the GHG reduction potential across European countries by comparing EVs with conventional gasoline and diesel vehicles. Using the 2013 electricity mix as a reference, their findings showed that EVs achieved an average emissions reduction of approximately 50–60 % when compared to their internal combustion counterparts. Latvia exhibited the highest emissions intensity due to the carbon footprint associated with imported electricity.

The objective of this study is to quantify and present the carbon footprint of the operation of two vehicles in Brazil: an ICEV (operating separately on ethanol and then gasoline) and an EV, in different regions of Brazil (with different electric grid mixes). An attributional "Well-to-Wheel" Life Cycle Assessment is developed herein. The carbon footprints of the different scenarios are compared and differences between the use of fuel and parts replacement are evaluated.

Materials and methods

Two of Brazil's best-selling EV and ICEV with similar characteristics are evaluated. The ICEV is Renault Kwid 1.0 12 V SCE *flex* Intense manual and the EV is Renault Kwid E-Tech. Characteristics of both vehicles are available on Renault's catalog (Renault, 2024) and shown in Table 1.

The LCA was developed with the help of SimaPro software version 9.5.0.1 (PRe Consultants, 2024), using the Ecoinvent 3.6 database (Ecoinvent, 2021). Due to concerns about climate change, the IPCC 2021 GWP 100y environmental impact assessment method was selected, which aggregates GHG emissions into a common metric (CO_2-eq) over 100 years (Intergovernmental Panel On Climate Change, 2021).

Table 1
Basic technical data of vehicles.

Model	Kwid Intense *flex*[*]		*Kwid E-Tech*
	Ethanol	Gasoline	Electric
Gearbox	Manual	Manual	Automatic
Average range (km)	414	589	185
Average consumption	10.8 km/l	15.5 km/l	0.145 kWh/km
Tank (l)	38	38	–
Maximum power	71 cv	68 cv	65 cv

[*] The flex fuel vehicles in Brazil are designed to run on a blend of gasoline and ethanol, or even 100 % ethanol or gasoline, allowing consumers to choose their fuel based on price and availability.

In defining the system boundaries, this study focuses on the Well-to-Wheel approach (Fig. 1), including fuel or charge supply and the maintenance and use of the vehicle during its operational life. The functional unit of this study is defined as 100,000 km of vehicle operation, with scheduled maintenance performed at intervals of every 10,000 km. For the electric vehicle, an efficiency loss of 0.85 % was considered for every 20,000 km driven, based on vehicle batteries with similar specifications (Argue, 2024).

The maintenance associated with the replacement of components and fluids follows Renault's maintenance plan, which outlines the necessary maintenance items during the analysis period, including the replacement of all four tires. The maintenance schedule is presented in Table 2.

Electric vehicle – Brazilian electricity mix

Data on power generation in Brazil was obtained from the National System Operator (2024) and the electricity mixes by Brazilian electricity subsystem were considered: North, Northeast, South, Southeast and National, with the latter being the sum of all the Brazilian energy subsystems, represented in Fig. 2. The electricity generated by source in each subsystem is shown in Table 3. Please note that the electricity subsystems do not correspond to the geographic region division of Brazil.

For the electric vehicle, its operation required the consumption of 14,732.76 kWh for all regions.

The representation of the different electricity mixes required the adaptation of the Ecoinvent database (Ecoinvent, 2021), employing the percentage shares of different generation technologies within the different subsystems, following the methodology presented in Carvalho and Delgado (2017).

Internal combustion engine vehicle – use of ethanol and gasoline

For the ICEV, two operation modes are considered: 100 % ethanol and 100 % gasoline. Please note that all automotive gasoline sold in Brazil contains, by mandate, a blend of 27 % anhydrous ethanol, or E27.

Herein the lifetime is considered as 100,000 km, divided into 50 % highway driving and 50 % city driving. The associated consumptions are 15.3 and 15.7 km/l, respectively, for the gasoline vehicle during city and highway conditions. For ethanol, the associated consumptions are 10.8 and 11.0 km/l, respectively, during city and highway conditions.

The inventory for the use and maintenance phase is shown in Table 4, considering a functional unit of 100,000 km.

