

Toward net-zero mobility: Evaluating scenarios for road transport decarbonization in Brazil

Guido Haytzmann, André Cieplinski, Arijit Sen, Gabe Alvarez

INTRODUCTION

The Brazilian government is set to reinforce its climate ambition at COP30 in Belém, Brazil, in November 2025. At COP29, the country published a new Nationally Determined Contribution under the Paris Agreement, increasing its greenhouse gas (GHG) reduction target for 2035 from 59% to 67% with respect to 2005 emission levels.¹ Brazil recently published a new climate plan for public consultation, the *Plano Clima Mitigação Estratégia Nacional*, a mitigation and adaptation strategy defining key policies and sector-specific targets for the next 10 years (to 2035).²

The near-term climate mitigation strategies in the climate plan are focused on land use and deforestation, the country's largest sources of emissions, while guidelines for decarbonizing transportation remain vague. The document establishes sectoral emission targets, with 2035 emission levels for the transportation sector allowed to range from 8% lower to 16% higher than 2022 levels. The cities sector, which includes urban mobility, has 2035 emission targets ranging from 18% to 45% lower than 2022 levels.³ The mitigation plans highlight electric vehicles (EVs) and biofuels as central to decarbonizing transportation but do not include clear electrification targets or guidelines on how to achieve net-zero emissions by 2050. This is despite the fact that the transportation sector in Brazil was responsible for 10% of the country's emissions

- 1 Brazilian Government, *Brazil's NDC: National Determination to Contribute and Transform*, 2024, <https://www.gov.br/mma/pt-br/assuntos/noticias/brasil-entrega-a-onu-nova-ndc-alinhada-ao-acordo-de-paris/brazils-ndc.pdf/>; Agência Gov, "Brasil Leva Meta Mais Ousada de Redução de Emissões para a COP 29, no Azerbaijão" [Brazil takes bolder emissions reduction target to COP 29 in Azerbaijan], November 11, 2024, <https://agenciagov.ebc.com.br/noticias/202411/brasil-leva-nova-meta-de-reducao-de-emissoes-para-a-cop-29-no-azerbajao>.
- 2 Ministério do Meio Ambiente e Mudança do Clima, *Plano Clima Mitigação Estratégia Nacional* [National climate mitigation strategy plan], presented at the Seminário Processo de Construção da Estratégia Nacional de Mitigação 2024–2035, May 28, 2024, <https://www.gov.br/mma/pt-br/composicao/smc/plano-clima/ApresentaoENM28052024Painellrev.pdf>.
- 3 Brasil Participativo, *Plano Clima Participativo: Metas Setoriais de Mitigação* [Participatory climate plan: Sectoral mitigation targets], accessed September 24, 2025, <https://brasilparticipativo.presidencia.gov.br/processes/planoclima/f/1353>.

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in 2023, of which 92% were from the road transportation sector, primarily from trucks (45%) and private cars (34%).⁴

Brazil's vehicle market is unique due to the large presence of flex-fuel vehicles. These cars can be fueled with 100% ethanol or gasoline, or any blend of these fuels, and now comprise about 80% of Brazil's circulating light-duty vehicle (LDV) fleet.⁵ Past ICCT research found that leading automakers' current decarbonization strategies in Brazil are focused on flex-fuel hybrid vehicles, although battery electric vehicles (BEVs) present significantly lower well-to-wheel (WTW) emissions.⁶ Additionally, the Green Mobility and Innovation (MOVER) Program—Brazil's binding carbon dioxide emission standards for automakers—has set an LDV emissions reduction target for 2027 of only 3% relative to 2025, which will require little additional effort from automakers. The first heavy-duty vehicle (HDV) targets under MOVER will be announced in 2029, with a compliance date of 2033.⁷

The Brazilian Sustainable Taxonomy defines what economic activities the government considers sustainable to guide investments.⁸ It identifies both zero-emission vehicles (ZEVs) and biofuels as important for the country's low-carbon transition, fostering the adoption of ZEVs and classifying fleets using 100% biofuels as sustainable.⁹

In this context of multiple decarbonization approaches for the Brazilian road transportation sector, this research brief seeks to determine the most effective pathway for mitigating road transport GHG emissions in Brazil. To do so, this study examines alternative scenarios for the evolution of road transportation GHG emissions in Brazil between 2025 and 2050. In particular, it compares the performance of scenarios relying mostly on increased adoption of zero-emission vehicles (BEVs and fuel-cell electric vehicles [FCEVs]) with a more mixed transition based on increasing biofuels use and the penetration of different powertrains, such as plug-in hybrid electric vehicles (PHEVs) and internal combustion engine vehicles (ICEVs) fueled by compressed natural gas (CNG).

The following section describes the methodological approach and the scenarios developed for this analysis. We then discuss the results, conclusions drawn from the analysis, and the policy implications.

METHODS

This section describes the capabilities of the ICCT's Roadmap model, which we used to estimate GHG emission trajectories from scenarios with different assumptions regarding the evolution of vehicle sales and fleet composition, as well as fuels used in

4 Observatório do Clima, "SEEG - Sistema de Estimativa de Emissões e Remoções de Gases de Efeito Estufa" [Greenhouse Gas Emissions and Removals Estimation System (SEEG)], accessed September 24, 2025, <https://plataforma.seeg.eco.br/?yearRange%5B0%5D=1990&yearRange%5B1%5D=2023§or%5B0%5D=477&category%5B0%5D=755&emissionType%5B0%5D=1&gas=8&groupBy=Detail&rankBy=State&filtersTab=filters>.

5 Masao Ukon et al., "Avançando nos Caminhos da Descarbonização Automotiva no Brasil" [Advancing on the paths of automotive decarbonization in Brazil], Boston Consulting Group, 2024, <https://www.bcg.com/publications/2024/brasil-avancando-nos-caminhos-da-descarbonizacao-automotiva-no-brasil>.

6 Chang Shen et al., *Electric Vehicles Development and Strategies among Leading Automakers: Comparing Brazil with Other Major Markets* (International Council on Clean Transportation, 2025), <https://theicct.org/publication/ev-development-and-strategies-among-leading-automakers-comparing-brazil-with-other-major-markets-oct25/>.

7 André Cieplinski et al., *The Regulation of Brazil's Green Mobility and Innovation (MOVER) Vehicle Emissions Program* (International Council on Clean Transportation, 2025), <https://theicct.org/publication/regulation-of-brazil-green-mobility-and-innovation-mover-vehicle-emissions-program-oct25/>.

8 Ministério da Fazenda, *Taxonomia Sustentável Brasileira* [Brazilian Sustainable Taxonomy], November 2025, <https://www.gov.br/fazenda/pt-br/orgaos/spe/taxonomia-sustentavel-brasileira/cadernos/cadernos-da-taxonomia-sustentavel-brasileira>.

9 Ministério da Fazenda, *Caderno 2.7 - CNAE H - Transporte, armazenagem e correios* [Notebook 2.7-CNAE H: Transportation, storage, and postal services] (2025), <https://www.gov.br/fazenda/pt-br/orgaos/spe/taxonomia-sustentavel-brasileira/cadernos/transporte-armazenamento-e-correio-cnae-h>.

Brazil between 2025 and 2050. It then presents the four scenarios we developed in this study, detailing vehicle sales by technology and segment and the emission factors for different biofuels' feedstocks and electricity. We express GHG emissions in terms of carbon dioxide equivalent (CO₂e) based on a 100-year global warming potential (CO₂e GWP100).

ROADMAP MODEL

The ICCT's Roadmap model calculates vehicle activity, energy consumption, and emissions based on a historical database developed by the ICCT. This model includes data for sales, vehicle stock, fleet average mileage, new vehicle energy intensity, fuel and electricity emission factors, and vehicle survival rate.¹⁰ The version of the Roadmap model used for this analysis (version 2.10) contains historical data through 2023. The model relies on the introduction of alternative inputs to simulate scenarios. These modifiable inputs include distribution of new vehicles sales among different technologies (powertrains), fuel emission factors, biofuel feedstocks, future projections of electricity emission factors, vehicle energy intensity, and vehicle survival rates.

