Anfavea

Decarbonization Pathways for the Automotive Sector in Brazil

Craddle to grave perspective

Publication Report

OCTOBER 13TH 2025

About the study

Study conducted during the second half of 2025 in partnership with ANFAVEA (National Association of Automotive Vehicle Manufacturers) and BCG, with the objective of assessing greenhouse gas emissions “cradle-to-grave” in the Brazilian automotive supply chain, in comparison with other relevant geographies.

This study builds on existing research and BCG’s experience to contribute to discussions on decarbonization of the supply chain.

Throughout the study, technical sessions, collaborative workshops, and comparative analyses were carried out, aiming to identify and debate the opportunities, challenges, and drivers for sector decarbonization together with ANFAVEA members.

Glossary of Terms Used in This Document

LCA: Life Cycle Assessment

B100: Vehicles powered by 100% biodiesel

B0/7/15/25: Vehicles powered with 0/7/15/25% biodiesel mix in gasoline

Cradle-to-grave: evaluation of the complete vehicle lifecycle (from raw material extraction to recycling)

BEV: Battery Electric Vehicles

H2: Vehicles powered by hydrogen (internal combustion or fuel cell)

CO2e: equivalence of emissions from different greenhouse gases

E100: Vehicles powered by 100% ethanol

E2/7/10/20/30/35: Vehicles powered with 2/7/10/20/30/35% ethanol mix in gasoline

FE: CO2e emission factor

Flex: Vehicles with flex-fuel engine (gasoline/ethanol)

GHG: Greenhouse gases (CO2, CH4, N2O, others)

ICEV: Internal Combustion Engine Vehicles

Brazilian average: average fuel consumption in Brazil (ethanol and gasoline)

HEV/MHEV: Hybrid and/or mild hybrid vehicles

PHEV: Plug-in hybrid vehicles

Well-to-wheel (WTW): emissions from fuel/energy production and distribution to vehicle use

xEV: Electrified vehicles (MHEV, HEV, PHEV, BEV)

xNG: Vehicles powered by gas (CNG, biomethane)

Contents |

Decarbonization Pathways for the Automotive Sector in Brazil: A Lifecycle Perspective

General context and perspectives for the automotive sector

Lifecycle methodology for measuring emissions in the automotive supply chain

Results of the comparative analysis of the Brazilian automotive supply chain versus other regions

Scenario development for potential impacts on vehicle emissions in Brazil

Contents |

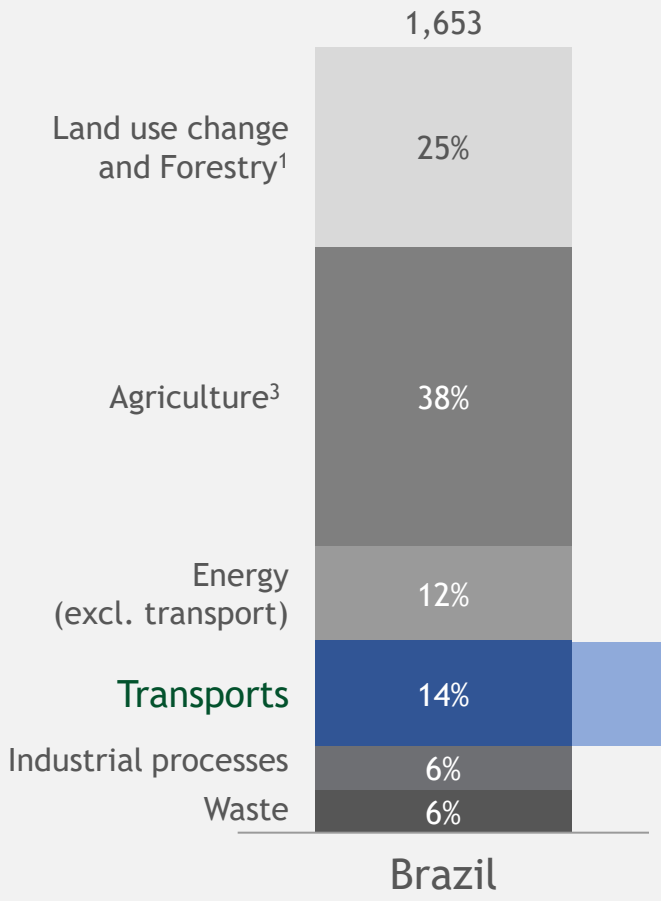
Decarbonization Pathways for the Automotive Sector in Brazil: A Lifecycle Perspective

1. General context and perspectives for the automotive sector
2. Lifecycle methodology for measuring emissions in the automotive supply chain
3. Results of the comparative analysis of the Brazilian automotive supply chain versus other regions
4. Scenario development for potential impacts on vehicle emissions in Brazil

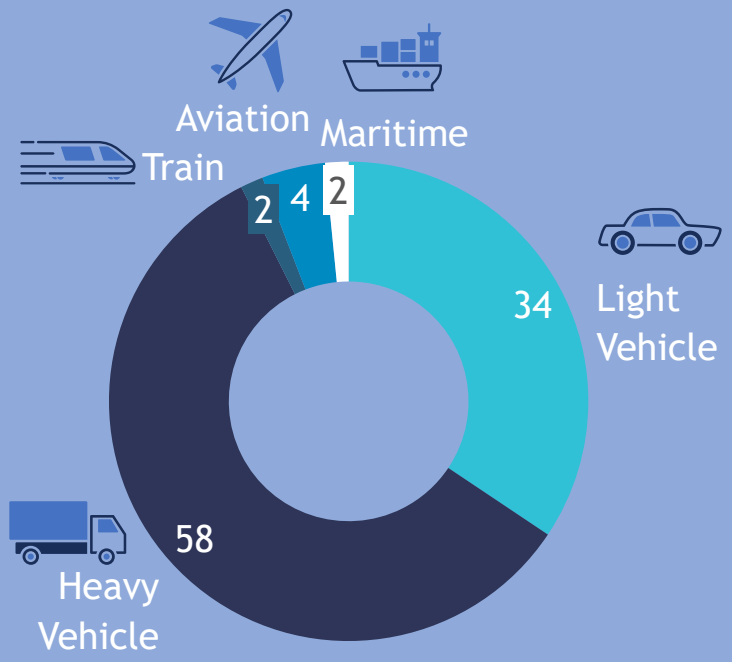
With reference to the study Advancing on the pathways of automotive decarbonization in Brazil (2024)