The well-to-heel approach does not account for the entire life cycle of the vehicle, and therefore excludes the production and end-of-life phases, such as manufacturing emissions and disposal or recycling processes. For the electric vehicle battery, a loss of efficiency of 0.85 % every 20,000 km was considered, based on data from batteries with the same technology (Argue, 2024). Constant fuel consumption was assumed for the ICEV. Another limitation lies in the availability and quality of the data. This research relies on national datasets that might not capture short-term fluctuations or micro-regional energy production specifics.

Results

Maintenance

The carbon footprints for the items consumed are shown in Table 5.

From Table 5, it is observed that tire replacement accounts for the

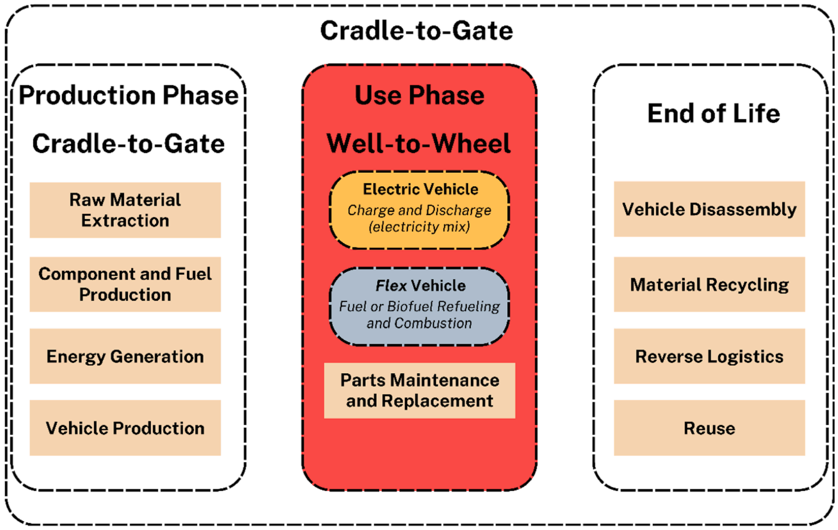

Fig. 1. Well to wheel approach for the LCA.

Table 2
List of vehicle maintenance items.

Component	Replacement frequency
Lubricant	10,000 km
Oil filter	10,000 km
Fuel filter	10,000 km
Interior filter	10,000 km
Air filter	10,000 km
Car ring	10,000 km
Spark plug	20,000 km
Car belt	50,000 km
Brake fluid	10,000 km
Coolant	30,000 km
12 V Battery	50,000 km
Tires	60,000 km

majority of emissions in this phase, followed by battery replacement. The production of tires requires a considerable amount of energy and results in high GHG emissions, especially during the manufacture of the rubber compounds and the vulcanization process (Katarzyna et al., 2020). Lead-acid batteries, present in both vehicles, due to their intensive manufacturing process and the use of materials such as lead, have a relatively high carbon footprint (Yudhistira, Khatiwada, and Sanchez 2022). Other components such as the piston ring, car belt and filters play a minor role due to their low contributions.

Operation

Table 6 presents the carbon footprint associated with each energy source of the Brazilian electricity mix.

When using the percentage shares of Table 3 and the emission factors of Table 6, the carbon footprint of the different electricity mixes is obtained, as shown in Table 7.

The carbon footprint associated with ethanol, compared to gasoline, is 65 % less for the same mass and 46 % lower for the same distance traveled: 0.411 kg CO_2-eq/kg of gasoline vs. 0.146 kg CO_2-eq/kg of ethanol. This substantial difference highlights ethanol's potential as low carbon alternative to gasoline, provided that its production processes are managed sustainably. The lower emissions of ethanol make it a key component in reducing the carbon footprint of transportation, especially when biofuel production adheres to environmental best practices. Table 8 shows the emissions associated with the operation of the vehicles in Brazil.

Regarding the electricity mixes, Northeast has the lowest carbon footprint for its regional electricity mix, at 0.071 kg CO_2-eq/kWh, due to its reliance on low carbon energy sources, such as wind, hydroelectric and solar power. In contrast, the South exhibits the highest carbon footprint at 0.281 kg CO_2-eq/kWh (294 % higher than the northeast region), reflecting a heavier dependence on fossil fuels, as coal, or less efficient energy production. The North and Southeast regions display moderate carbon footprints of 0.179 kg CO_2-eq/kWh and 0.114 kg CO_2-eq/kWh, respectively. Nationally, Brazil averages 0.140 kg CO_2-eq/kWh, highlighting the overall variability in the environmental impact of electricity generation.