The Roadmap model is a bottom-up, sales-driven model that combines vehicles sales and retirement to estimate the fleet. The model works by calculating the turnover of the last historical year's stock of vehicles based on retirement age, defined by vehicle survival curves for each segment. For a given year, the remaining stock from the previous year multiplied by the average mileage for the given year yields a certain portion of the projected activity in the respective vehicle segment. The target shortfall is divided by the average mileage, which calculates the number of new vehicles that need to be sold for the projected activity target to be met in a given year.

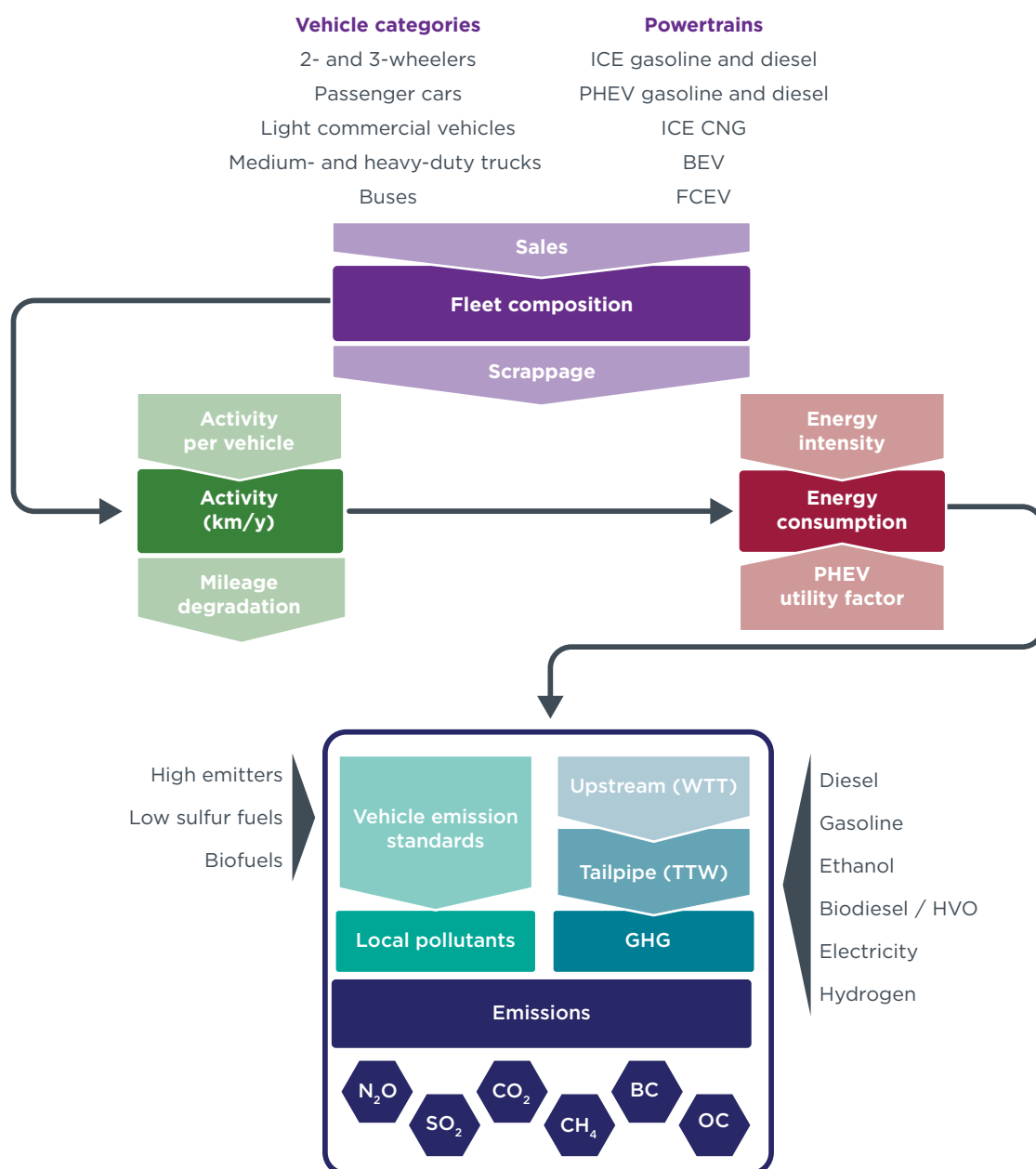
This process is iterated for each future year (i.e., from 2025 to 2050) for all vehicle segments. Once the stock for each future year is created by vintage (i.e., a distribution of vehicles based on the calendar year they were sold), vintage-specific emissions are calculated as shown in Equation 1. Each vintage has the fleet's average mileage and emission factors for that stock year.

$$\text{vintage emissions} = \text{vintage stock} \times \text{fleet average mileage} \\ \times \text{vintage specific energy intensity} \times \text{emission factors} \quad (\text{Equation 1})$$

A visual representation of the Roadmap model is presented in Figure 1, showing the initial inputs of new vehicle sales by powertrain, the definitions of vehicle categories, fleet activity rates and energy consumption, and the calculation of GHG and local pollutant emissions.

¹⁰ Gabriel Hillman Alvarez, *Roadmap v2.10 Documentation*, computer software, International Council on Clean Transportation, 2025, <https://theicct.github.io/roadmap-doc/versions/v2.10/>.

Figure 1
The ICCT's Roadmap model



Note: The light-shaded shapes indicate model inputs: the distribution of new vehicles sales by segment and powertrain, their energy intensity, activity per vehicle, fuel usage, and biofuels blends. Dark-shaded shapes are outputs: composition of vehicle fleet, its total activity level, energy consumption, and emissions. Well-to-tank (WTT) emissions are emissions generated in the production of fuels or electricity, while tank-to-wheel (TTW) emissions account for the emissions generated during the use of the vehicle (combustion). Together, WTT and TTW compose WTW emissions.

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The distance driven per vehicle varies according to the vehicle segment but remains constant over time. These assumptions are the default inputs from the model, the sources of which can be accessed in the model documentation.¹¹

Each scenario described in the next section considers the same growth rates in vehicles sales but has different distribution of sales by powertrain. These growth rates are summarized in Table 1.

¹¹ Alvarez, *Roadmap v2.10 Documentation*.

Table 1
Annual growth rates of new vehicle sales by segment used in scenarios assessed, 2025–2050

Segment	Annual growth rate of sales
Motorcycles	-1.1%
Passenger cars	2.0%
Light-commercial vehicles	-1.5%
Medium-duty trucks	-4.5%
Heavy-duty trucks	1.3%
Buses	0.03%

The model uses historical stock and sales data from Brazil.¹² New vehicle sales and energy intensity data are reported at the powertrain level: ICE gasoline, ICE diesel, ICE CNG, ICE liquefied petroleum gas, PHEV gasoline, PHEV diesel, BEV, and FCEV. Given that sales and usage data for FCEVs are scarce, an emission intensity value is derived from Argonne National Laboratory’s Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) model calculations.¹³

SCENARIOS

Four scenarios were modeled for this analysis, progressing from an ICEV-based fleet to greater penetrations of EVs by 2050. The four scenarios can be summarized as follows:

- » **Baseline:** This scenario represents business as usual, only incorporating the CO₂e emission and energy efficiency targets compatible with the first phase of LDV targets under the MOVER Program.¹⁴ ICEVs dominate sales until 2050, with mild increases in ethanol usage for LDVs.
- » **Mixed Transition:** This scenario represents the current decarbonization pathway among most automakers relying on multiple solutions, involving a mix of biofuels, biomethane, and green hydrogen, along with full and hybrid electrification.¹⁵ The BEV share among new sales follows the same trajectory as the Baseline scenario. The sum of all alternative technology (BEV, PHEV, FCEV, and CNG) shares across all vehicle segments is the same as in the Moderate Electrification scenario (discussed below), but with a greater share of PHEVs among LDVs and a greater share of FCEVs and CNG vehicles among HDVs. We increase the share of biomass-based diesel (biodiesel and hydrotreated vegetable oil [HVO]), or “green diesel,” blended into the diesel fuel pool according to biodiesel blending mandates and

12 ADK Automotive, *Brazil’s Light-duty Vehicle Registration Database, 2010–2020*, database; Jato Dynamics, *Venda de Carros de Passageiro e Veículos Comerciais Leves, 2021–2024* [Passenger car and light commercial vehicle sales, 2021–2024], database, <https://info.jato.com/pt-br/jato-brasil>.