In Brazil, road transport is the most relevant for transport emissions

Net emissions by sector (MtCO2e-2023)



Road transport accounts for over 90% of all emissions in the transport sector

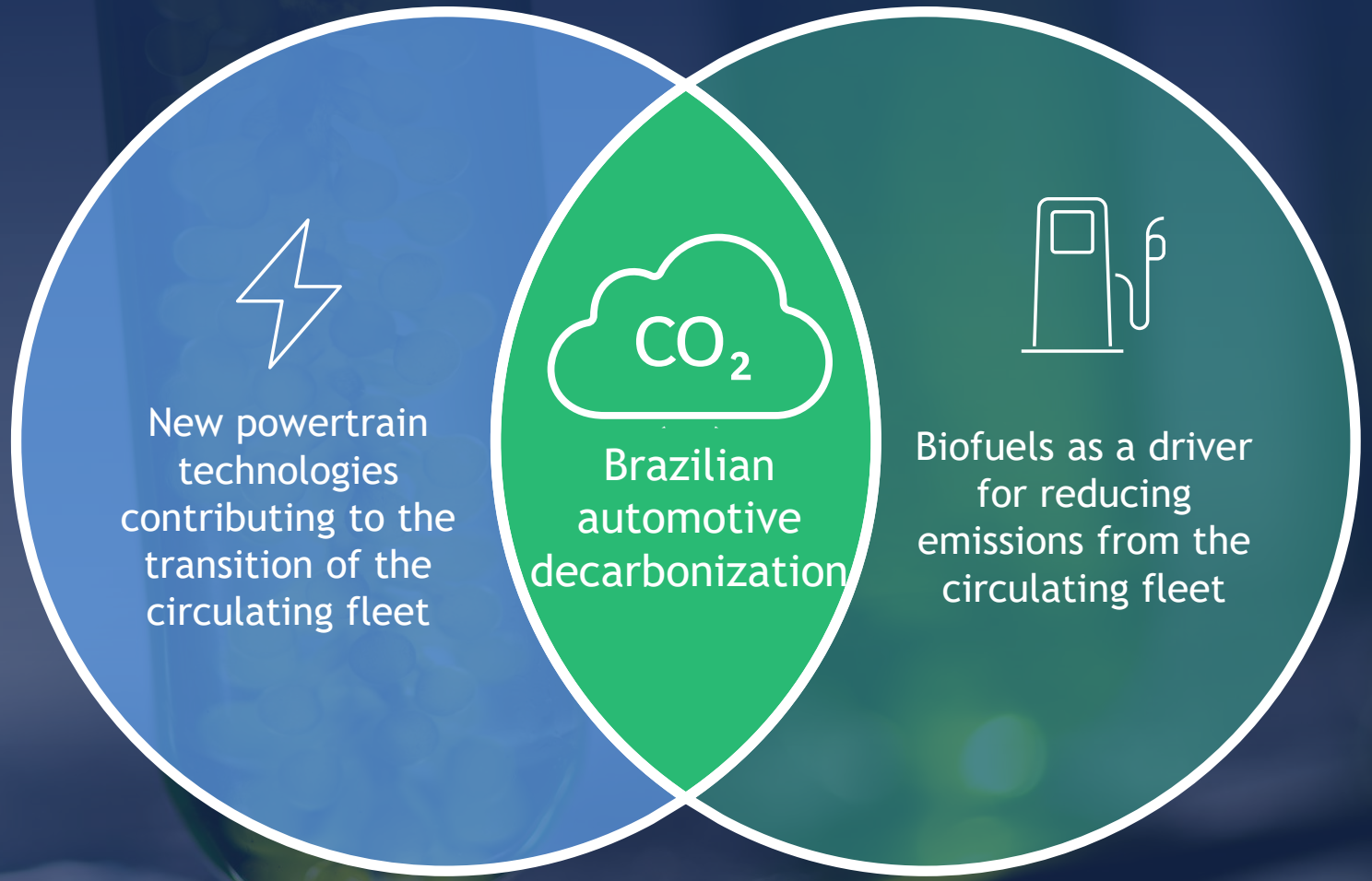


Road transport: emission of 200 Mt of CO_2e in Brazil in 2023[4]

1. Considers CO_2 capture and release: atmospheric due to land use change (e.g., forest area converted to agricultural area). Negative values may exist for changes in land use that capture atmospheric CO_2. 2. Includes United Kingdom in EU. 3. Includes fertilizers. 4. Emissions associated with the tank-to-wheel use phase.
Source: SEEG, CAIT, BCG Analysis