When analyzing the emissions from different energy sources, a significant variation in the carbon footprint associated with each fuel was observed. In the case of the Brazilian average, although hydropower makes up 67.13 % of the electricity, it contributes to 47.05 % of the total carbon footprint. In contrast, even though only 1.18 % of energy comes from coal, this source is responsible for 22.69 % of the overall carbon footprint. Similarly, natural gas, which accounts for 3.00 % of energy generation, is responsible for 16.23 % of the GHG emissions associated with the vehicle. Fig. 3 compares the share of different energy sources with their contribution to the carbon footprint in each electric subsystem.

In the Northeast, 60.40 % of electricity comes from wind power, but this has an impact of 17.03 % on the carbon footprint. Hydropower, though responsible for 33.52 % of the carbon footprint, generates 24.32 % of the electricity, making it the primary contributor to emissions in this area. In the South, 78.72 % of electricity is generated by hydroelectric plants, accounting for 27.51 % of emissions. Conversely, coal, which supplies 7.11 % of the region's electricity, contributes disproportionately to emissions, accounting for 68.29 % of the carbon footprint.

Table 9 shows the overall carbon footprint associated with the operation of the vehicles in Brazil, considering different fuels (gasoline, ethanol) for the ICEV and different geographic energy subsystems in Brazil (North, Northeast, Southeast, South, and Brazilian average). Fig. 4 shows the comparison across scenarios.

The Kwid E-Tech in the northeast has the lowest emissions, followed by the ethanol Kwid Intense *flex*. In the worst-case scenario, the Kwid E-Tech in the south, impacted by the carbon footprint associated with the use of coal in its energy mix. The inventory proposed for the vehicle maintenance stage shows that the EV has a potential emissions reduction of 13.40 % compared to the ICEV. However, the environmental impact of vehicle maintenance over time has a lower impact than the fuel used to run the vehicle, corresponding to between 3.45 and 13.89 % of total emissions. For example, a Kwid *flex* fueled entirely with ethanol has