13 Argonne National Laboratory, *Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool*, accessed October 6, 2025, <https://afleet.esia.anl.gov/home/>.

14 Cieplinski et al., *Regulation*.

15 Nayara Machado, “Brasil Aposta em Veículos Flex e Hidrogênio em Cenários para Transição” [Brazil bets on flex vehicles and hydrogen in transition scenarios], *Eixos*, August 1, 2025, https://eixos.com.br/newsletters/dialogos-da-transicao/brasil-aposta-em-veiculos-flex-e-hidrogenio-em-cenarios-para-transicao/?utm_source=newsletters+eixos&utm_campaign=249bf32482-EMAIL_CAMPAIGN_2025_08_01_08_57&utm_medium=email&utm_term=0_249bf32482-505; André Catto, “Híbridos Flex: Por Que a Tecnologia Está no Centro dos R\$ 117 Bilhões de Investimentos das Montadoras” [Flex hybrids: Why the technology is at the center of automakers’ R\$ 117 billion investments], *Globo.com*, March 9, 2024, <https://g1.globo.com/carros/noticia/2024/03/09/hibridos-flex-por-que-a-tecnologia-esta-no-centro-dos-r-117-bilhoes-de-investimentos-das-montadoras.ghtml>; Mário Sérgio Venditti, “Nossa Aposta é nos Automóveis com a Tecnologia Híbrido-Flex, Diz Diretor da Toyota do Brasil” [Our bet is on vehicles with flex hybrid technology, says Toyota Brazil’s director], *Estadão Mobilidade*, April 24, 2024, <https://mobilidade.estadao.com.br/mobilidade-para-que/nossa-aposta-e-nos-automoveis-com-a-tecnologia-hibrido-flex-diz-diretor-da-toyota-do-brasil/>.

expanded capacity for HVO production as a co-product of sustainable aviation fuel production.

- » **Moderate Electrification:** This scenario includes greater penetration of BEVs in all segments, aligned with targets from Mexico, Colombia, Chile, and Ecuador, as in the Electrification scenario from Cieplinski et al.¹⁶ We assume the same biofuel blend shares as the Baseline scenario.
- » **Ambitious Electrification:** This scenario reflects an accelerated achievement of 100% ZEV sales in all segments. The transition coheres with a global carbon budget compatible with a well below 2 °C warming scenario.¹⁷ We assume the same biofuel blend shares as the Baseline scenario.

Table 2 summarizes the composition of vehicles sales by technology in the six segments analyzed for each scenario, presented for the years 2030, 2040, and 2050. The table shows only new technologies; the remaining sales are mainly of ICEVs.

Table 2

Sales share of new technology by vehicle segment in the four scenarios in 2030, 2040, and 2050

			Baseline				Mixed Transition			Moderate Electrification			Ambitious Electrification		
			2025	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Motorcycles	BEV	2%	20%	55%	90%	20%	55%	90%	20%	70%	100%	20%	100%	100%	
Passenger cars	BEV	4%	10%	26%	42%	10%	26%	42%	16%	40%	70%	30%	80%	99%	
	FCEV	0%	0%	0%	1%	0%	0%	1%	0%	0%	1%	0%	0%	1%	
	PHEV	4%	10%	15%	15%	14%	29%	38%	10%	15%	10%	1%	1%	0%	
Light commercial vehicles	BEV	0%	1%	20%	40%	1%	20%	40%	9%	45%	71%	28%	95%	95%	
	FCEV	0%	0%	0%	1%	1%	2%	3%	2%	5%	5%	2%	5%	5%	
	PHEV	0%	0%	0%	0%	12%	43%	43%	4%	15%	10%	0%	0%	0%	
Medium-duty trucks	BEV	1%	3%	6%	10%	10%	26%	42%	13%	48%	83%	28%	93%	93%	
	FCEV	0%	0%	0%	0%	2%	10%	15%	2%	7%	7%	2%	7%	7%	
	ICE CNG	0%	0%	0%	2%	3%	19%	35%	0%	0%	2%	0%	0%	0%	
Heavy-duty trucks	BEV	1%	1%	3%	4%	1%	3%	4%	2%	15%	40%	18%	83%	92%	
	FCEV	0%	0%	0%	0%	2%	10%	15%	2%	7%	8%	2%	7%	8%	
	ICE CNG	0%	0%	0%	1%	1%	10%	30%	0%	0%	1%	0%	0%	0%	
Buses	BEV	5%	10%	25%	41%	10%	25%	41%	21%	62%	92%	55%	92%	92%	
	FCEV	0%	0%	0%	2%	5%	8%	8%	5%	8%	8%	5%	8%	8%	
	ICE CNG	0%	1%	1%	1%	11%	37%	51%	0%	0%	0%	0%	0%	0%	

In the Moderate Electrification scenario, BEV projections are based on targets from other Latin American countries, as previously noted. Projections of FCEVs follow those

¹⁶ André Cieplinski et al., *The Transition to Electric Vehicles in Brazil's Automotive Industry and Its Effects on Jobs and Income* (International Council on Clean Transportation, 2025), <https://theicct.org/publication/the-transition-to-electric-vehicles-in-brazils-automotive-industry-and-its-effects-on-jobs-and-income-june25/>.

¹⁷ Arijit Sen et al., *Vision 2050 Strategies to Align Global Road Transport with Well Below 2 °C* (International Council on Clean Transportation, 2023), <https://theicct.org/publication/vision-2050-strategies-to-reduce-gap-for-global-road-transport-nov23/>.

of the Ambitious Electrification scenario. Shares of PHEVs for passenger cars (PCs) and light commercial vehicles (LCVs) are similar to PCs in the Baseline scenario, while ICE-CNG shares remain minimal.

The Mixed Transition scenario was designed to maintain the same share of alternative technologies as the Moderate Electrification scenario but with less focus on BEVs. In this case, BEV shares are equal to those of the Baseline scenario, and the remaining share is distributed among PHEVs for LCVs and FCEVs and CNG ICEVs for HDVs. This scenario aims to explore a pathway set out in some government documents and in automaker statements.¹⁸ In 2050, the combined passenger car share of BEVs, FCEVs, and PHEVs is 81% in both the Mixed Transition and Moderate Electrification scenarios. The BEV share in the Mixed Transition scenario is 42% (the same as in the Baseline scenario), and in the Moderate Electrification scenario the BEV share is 70%.