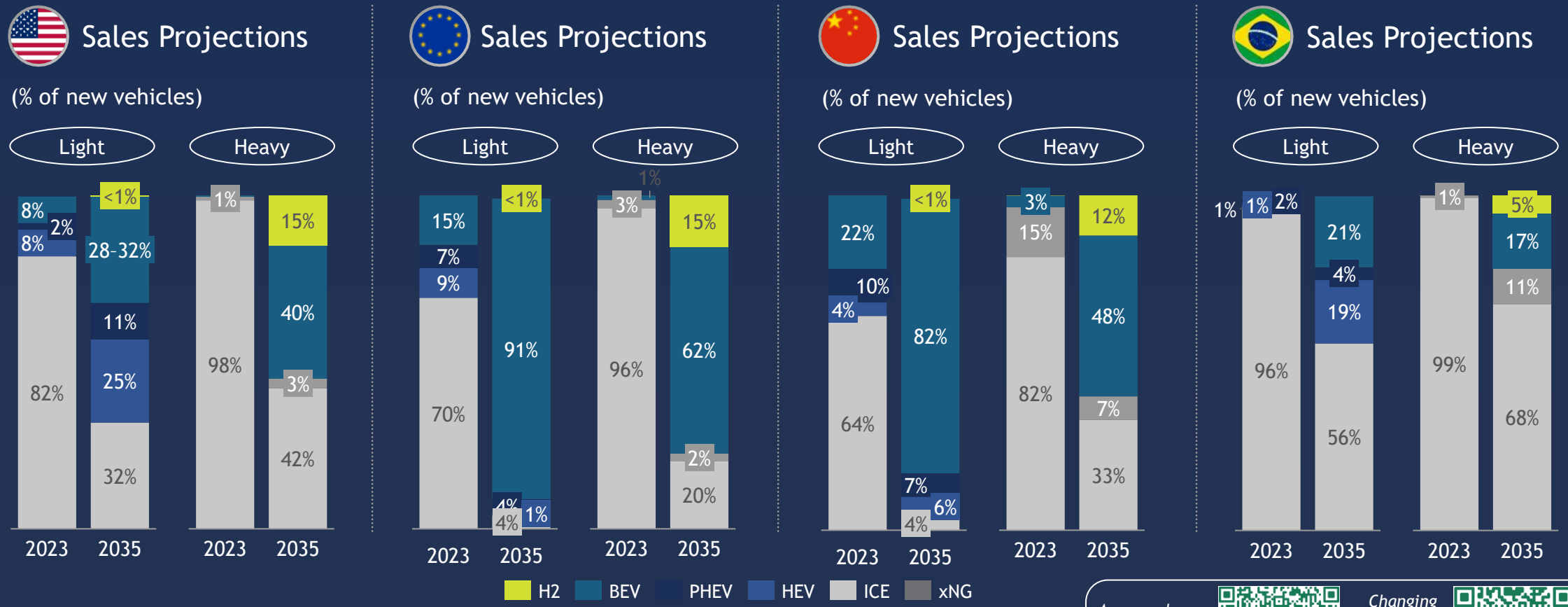
With reference to the study *Advancing Pathways for Automotive Decarbonization in Brazil, 2024*

Brazil has the potential to combine new powertrain technologies and the application of biofuels as drivers for decarbonizing the automotive sector



Projections show growth of EVs — Brazil follows a gradual pace, particularly due to the contribution of biofuels

BCG estimates for 2035



Note: Includes light-duty vehicles <3.5t; EU27: EU27 + EFTA + UK; Mainland China; FCEV = fuel cell electric vehicle, BEV = 100% electric vehicles, PHEV = plug-in hybrid vehicle, HEV = hybrid electric vehicle, ICE = internal combustion (diesel + gasoline+ MHEV) MHEV = mild hybrid Vehicle; Heavy projections based on BCG model from 2023; includes Medium and Heavy Duty trucks >6t Gross Vehicle Weight (GVW); Source: S&P GADT (03/2025), BCG Powertrain model (05/2025).

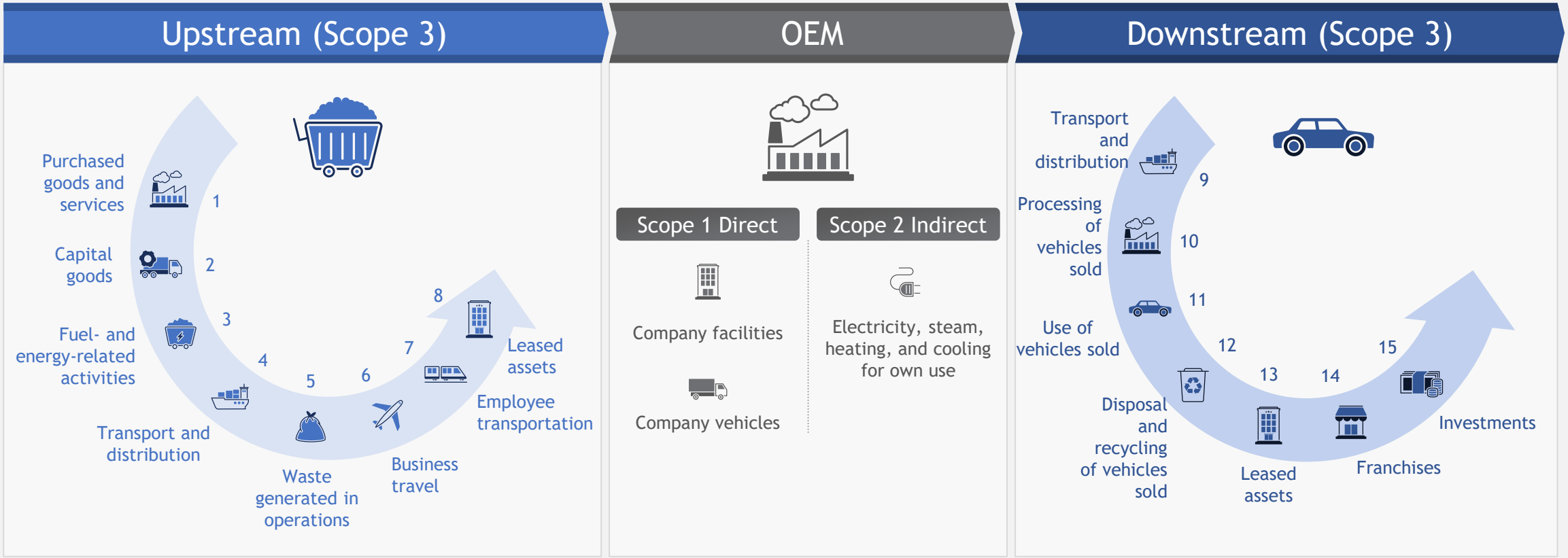
Avançando nos Caminhos da Descarbonização Automotiva no Brasil (2024)

Changing Lanes: EV Strategies in the US, Europe, and China (2025)

This study seeks to assess the entire automotive value chain to identify the main sources of emissions

OEM emissions by scope (%)

Light Vehicles Heavy Vehicles



For OEMs, over 90% of emissions are concentrated in Scope 3, linked to vehicle use and the supply chain

Source: GHG Protocol, BCG analysis

Contents |

Decarbonization Pathways for the Automotive Sector in Brazil: A Lifecycle Perspective