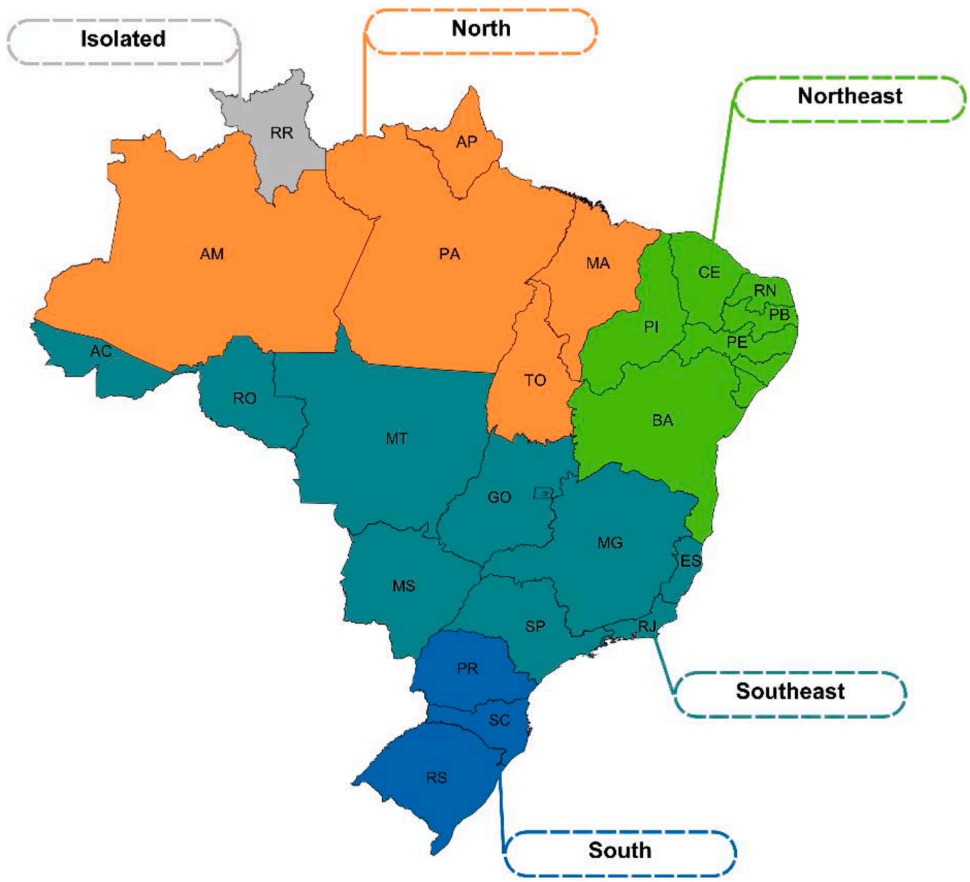

Fig. 2. Brazilian electric subsystems.

Table 3
Power generation in Brazil per energy source, in 2023.

Energy Source	Energy Produced (GWh)				
	Northeast	North	South	Southeast	Brazil
Gas	2247.97	10,616.56	7112.51	30.08	19,919.23
Hydraulic	35,308.73	71,571.19	256,013.71	82,698.28	445,185.63
Oil	591.25	29.6	117.07	47.13	787.81
Coal	172.53	41.85	44.79	7466.61	7809.12
Nuclear	0.00	0.00	14,777.77	0.00	14,718.90
Biomass	1134.08	151.07	22,107.11	1122.10	24,443.29
Wind	87,695.19	1861.80	62.1	5643.58	95,742.30
Solar	18,035.25	2261.93	26,177.95	8050.22	54,583.73
Total	**145,185.00**	**86,534.00**	**326,413.00**	**105,058.00**	**663,190.00**
Share of energy produced (%)					
Gas	1.55	12.27	2.18	0.03	3.00
Hydraulic	24.32	82.71	78.43	78.72	67.13
Oil	0.41	0.03	0.04	0.04	0.12
Coal	0.12	0.05	0.01	7.11	1.18
Nuclear	0.00	0.00	4.53	0.00	2.22
Biomass	0.78	0.17	6.77	1.07	3.69
Wind	60.40	2.15	0.02	5.37	14.44
Solar	12.42	2.61	8.02	7.66	8.23

13.89 % of its emissions caused by vehicle maintenance, while a Kwid E-Tech in the South has a percentage equivalent to 3.45 %.

Based on these insights, the results suggest that if regional electricity emissions are kept below 0.140 kg CO_2-eq/kWh (the Brazilian average), EVs should be prioritized over gasoline-powered vehicles. In regions with emissions under 0.071 kg CO_2-eq/kWh, such as the Northeast, EVs are the most environmentally friendly option, outperforming even ethanol in terms of GHG emissions.

The significant contribution of the use phase, specifically vehicle charging, emphasizes the importance of the electricity source used to charge the vehicle. In regions where the energy matrix has a higher share of hydro or renewable energy, the carbon footprint of vehicle use can be significantly reduced. Although maintenance contributes relatively little to the total carbon footprint, it is important to consider sustainable practices and the choice of replacement parts with lower environmental impact to further reduce this contribution.

Although Choma and Ugaya (2017) employed a decisional approach to estimate the impacts of increasing the EV fleet in Brazil, considering

Table 4
Inventory of resources used during the lifetime of the vehicles.

Inputs	Functional unit (100,000 km)	Unit	Material
Power Consumption			
Ethanol	7238.53	kg	Ethanol
Gasoline	4767.58	kg	Gasoline E27
Electricity	14,732.76	kWh	Electric mix
Material Consumption			
ICEV			
Lubricants	7.20	kg	Synthetic oil
Oil filter	1.70	kg	Stainless steel
Fuel filter	1.00	kg	Armored steel
Interior filter	4.00	kg	Cellulose paper
Air filter	2.07	kg	Cellulose paper
Piston ring	0.02	kg	Galvanized steel
Spark plug	0.20	kg	Nickel
Car belts	0.23	kg	Rubber
Brake fluid	3.09	kg	Glycols + additives
Coolant	2.52	kg	Ethylene glycol + additives
12 V Battery	26.00	kg	69 % Pb + 8 % H_2SO_4 + 15 % H_2O
Tires	26.00	kg	Rubber
EV			
Lubricants	7.20	kg	Synthetic oil
Interior filter	4.00	kg	Cellulose paper
Brake fluid	3.09	kg	Glycols + additives
Coolant	1.68	kg	Ethylene glycol + additives
12 V Battery	26.00	kg	69 % Pb + 8 % H_2SO_4 + 15 % H_2O
Tires	26.00	kg	Rubber

Table 5
Carbon footprint associated with the consumption of materials.