BIOFUEL BLENDS

Each scenario has different assumptions regarding biofuel usage. The percentage of ethanol, biodiesel, and biomethane used is listed in Table 3. In all four scenarios, ethanol usage reaches 62% by 2034 and remains fixed until 2050. This percentage includes both the mandatory blend of anhydrous ethanol blended in Brazil’s gasoline (27%–30% blend) and hydrous ethanol (E100) sold directly at gas stations. Overall ethanol use projections are based on a recently published report by the Energy Research Office (EPE).¹⁹

Table 3
Evolution of biofuel blend rate within each fuel pool under each scenario

	Baseline				Mixed Transition			Moderate Electrification			Ambitious Electrification		
	2025	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
Ethanol	56%	60%	62%	62%	60%	62%	62%	60%	62%	62%	60%	62%	62%
Biodiesel	15%	20%	20%	20%	20%	28%	37%	20%	20%	20%	20%	20%	20%
Biogas CNG	0%	1%	1%	1%	7%	15%	15%	1%	1%	1%	1%	1%	1%

In all scenarios, the biodiesel blend is assumed to increase from the current 15% to the 20% stipulated for 2030.²⁰ The Mixed Transition scenario is the only one that includes contributions from HVO, which is a co-product of sustainable aviation fuel production and can be used in diesel engines at blend rates of up to 100%. We cite biodiesel blend projections from EPE through 2034 and estimate HVO production based on sustainable aviation fuel facility announcements through that period.²¹ We assume that HVO makes up 50% of the distillate fuel product slate by volume. We project a linear increase in biomass-based diesel consumption between 2034 and 2050 until the total

18 Centro Brasileiro de Relações Internacionais, Empresa de Pesquisa Energética (EPE), Banco Interamericano de Desenvolvimento, Centro de Economia Energética e Ambiental, *Neutralidade de Carbono Até 2050: Cenários para uma Transição Eficiente no Brasil* [Carbon neutrality by 2050: Scenarios for an efficient transition in Brazil], 2023, https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-726/PTE_RelatorioFinal_PT_Digital_.pdf.

19 EPE, *Nota Técnica: Descarbonização do Setor de Transporte Rodoviário, Intensidade de Carbono das Fontes de Energia* [Technical note: Decarbonization of the road transport sector, carbon intensity of energy sources], 2025: 25, Table 4, https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-708/topico-770/NT-EPE-DPG-SDB-2025-03_Intensidade_de_Carbono_Transporte_Rodovi%C3%A1rio.pdf.

20 Lei No. 14.993, de 8 de Outubro de 2024 [Law No. 14.883, of October 8, 2024], https://www.planalto.gov.br/ccivil_03/_ato2023-2026/2024/lei/l14993.htm.

21 EPE, *Nota Técnica—Investimentos e Custos Operacionais e de Manutenção no Setor de Biocombustíveis: 2024–2033* [Technical note—Investments, operation, and maintenance costs of bioelectricity 2024–2033], 2023, https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-783/NT-EPE-DPG-SDB-2023-05_Investimentos_Custos_O_e_M_Bios_2024-2033.pdf.

biomass-based diesel mix reaches 37%. This scenario also projects a gradual increase of biomethane from 0% in 2025 to 15% after 2040. In a forthcoming ICCT study, Rebouças et al. estimate the maximum biomethane blend in fossil gas to be 18% for Brazil in the next few decades.²² The 1% biomethane assumed in the other scenarios is the mandatory biomethane blend from the Combustível do Futuro law.²³

Although the same blend for biofuels is assumed for three scenarios—Baseline, Moderate Electrification, and Ambitious Electrification—the total volume of biofuels consumed changes. Because the Ambitious Electrification scenario assumes faster BEV uptake, the circulating fleet of ICEVs that can use biofuels decreases by 2050. On the other hand, ICEVs comprise most of the fleet in the Baseline scenario until 2050. These differences are presented in the results section.

BIOFUEL EMISSION INTENSITY

Not only does ethanol use in ICEVs increase over time, but the feedstock shares used to produce it also changes. Table 4 presents the carbon intensities of sugarcane and corn ethanol in Brazil, as well as the evolution of these feedstocks over time, which shows a small relative increase in corn vis-à-vis sugarcane ethanol. The carbon intensities for the production, or well-to-tank (WTT), phase of ethanol are estimated using average RenovaBio values by pathway for projects certified between 2022 and 2024.²⁴ We weight the certified emissions intensities by the share of anhydrous and hydrous ethanol consumed in 2023, the latest year data were reported.²⁵ Approximately 90% of ethanol consumed in the transport sector is certified under RenovaBio; therefore, we assume these values are reflective of the current and future ethanol mix in Brazil. The indirect land-use change (ILUC) values for sugarcane and corn ethanol are based on updated Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) values.²⁶ The feedstock shares between sugarcane and corn were estimated by EPE up to 2034 and we fix the share afterwards.²⁷ The default WTW emission factor for gasoline in the Roadmap model is 93.4 CO₂e.

22 Ana Beatriz Rebouças et al., *Are Natural Gas and Biomethane Effective Decarbonization Strategies for Heavy-Duty Vehicles in Brazil? A Life-cycle Greenhouse Gas Assessment* (International Council on Clean Transportation, forthcoming).

23 Lei No. 14.993.

24 Agência Nacional do Petróleo, *Painel Dinâmico RenovaBio Certificação de Biocombustíveis* [RenovaBio dynamic dashboard of fuel certification], accessed October 3, 2025, <https://app.powerbi.com/view?r=eyJ-JrljoiMjVjNDcwYmEtZjU4Zi00ZmJmLTg2MWUtMjE5NTJmNjE3ZDNhliwidCI6IjQ0OTlmNGZmLTl0YTtYtNGI-0Mi1iN2VmLTEyNGFmY2FkYzkyMyJ9>.

25 EPE, *Analysis of Biofuels' Current Outlook*, accessed October 3, 2025, <https://www.epe.gov.br/en/publications/publications/analysis-of-biofuels-current-outlook-2023>.

26 International Civil Aviation Organization, *CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels*, 2025, <https://www.icao.int/sites/default/files/environmental-protection/CORSIA/Documents/CORSIA%20Eligible%20Fuels/ICAO-document-06-Default-Life-Cycle-Emissions-June-2025.pdf>.

27 EPE, *Nota Técnica: Descarbonização do Setor de Transporte Rodoviário, Intensidade de Carbono das Fontes de Energia* [Technical note: Decarbonization of the road transport sector, carbon intensity of energy sources], 2025, https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-708/topico-770/NT-EPE-DPG-SDB-2025-03_Intensidade_de_Carbono_Transporte_Rodovi%C3%A1rio.pdf.

Table 4**Ethanol carbon intensity and share by feedstock**

	Direct emissions	ILUC emissions	WTW emissions (total)	Feedstock share			
				2025	2027	2032	2034
	g CO ₂ e/MJ	g CO ₂ e/MJ	g CO ₂ e/MJ	%	%	%	%
Corn	32.5	26.2	58.7	24%	29%	31%	32%
Sugar cane	29.1	11	40.1	76%	71%	69%	68%
Average WTW g CO₂e/MJ				44.5	45.4	45.9	46.0

In contrast to ethanol, there are no official projections for the evolution of Brazil's biodiesel feedstocks. Therefore, we assume the last observed shares from 2024 remain fixed in our scenarios.²⁸ Biodiesel produced from residues such as used cooking oil and animal fats do not have an associated ILUC emission factor. We cite ILUC values for the remaining feedstocks from CORSIA. Because only a small share of biodiesel is certified under RenovaBio and results are not disaggregated by feedstock, we do not cite RenovaBio values for biodiesel pathways. Instead, we source biodiesel emission factors from the GREET model, using energy-based allocation for oil and meal.²⁹ The default WTW emission factor for diesel in the Roadmap model is 94.9 g CO₂e. These shares and their respective carbon intensities are listed in Table 5.

Table 5**Biodiesel carbon intensity and share by feedstock**

	Direct emissions	ILUC emissions	WTW emissions (total)	Feedstock share
	g CO ₂ e/MJ	g CO ₂ e/MJ	g CO ₂ e/MJ	%
Soybean oil	34.7	20.7	55.4	84%
Palm oil	35.5	36.6	72.1	2%
Canola oil	41.8	23.9	65.7	1%
Used cooking oil	19	0.0	19	2%
Animal fats	24.6	0.0	24.6	11%
Average g CO₂e/MJ	33.3	18.3	51.7	

The carbon intensity of biomethane is also based on different feedstocks weighted by their share, shown in Table 6. Given the very limited production levels in 2025, and the projected increase of biomethane usage in our scenarios, the feedstocks' average carbon intensity is based on the production potential for each feedstock in Brazil.³⁰ Every biomethane feedstock was considered to be a residue. Thus, in contrast to the main ethanol and biodiesel feedstocks, no ILUC emissions are included. Biomethane production captures methane that would otherwise be released in the atmosphere, which explains the negative or low emissions in the production phase. The Roadmap model's default WTW emission factor for CNG is 69.7 g CO₂e.