General context and perspectives for the automotive sector

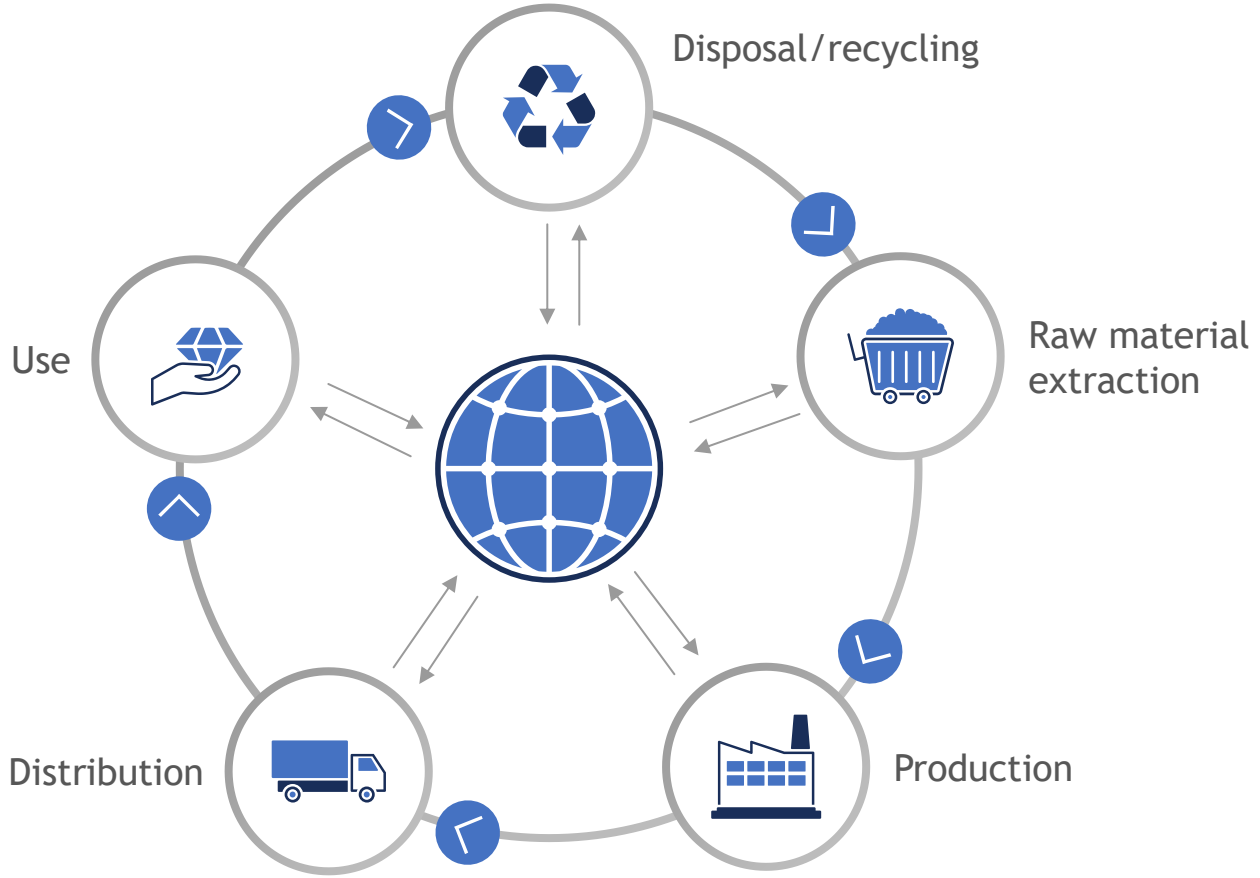
Lifecycle methodology for measuring emissions in the automotive supply chain

Results of the comparative analysis of the Brazilian supply chain versus other regions

Scenario development for potential impacts on vehicle emissions in Brazil

The study adopts the Life Cycle Assessment methodology to measure emissions associated with the vehicle

- Life Cycle Assessment is a quantitative analysis of the environmental impacts of a product, process, or service
- With LCA, it is possible to assess the environmental impacts of a given product or service at any stage of the lifecycle



Source: GHG protocol; ISO 14067, analysis BCG

GHG emissions were calculated based on activity data and emission factors related to the vehicle lifecycle

CO_2e

CO_2 equivalent

Metric defined by the IPCC that consolidates all greenhouse gases based on global warming potential (GWP-100)

=

Activity level

Indicators of activities related to vehicle production, use, and end of life

Ex: *kilometers driven, liters of fuel consumed, kWh of energy for assembly, kg of steel or aluminum for production*