Item	Carbon footprint (kg CO_2-eq/kg)	Functional unit (kg CO_2-eq/100.000 km)	
		ICEV	EV
Lubricants	1.37	9.75	9.75
Oil filter	5.20	8.85	0.00
Fuel filter	2.16	2.16	0.00
Interior filter	2.92	11,70	11.70
Air filter	2.92	6.05	0.00
Piston ring	1.68	0.03	0.00
Spark plug	17.15	3.43	0.00
Car belts	2.72	0.63	0.00
Brake fluid	2.30	7.11	7.11
Coolant	2.02	5.10	3.40
12 V Battery	1.73	44.95	44.95
Tires	2.72	70.73	70.73
Total		**170.48**	**147.64**

Table 6
Carbon footprint of different electricity sources (per kWh) within the Brazilian electricity mix.

Emission Factors	Carbon Footprint (kg CO_2-eq/kWh)
Hydro	0.098
Wind	0.020
Solar	0.106
Biomass	0.161
Gas	0.756
Nuclear	0.016
Coal	2.697
Oil	1.434

Table 7
Carbon footprint associated with each electricity mix within Brazil.

Electricity mix	Carbon Footprint (kg CO_2-eq/kWh)
Northeast	0.071
North	0.179
Southeast	0.114
South	0.281
Brazil (average)	0.140

Table 8
Carbon footprint associated with operation of the vehicles in Brazil.

	Source of power	*Carbon footprint*
Fuel	Gasoline	19.595 g CO_2-eq/km
	Ethanol	10.568 g CO_2-eq/km
Electricity	Northeast	10.486 g CO_2-eq/km
	North	26.399 g CO_2-eq/km
	Southeast	16.866 g CO_2-eq/km
	South	41.350 g CO_2-eq/km
	Brazil (average)	20.620 g CO_2-eq/km

an ethanol ICEV and an EV powered by the Brazilian electric grid (average). Aligned the results presented herein, the EV was the best option for global warming. However, the ethanol-fueled ICEV could benefit from improvement in vehicle efficiency and sugarcane production gains.

Mera et al. (2023) present a comprehensive analysis of the Brazilian automotive sector, demonstrating that battery electric vehicles (BEVs) yield significantly lower life cycle GHG emissions compared to ICEVs running on a flex-fuel system. According to their findings, BEVs reduce life cycle GHG emissions by 65 % to 67 % across categories including compact cars, midsize cars, and compact SUVs. This substantial reduction is largely attributed to two primary factors: the markedly lower energy consumption of BEVs, which is approximately one-third of that of comparable ICEVs, and the cleaner energy profile of Brazil's electricity grid. The energy cycle emissions of EVs operating within Brazil's renewable-rich electricity matrix are almost three times lower than those of flex-fuel ICEVs, which typically run on a market average mix of gasoline C and hydrous ethanol over their operational lifespan.

Studies by Lavrador and Teles (2022) and Souza et al. (2018) provide robust evidence supporting the use of EVs instead of ICEVs as a less impactful option in relation to global warming potential and also the use of ethanol as an option with less impact on the environment than gasoline. The operational phase of EVs, when powered by low carbon electric grids (which is the case of Brazil), results in significantly lower greenhouse gas emissions compared to ICEVs. These studies not only validate the viability of EVs as a sustainable alternative but also underscore their pivotal role in achieving climate resilience and advancing the global agenda for sustainable urban mobility.