28 Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, *Painel Dinâmico de Produtores de Biodiesel* [Dynamic panel of biodiesel producers], September 24, 2025, <https://www.gov.br/anp/pt-br/centrais-de-contenido/paineis-dinamicos-da-anp/paineis-e-mapa-dinamicos-de-produtores-de-combustiveis-e-derivados/painel-dinamico-de-produtores-de-biodiesel>.

29 Argonne National Laboratory, *GREET: The Greenhouse gases, Regulated Emissions, and Energy use in Technologies model*, computer software, 2023, <https://greet.anl.gov/index.php>.

30 Rebouças et al., *Natural Gas and Biomethane*.

Table 6**Biomethane carbon intensity and share by feedstock**

	Direct emissions	ILUC emissions	WTW emissions (total)	Feedstock share
	g CO ₂ e/MJ	g CO ₂ e/MJ	g CO ₂ e/MJ	%
Swine	-191.7	0.0	-191.7	12%
Agricultural residues	21.2	0.0	21.2	52%
Landfill	14.2	0.0	14.2	31%
Sewage	29.4	0.0	29.4	5%
Average g CO ₂ e/MJ	-7.2	0.0	-7.2	

Like ethanol, hydrogen feedstock shares are projected to change over time, as depicted in Table 7.³¹ The renewable electricity share increases significantly throughout the years, causing the average carbon intensity of hydrogen in Brazil to be cut in half between 2030 and 2050.

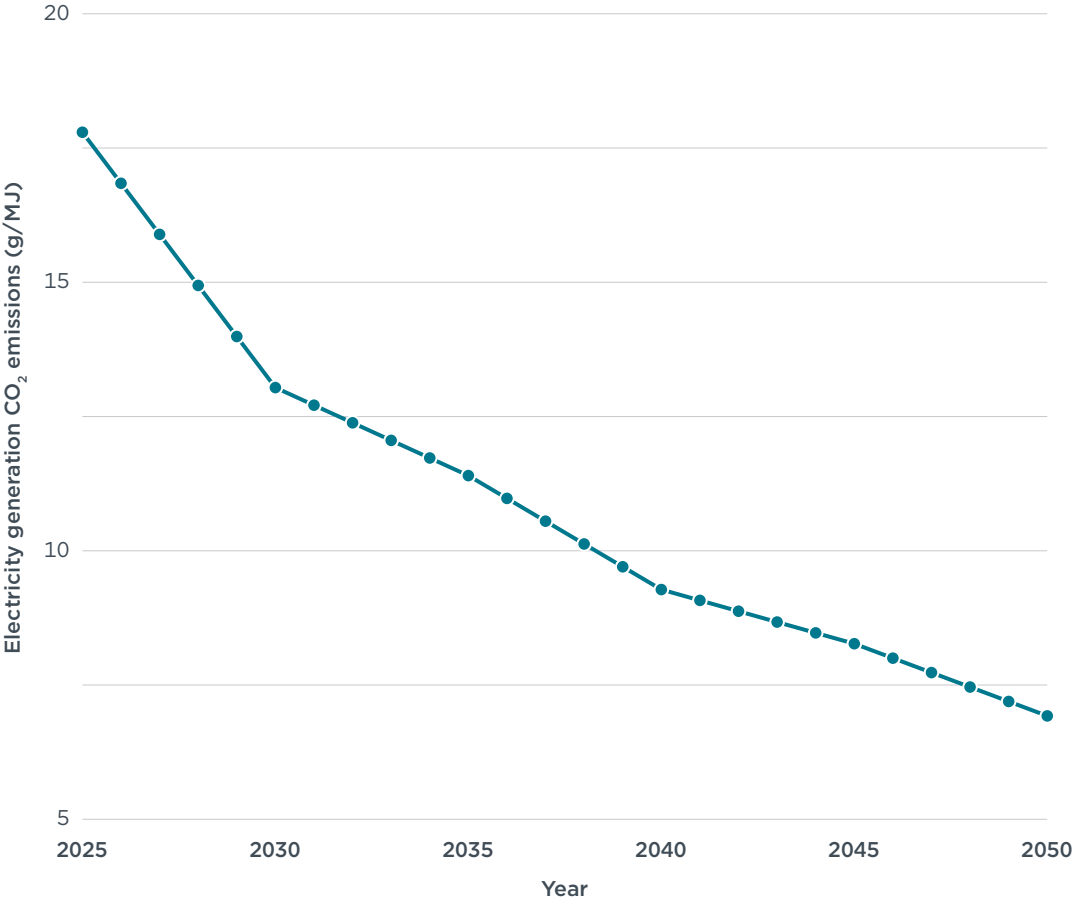
Table 7**Hydrogen carbon intensity and share by feedstock**

	WTW emission (total)	Feedstock share		
	g CO ₂ e/MJ	2030	2040	2050
Natural gas	84.1	85%	52.5%	20%
Natural gas + carbon capture	65.3	0%	10%	20%
Renewable electricity	13.3	15%	37.5%	60%
Average g CO ₂ e/MJ		73.5	55.7	37.9

³¹ Alvarez, Roadmap v2.10 Documentation.

Figure 2 shows the projected carbon intensity of the Brazilian electricity grid through 2050.³²

Figure 2
Time series of electricity generation carbon intensity, 2025–2050



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RESULTS

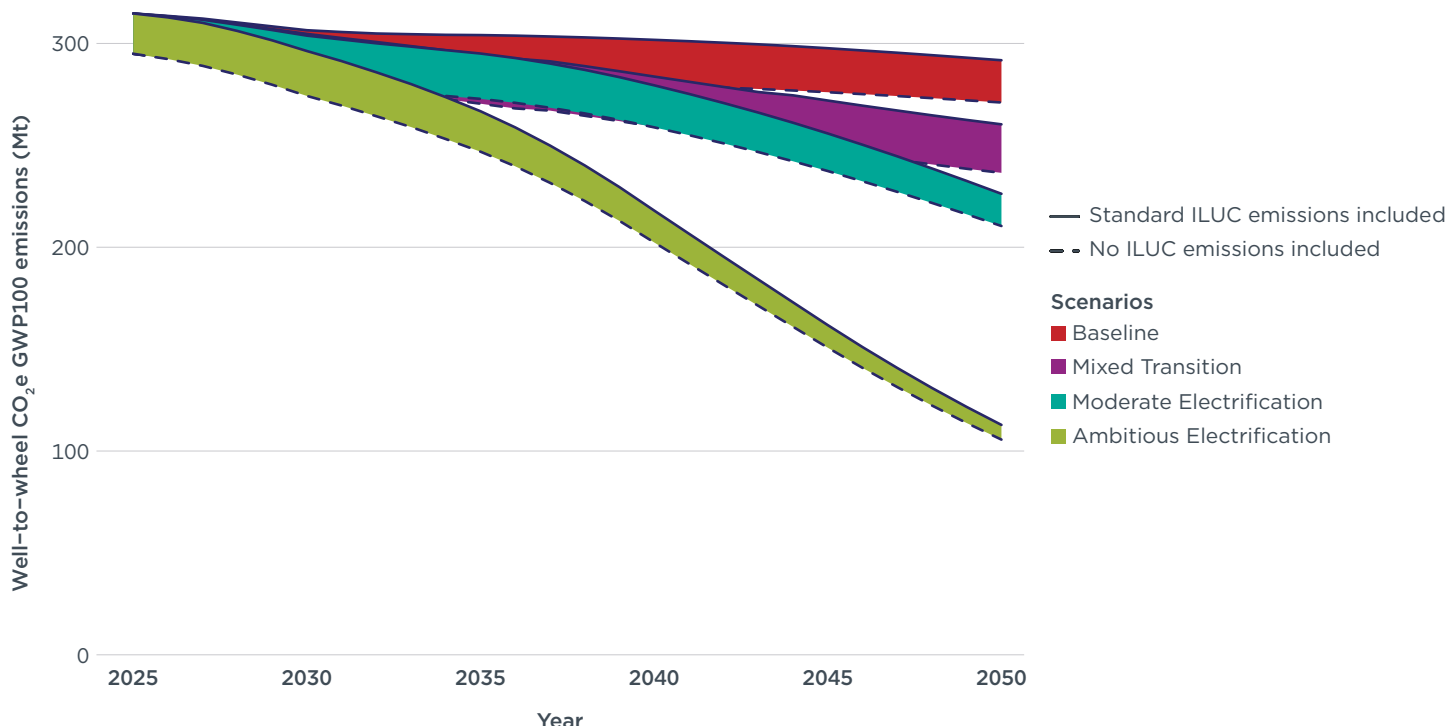
This section presents the modeling results, comparing the four scenarios in terms of GHG emissions. It also breaks down emissions by the main drivers of GHG emission reductions.