X

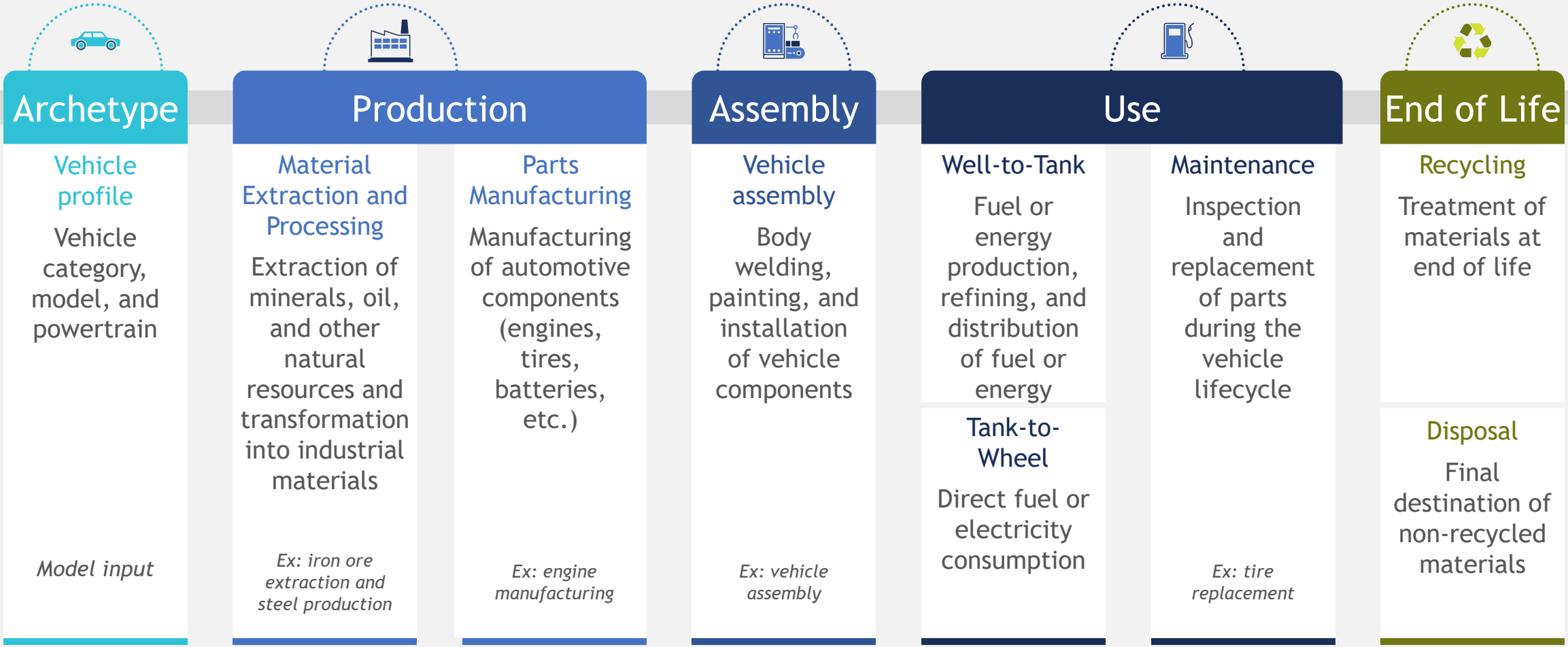
Emission factor

Emission per unit of activity, based on life cycle assessment (LCA) and scientific sources

Ex.: *X gCO2e/L of ethanol, X gCO2e/kg of steel, X gCO2e/kWh*

Source: GHG protocol; ISO 14067, BCG analysis

Analysis considers the lifecycle stages with the greatest impact, structured from raw material extraction to vehicle disposal



A set of common assumptions regarding vehicle profile and use are considered to enable comparability between markets

Vehicle Archetypes

- Medium light-duty vehicles (Otto cycle engine, hybrid and electric motors) and heavy-duty vehicles (Urban truck, urban bus, long-haul truck)
- Standardized mass and material composition
- Same energy efficiency profile (km/l, kWh/100km or kg/100km) across all geographies
- Standard assumed service life, as per CONAMA and PROCONVE Resolution:
  - Light-duty: 160,000 km
  - Urban truck: 300,000 km
  - Urban bus and long-haul truck: 700,000 km

Production and Assembly

- Origin of materials considered local (no import or export)
- Batteries produced locally, except in Brazil (imported from China)
- Stage includes energy consumption from part manufacturing and final assembly, as well as inbound/outbound transportation

Use

- Biofuel and fossil fuel blend defined based on current mandate, average country consumption, and Future Fuel Program guidelines
- Maintenance limited to tire replacement and engine oil change

End of Life

- Main impact related to energy consumption in the process of disposal
- Recycling credits applied to selected materials, when recovery is feasible

All assumptions are standardized across geographies to ensure comparability of archetypes

Source: BCG analysis

Contents |

Decarbonization Pathways for the Automotive Sector in Brazil: A Lifecycle Perspective

General context and perspectives for the automotive sector

Lifecycle methodology for measuring emissions in the automotive supply chain

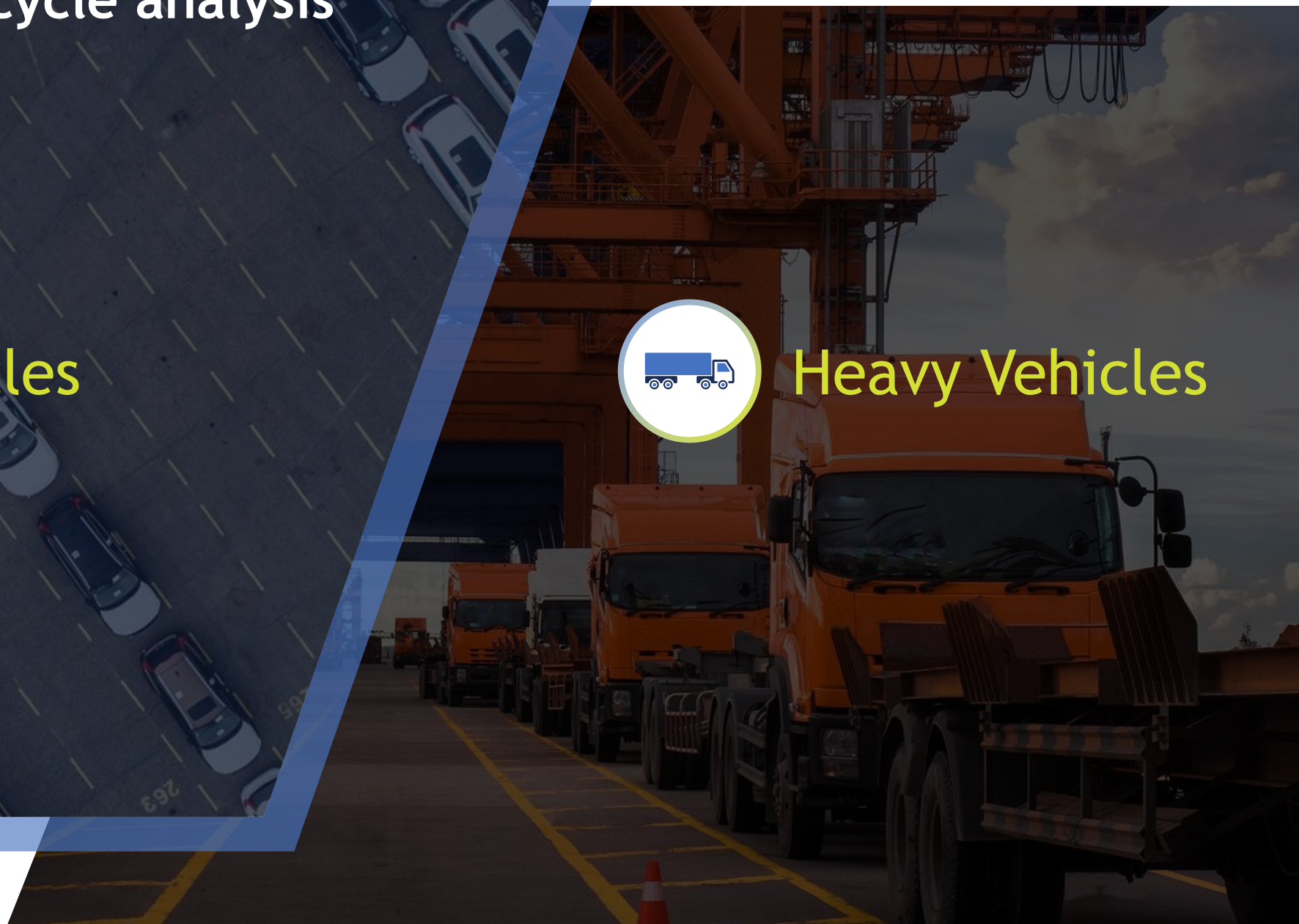
Results of the comparative analysis of the Brazilian supply chain versus other regions