The expansion of the electric grid to accommodate the charging demand for EVs represents a significant infrastructure challenge (Lu et al., 2024; Singh et al., 2024). As the adoption of EVs increases, there is a need for a more robust and flexible electric grid that can support the associated electricity load. Integrating renewable energy sources into the grid is critical to ensuring that the environmental benefits of EVs are maximized. Furthermore, the grid will need to adapt to varying peak demand times, particularly in residential areas where EV owners may charge their vehicles overnight. Investments in smart grid technologies, energy storage solutions, and grid management systems are essential to support a seamless transition, improve energy resilience, and reduce potential strain on existing infrastructure.

Sustainable development is an essential concept for contemporary growth, aiming to meet the demands of the present without compromising the ability of future generations to meet their own needs (Ruggerio, 2021). This development is based on three equally important pillars: social, economic, and environmental. Within this context,

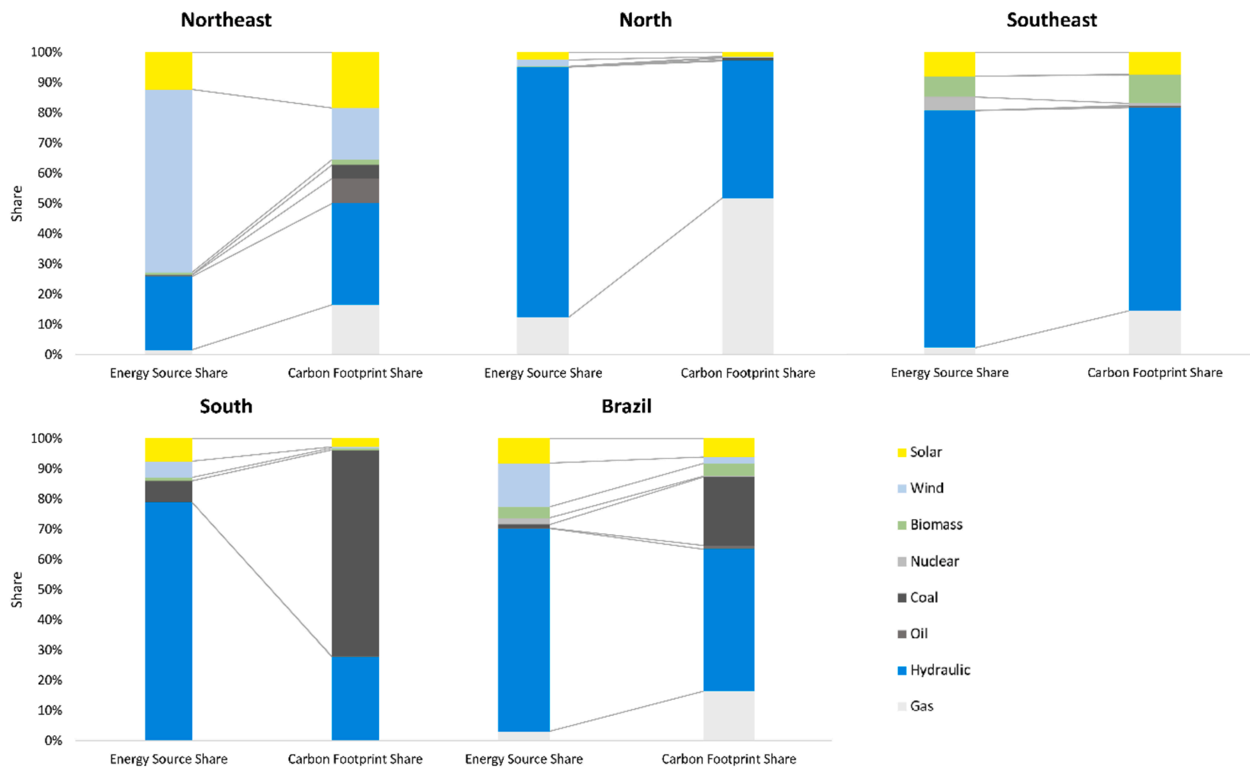

Fig. 3. Potential energy sources: energy used and associated carbon footprint.

Table 9
Emissions for each scenario.