Figure 3 depicts the projections of WTW CO₂e emissions from 2025 to 2050 under the four scenarios, showing results with and without considering ILUC emissions. Each scenario is represented by a colored stripe, delimited on top by a solid line and at the bottom by a dashed line. The dashed lines indicate the evolution of the emissions of the scenario disregarding ILUC emissions, while the solid lines include them.

³² International Energy Agency, *World Energy Outlook 2023*, 2023: 259–294, Annex A, <https://www.iea.org/reports/world-energy-outlook-2023>.

Figure 3

Evolution of GHG emissions in the four scenarios, 2025-2050



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Each scenario follows a unique pathway, which results in distinct evolutions of GHG emissions over time. Emissions in the Baseline scenario are projected to be the highest among all scenarios, with 2050 levels only 7% below 2025. As noted above, the Baseline scenario reflects a business-as-usual case, meaning that the adoption of alternative technologies only follows current trends.

In the Mixed Transition scenario, the increase in biofuels, CNG, and hydrogen for heavy-duty trucks (HDTs) and the more widespread adoption of PHEVs among LDVs result in 2050 emission levels 17% lower than in 2025, considering ILUC emissions.

The Moderate Electrification scenario shows a faster reduction in GHG emissions. This scenario includes electrification sales targets aligned with those of other Latin American countries. This pathway yields modeled emission levels in 2050 that are 28% lower than in 2025.

The Ambitious Electrification scenario is projected to be the most efficient pathway to promote the decarbonization of the road transportation sector. The accelerated ZEV transition focused on BEVs, combined with Brazil's low-carbon intensity electricity grid, results in 64% lower emissions in 2050 than in 2025.

Emission factors for biofuels include ILUC emissions.³³ There is no consensus among researchers regarding absolute values for ILUC emissions, as these estimates are model dependent and may vary depending on the methodology used.³⁴ In this brief, we use CORSIA estimates for ILUC emissions. Unlike fuels regulations in several other

³³ André Cieplinski and Carmen Araújo, "Impacto Ambiental dos Biocombustíveis no Brasil: O que Ficou de Fora?" [The environmental impact of biofuels in Brazil: What was left out?], *ICCT Staff Blog*, March 28, 2023, <https://theicct.org/impacto-ambiental-biocombustiveis-brasil-mar23>.

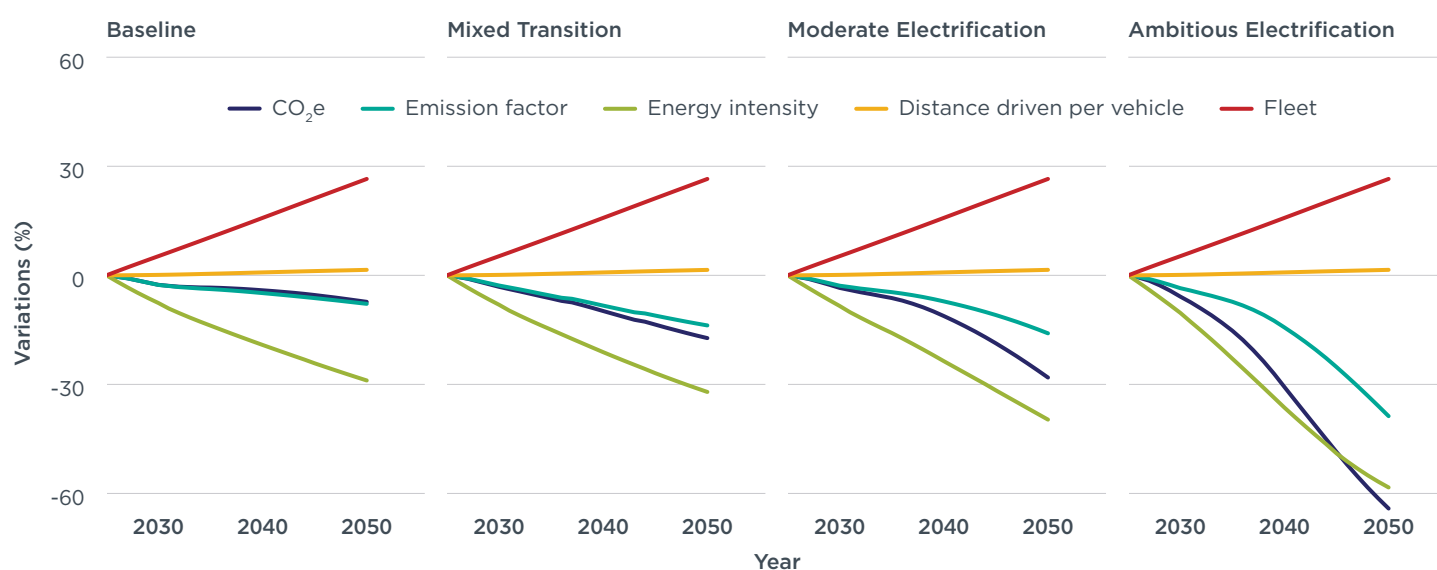
³⁴ International Civil Aviation Organization, *CORSIA Eligible Fuels – Life Cycle Assessment Methodology*, 217, Table 115, 2024, https://www.icao.int/sites/default/files/environmental-protection/CORSIA/Documents/SCS-Evaluation/CORSIA_Supporting_Document_CORSIA-Eligible-Fuels_LCA_Methodology_V6.pdf.

countries, Brazil's current domestic fuels policies do not account for ILUC emissions within life-cycle assessment (LCA) methodologies.³⁵ Therefore, we present our emissions trajectories both with and without ILUC emissions. This approach aims to investigate whether there could be a scenario where emissions estimates that do not account for ILUC would be lower than those of another scenario that does account for it.

The results show that in 2050, emissions from faster electrification pathways fall below those of a mixed transition, even if the latter does not include ILUC emissions. However, not accounting for ILUC leads to a significant underestimation of emissions over time. The accumulated ILUC emissions between 2025 and 2050 are 590 Mt CO₂e in the Baseline scenario, 631 Mt CO₂e in the Mixed Transition scenario, 547 Mt CO₂e in the Moderate Electrification scenario, and 445 Mt CO₂e in the Ambitious Electrification scenario.

Figure 4 plots an adapted Kaya Identity, or $I = PAT$, for the transportation sector for all scenarios.³⁶ This approach consists of factoring CO₂e emissions into distinct variables to clarify what is driving the variations. In this figure, we disaggregate CO₂e emissions into the average carbon intensity of the energetic source (fuels and electricity), energy intensity, distance driven, and size of the fleet. Fleet averages are based on all vehicle segments, weighted by the number of vehicles on the road.³⁷

Figure 4
Contribution of different variables to GHG emissions



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The evolution of the fleet size and vehicle use intensity are the same in all scenarios. Hence, the distinct evolution of the vehicle's energy source emission factor and the fleet energy intensity are the main drivers of the differences in the CO₂e emission projections among the scenarios.