Scenario development for potential impacts on vehicle emissions in Brazil

Results of the lifecycle analysis

Light Vehicles

Heavy Vehicles



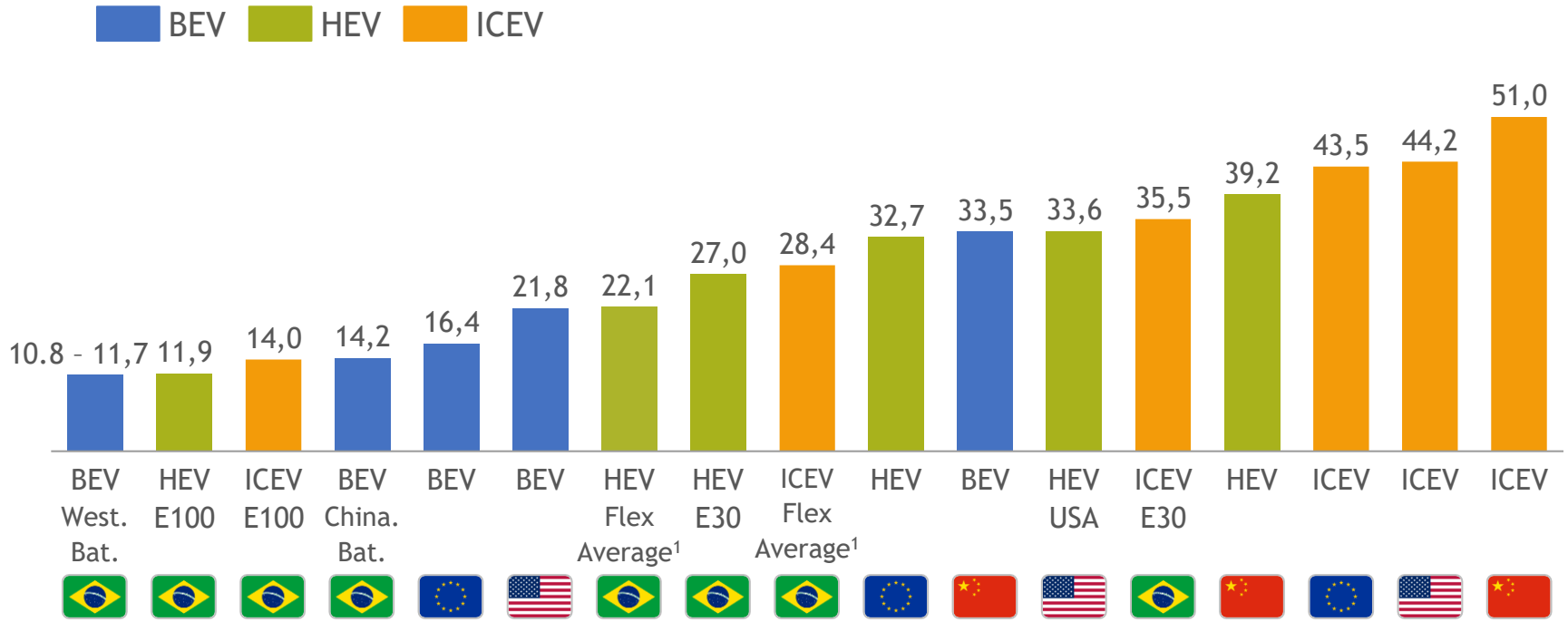
Results of the lifecycle analysis

Light Vehicles

Heavy Vehicles

Brazil has a comparatively lower emissions profile among the geographies analyzed— highlight for BEVs and ethanol powertrains

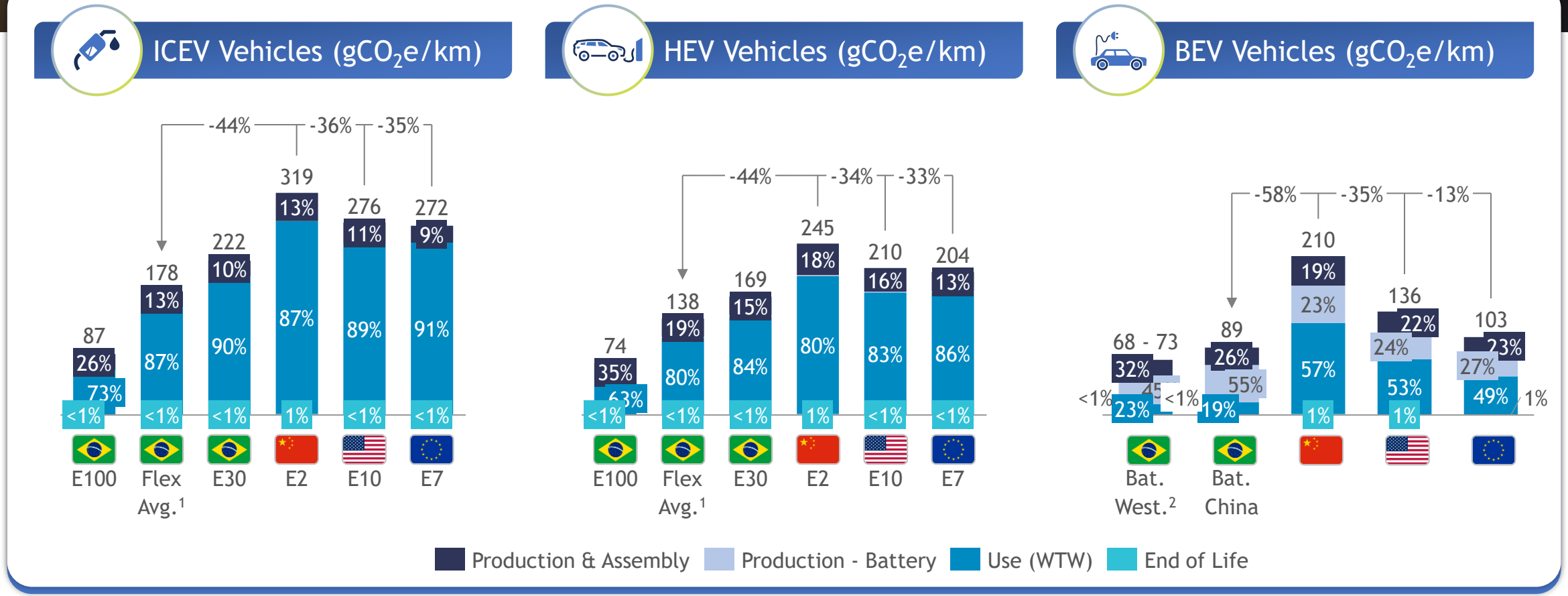
Light vehicle emissions along the lifecycle by country of production and use (ton CO_2e/lifetime)