	EV – Kwid E-Tech (kg CO_2-eq)					ICEV – Kwid Intense *flex* (kg CO_2-eq)	
	Northeast	North	Southeast	South	Brazil (Average)	Gasoline E27	Ethanol
Fuel	1048.56	2639.92	1686.62	4134.99	2061.97	1959.47	1056.82
Maintenance	147.64	147.64	147.64	147.64	147.64	170.48	170.48
Total	1196.20	2787.56	1834.26	4282.63	2209.61	2129.95	1227.30

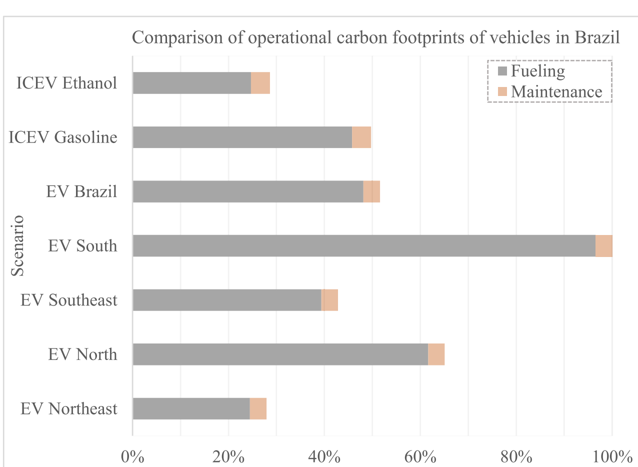

Fig. 4. Comparison of the emissions associated with the operation of vehicles in Brazil.

sustainable mobility emerges as a crucial aspect, addressing both land use and transport management (Papadakis et al., 2024). The goal is to ensure efficient access to goods and services for all citizens while preserving or even enhancing the quality of life for the population.

Sustainable mobility is not limited to efficient urban transportation but also ensures that these practices do not compromise the ability to meet the needs of future generations. Reducing GHG is one of the pillars of sustainable urban mobility. An effective strategy to achieve this goal is the adoption of low carbon transportation modes and encouraging new urban mobility technologies (electric scooters, shared bicycles, and carpooling). Active mobility (walking or cycling) can also contribute to lower GHG emissions, along with the broader use of public transportation. These actions not only reduce GHG emissions in the atmosphere but also promote a healthier and more sustainable lifestyle for the population.

Conclusion

This study provides a comprehensive GHG assessment of the Renault Kwid E-Tech (EV) and the Renault Kwid Intense *flex* (gasoline and ethanol - ICEV), both vehicles in their 2024 versions, using a Well-to-Wheel LCA approach. The results highlighted the importance of regional electricity sources and fuel types in defining the overall environmental performance of these vehicles in the Brazilian context. To this end, the LCA methodology was used, where the functional unit was defined as 100,000 km, and the emission sources for the vehicle were associated with refueling, driving, and maintenance and part replacements carried out during the period.

The analysis revealed that the carbon footprint of different electricity generation sources in Brazil, such as coal, has a significant impact on global warming potential. EVs charged with electricity from the Northeast, with a carbon intensity of 0.071 kg CO_2-eq/kWh, offer the lowest global warming potential, even outperforming ethanol.

The use of ethanol demonstrated an average 46 % reduction in GWP compared to gasoline, reaffirming Brazil's potential for biofuel use in reducing the environmental impacts of transportation. Biofuels are highlighted as an efficient, low-carbon alternative for internal combustion engine vehicles.

Regional strategies to mitigate emissions arise as a necessity, with the South region requiring more focus on low carbon energy technologies and the integration of renewables. Furthermore, although ethanol remains a significantly better option than gasoline in terms of GHG emissions, its production must be carefully managed to avoid ecological damage.

Sensitivity analyses are recommended to evaluate the influence of the electricity mix and other critical variables on the life cycle performance of electric vehicles. Deeper insights into the potential range of emission reductions achievable over time can be seen using a more comprehensive sensitivity analysis focusing on key parameters: *energy and fuel sources, technological advancements in vehicle efficiency and variations in fuel pathways.* Furthermore, other impact categories can be used to broaden the environmental assessment, such as air quality indicators, use of natural resources, and waste generation.

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CRediT authorship contribution statement

João Marcelo Fernandes Gualberto Galiza: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Silvia Guillén-Lambea:** Writing – review & editing, Visualization, Validation, Supervision. **Monica Carvalho:** Writing – review & editing, Software, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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