35 Nikita Pavlenko and Carmen Araujo, *Opportunities and Risks for Continued Biofuel Expansion in Brazil* (International Council on Clean Transportation, 2019), https://theicct.org/wp-content/uploads/2021/06/ICCT_Brazil_lowcarbon_fuel_opp_20190726.pdf.

36 Stands for Impact = Population, Affluence, and Technology.

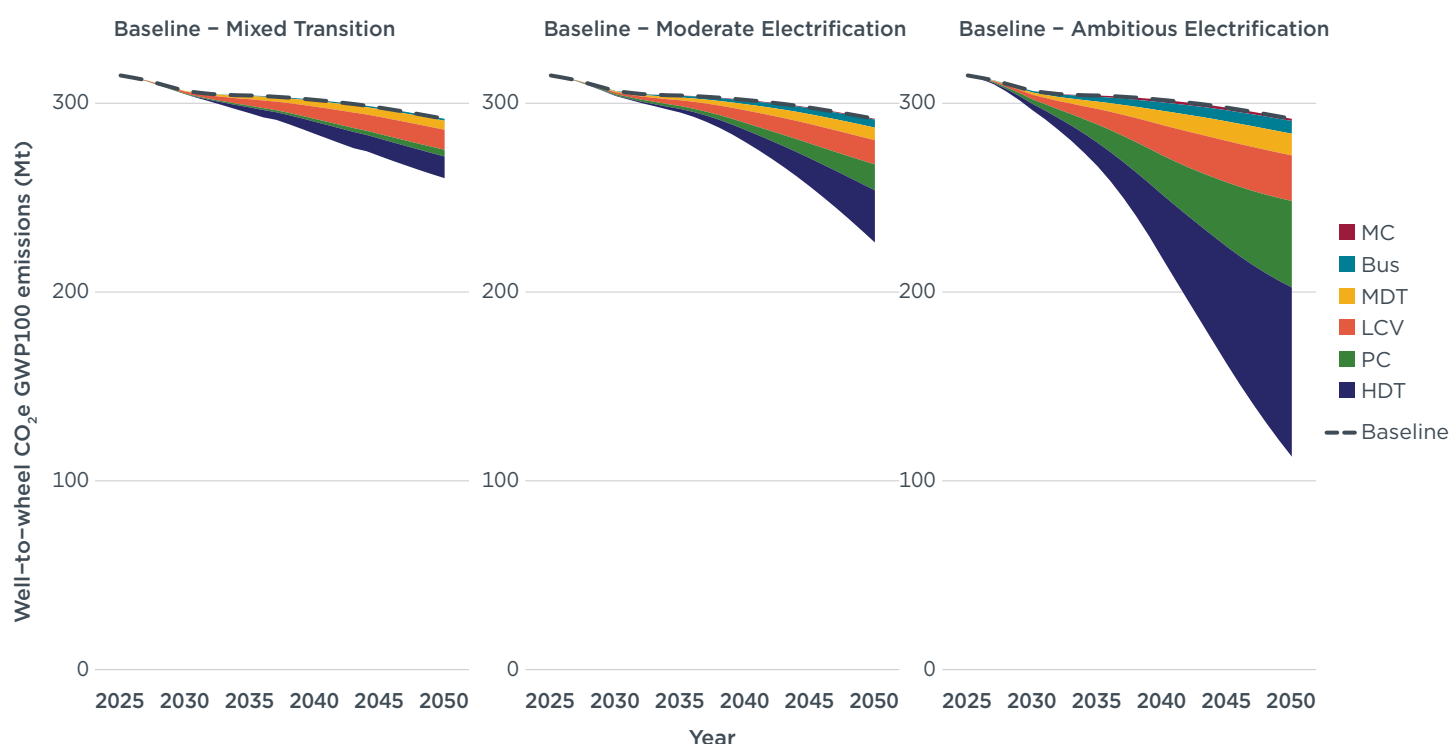
37 The decomposition is an identity stated as: $CO_2 = \frac{CO_2}{PJ} \cdot \frac{PJ}{km} \cdot \frac{km}{veh} \cdot fleet$. From left to right these terms are: the carbon intensity of the fleet, the fleet's energy intensity, the average level of activity per vehicle, and the size of the fleet.

In the Baseline scenario, the improvement in the fleet's energy efficiency and the slow transition to low-carbon energy sources are counterbalanced by the growth in fleet size and distance driven per vehicle, causing the GHG emissions to decrease at a slow pace. In the Mixed Transition scenario, there is no increase in the rate of BEV adoption above the Baseline scenario, which results in minor energy efficiency gains relative to the Baseline. However, there is a considerable increase in biofuel and hydrogen use among HDTs and medium-duty trucks (MDTs), which contributes to a faster decrease in the emission factor in the Mixed Transition scenario than in the Baseline scenario, causing the GHG emissions to decrease more significantly. The faster ZEV transition in both the Moderate and Ambitious Electrification scenarios lead to a greater reduction in the fleet's energy intensity and emission factor, and therefore in emissions. In other words, the faster the ZEV transition, the higher the amount of GHG emissions avoided. This occurs because BEVs consume less energy than ICEVs, and Brazil's electricity production grid has a low carbon intensity, as presented in Figure 2.

Figure 5 shows the contribution of each vehicle segment to reducing emissions with respect to the Baseline scenario and reaching the emission levels projected for the Mixed Transition, Moderate, and Ambitious Electrification scenarios. The lines at the top of the colored areas indicate the Baseline scenario emissions, while the bottom lines indicate the emissions of each panel's respective scenario. The colored bands between these lines represent the contribution of each vehicle segment to the emission reductions. The larger the width of a segment, the larger the projected reduction from the Baseline scenario.