- Brazil starts from a lower emissions baseline, due to a 90% renewable electricity matrix, reducing the footprint throughout the chain
- In all peer comparisons, electric vehicles present the lowest emission profile being the long term decarbonization solution
- Ethanol and Flex technology provide a unique advantage for Brazil, enabling emissions reduction immediately in the current fleet, while electrification gradually progresses

1. Brazilian Average: ~33% hydrous ethanol and ~67% gasoline (with 30% anhydrous ethanol); 2. Cradle-to-grave emissions of BEVs vary according to battery origin: Europe: 10.8 tCO_2e; USA: 11.7 tCO_2e; China: 14,2 tCO_2e. Brazil E30: exclusive use of gasoline (30% anhydrous ethanol). Brazil E100: 100% ethanol. Ethanol content in gasoline by region: Brazil (30%), US (10%), China (2%), EU27 (7%). Considers only Otto cycle engines. Battery production emission factor for BEV and HEV: Brazil and China (131 kgCO2e/kWh), USA (88 kgCO2e/kWh), EU27 (74 kgCO2e/kWh). Sources: GREET (Argonne National Laboratory), Joanneum Research (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, EPE, ICCT (Comparison of the Life-Cycle GHG Emissions of Combustion Engine and Electric Passenger Cars), Green NCAP (Life Cycle Assessment Methodology and Data), IEA (LCA Methodology and emission factors of the energy matrix by region), European Commission, European Environment Agency, PROCONVE, INMETRO, International Copper Association, ANP, BCG analysis.

Use accounts for the largest share of emissions in the lifecycle of combustion vehicles; for electric vehicles, battery production stands out



Note: 1. Brazilian Average: ~33% hydrous ethanol and ~67% gasoline (with 30% anhydrous ethanol). 2. Cradle-to-grave emissions of BEVs vary according to battery origin: Europe: 68 gCO_2e/km; USA: 73 gCO_2e/km; China: 89 gCO_2e/km. Brazil E100: 100% ethanol. Ethanol content in gasoline by region: Brazil (30%), USA (10%), China (2%), EU27 (7%). Only considers Otto cycle engines. Battery production emission factor in BEV and HEV: Brazil and China (131 kgCO2e/kWh), USA (88 kgCO2e/kWh), EU27 (74 kgCO2e/kWh). Sources: GREET (Argonne National Laboratory), Joanneum Research (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, EPE, ICCT (Comparison of the Life-Cycle GHG Emissions of Combustion Engine and Electric Passenger Cars), Green NCAP (Life Cycle Assessment Methodology and Data), IEA (LCA Methodology and emission factors by energy matrix and region), European Commission, European Environment Agency, PROCONVE, INMETRO, International Copper Association, ANP, BCG analysis.

Light Vehicles | Key Comments

Brazil has a competitive advantage in low-emissions vehicles, even with a gradual adoption of electric vehicles

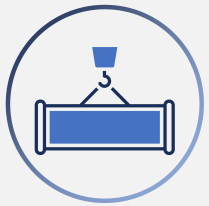
Light-duty vehicles in Brazil have comparative lower footprint than in other markets, thanks to ethanol and the renewable power matrix

Currently, ethanol is a solution with lifecycle emissions close to to BEVs in Brazil

When considering the entire supply chain with the cradle-to-grave methodology, etanol vehicles in Brazil are close to BEVs, reinforcing the role of biofuel in decarbonization

Electric vehicles have lower lifecycle emissions, though important to highlight the influence of battery production

When the battery comes from geographies with a fossil-based power matrix and more emissive technology, as currently observed in China, the footprint of BEVs increases