Figure 5

GHG emission reductions by vehicle segment with respect to the Baseline scenario



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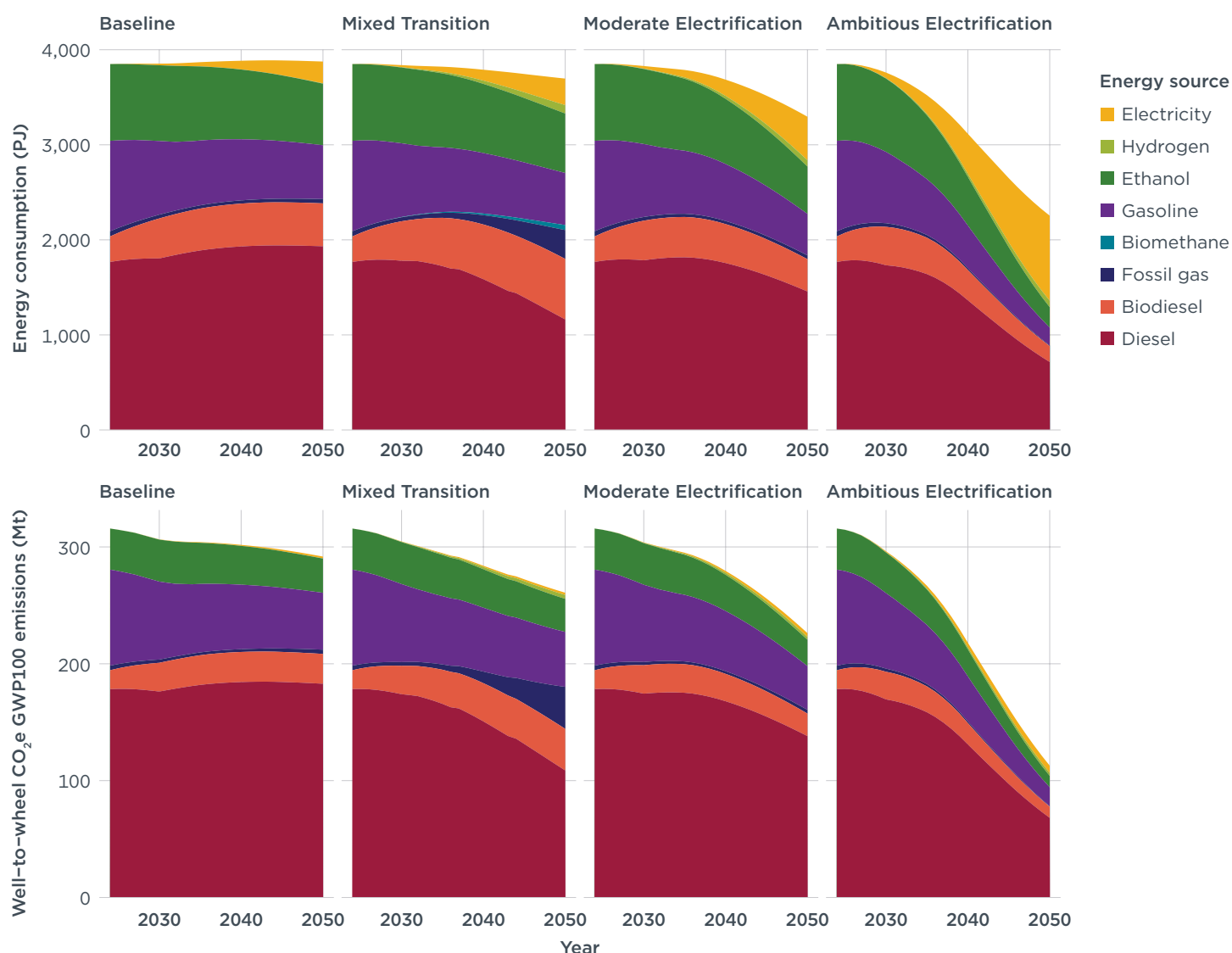
Avoided emissions from HDVs (HDTs and MDTs) and LCVs play a leading role in the transition to a less carbon-intensive road transportation sector. The gap between the Baseline scenario and the alternative pathways is primarily driven by emission reductions in these segments, which are typically diesel based, long haul, and highly

energy-intensive. The main differences between Baseline and Mixed Transition scenarios are the increase in biodiesel use, the expansion of FCEV and CNG shares in the HDT and MDT segments, and the broader adoption of PHEVs in the LDV segment. These measures impact the HDT, MDT, and LCV segments most. As we move from the Baseline to the Moderate and Ambitious Electrification scenarios, the relative importance of PCs in decarbonization increases proportionally to the speed of the ZEV transition. This dynamic is represented in the first panel, where diesel-dependent segments dominate, while in the Ambitious Electrification scenario, avoided emissions are more evenly distributed across all segments. Motorcycles remain a minor contributor due to their low emission levels relative to the other segments, even in the Baseline scenario.

Figure 6 illustrates the evolution of the total energy consumption (top panels) and CO₂e emissions (bottom panels) by energy source for all scenarios. Each energy source is represented by a color. The width of each color band represents the amount of energy or CO₂e emissions relative to that energy source.

Figure 6

Evolution of energy consumption (top) and GHG emissions (bottom) by source



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The results show that in both the Baseline and Mixed Transition scenarios, the total energy demand will remain approximately constant between 2025 and 2050. As shown in Figure 4, this process is explained by the slow improvements in the fleet's energy efficiency, counterbalanced by the increase in the size of the fleet. Despite the slower BEV uptake compared with the other scenarios, an increase in electric energy demand can be observed over time in the Baseline and Mixed Transition scenarios. The expansion of biodiesel, CNG, and biomethane over diesel is notable in the Mixed Transition scenario, which also depicts an increase in hydrogen demand. This transition has an impact on the evolution of the CO₂e emissions, which decrease faster in the Mixed Transition scenario than in the Baseline scenario.

There is a considerable decrease in the overall energy demand in both the Moderate and Ambitious Electrification scenarios. The energy efficiency gains caused by the faster ZEV transition outweigh fleet growth, reducing overall energy demand. In these scenarios, the increase in electricity demand is considerable, but its share of the total emissions continues to be lower than that of liquid fuels, due to the low carbon intensity of the electricity grid in Brazil.

The model projects fossil fuel demand in the Ambitious Electrification scenario in 2050, even though no new combustion engine vehicles will be sold in that year. This demand (and the associated emissions) come from the remaining fleet of ICEVs on the road.

DISCUSSION AND CONCLUSION

In this study, we modeled WTW CO₂e emissions of the Brazilian transportation sector under four scenarios between 2025 and 2050. The Baseline scenario, representing current trends without the adoption of additional decarbonization measures, was projected to have the highest emission levels by 2050, estimated to be only 7% lower than in 2025. The Mixed Transition scenario evaluated an increase in biofuel blends and a greater market share of PHEVs among passenger cars and of FCEVs and CNG ICEVs among buses and heavy trucks. Emissions in this scenario in 2050 were projected to be 17% lower than in 2025. The Moderate Electrification scenario included the same biofuel blends as the Baseline scenario and added electrification targets aligned with those from Mexico, Colombia, Chile, and Ecuador, which yielded a 28% reduction of CO₂e emissions from 2025 to 2050. The Ambitious Electrification scenario featured the fastest electrification pace across all vehicle segments, leading to CO₂e levels in 2050 that were 64% lower than in 2025, the greatest reduction of all scenarios.

Because BEVs are more energy efficient, they need less energy to drive the same distance and emit less CO₂e compared with ICEVs.³⁸ The reduction in energy consumption provided by electrification is such that in both the Moderate and Ambitious Electrification scenarios, the total energy demand by 2050 was projected to be 14.5% and 41.5% lower, respectively, than in 2025 despite 27% fleet growth. The Kaya Identity analysis demonstrated that electrification could improve both the fleet's energy efficiency and the emission factors of the energy sources due to the low carbon intensity of Brazil's electric grid.

Considering these results within Brazil's current policy and automotive industry context, this analysis suggests that battery electric vehicles offer the most effective pathway toward mitigating emissions from Brazil's vehicle fleet. The introduction of electrification targets in Brazil, as well as stricter emission targets in the second

38 Guido Haytzmman and André Cieplinski, *Tecnologias de Propulsão e Emissões de CO₂e: Comparação de Veículos Elétricos e Híbridos no Brasil* [Propulsion technologies and CO₂e emissions: Comparison of electric and hybrid vehicles in Brazil] (International Council on Clean Transportation, 2025), <https://theicct.org/publication/pt-tecnologias-de-propulsao-e-emissoes-de-co2e-mar25/>.

phase (2028–2032) of the MOVER Program, can incentivize BEV sales and domestic production. Non-financial incentives for ZEVs, such as access to low- and zero-emission zones, road access privileges, and dedicated parking spaces, can provide effective incentives in urban settings.

Vehicle segments with more intensive use cases, such as HDVs and LCVs, are crucial for the decarbonization of the road transportation sector. The current fleets of HDVs and LCVs primarily use diesel, and HDTs in particular combine intensive use with a long service life, meaning that many of the trucks sold over the next 10 years could still be operating in 2050.³⁹ In this context, increasing blends of low-carbon biofuel, although not a substitute for electrification, could serve as a transitional measure to reduce emissions from the circulating fleet. Electrification of LCVs is generally easier to implement as these vehicles typically operate in urban settings and have the possibility of depot charging, whereas HDV electrification remains challenging in Brazil, requiring substantial public and private investment in charging networks beyond major urban centers. Considering the importance of HDVs for the decarbonization of Brazil's transportation sector, identifying key corridors and cities to increase the availability of public charging infrastructure is important to spur electrification of the segment.

³⁹ Thiago Rodrigues, *Evolução do Mercado de Veículos Pesados no Brasil* [Evolution of the heavy vehicle market in Brazil] (International Council on Clean Transportation, 2025), <https://theicct.org/publication/evolucao-do-mercado-de-veiculos-pesados-no-brasil-apr25/>.



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