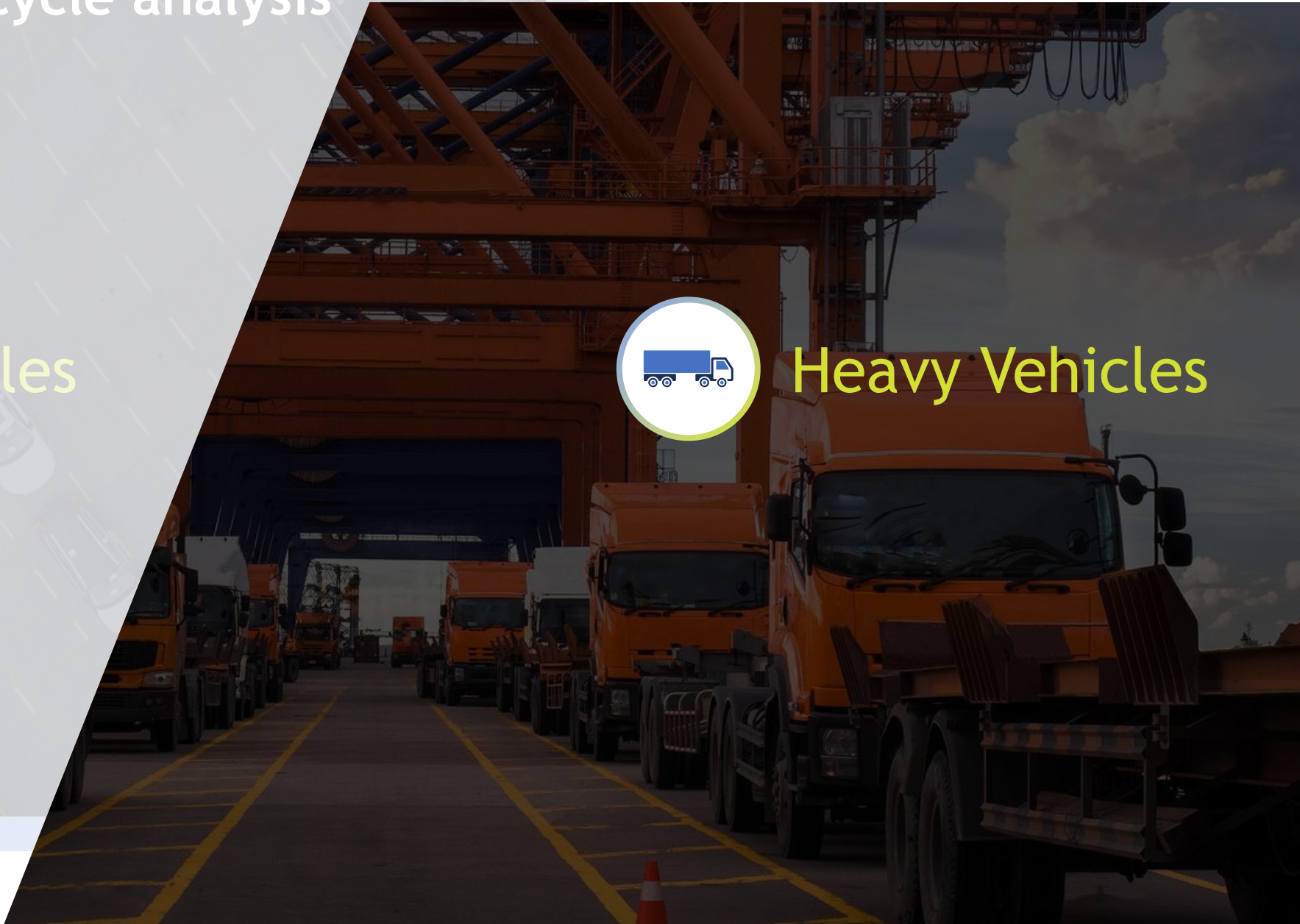


With lower emissions in use and operation, Scope 3 upstream decarbonization gains relevance

Brazil already performs favorably in Scopes 1, 2, and 3 downstream; further emission reduction opportunities lie in decarbonizing the supply chain (Scope 3 upstream)

Results of the lifecycle analysis

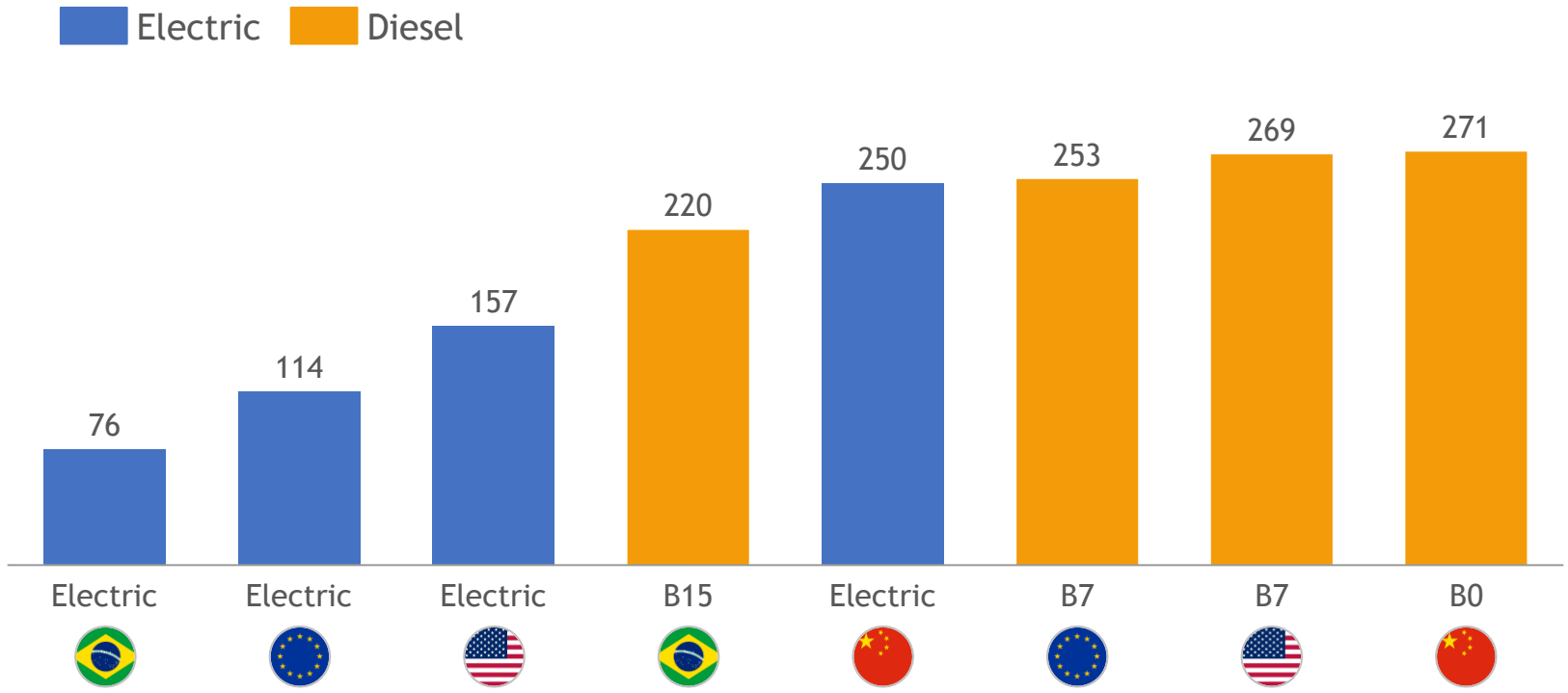
Light Vehicles



Heavy Vehicles

Urban Truck | Renewable electricity matrix enables lower emissions from heavy-duty vehicles produced and used in Brazil

Heavy vehicle emissions over the lifetime by country of production and use (ton CO_2e/useful life)

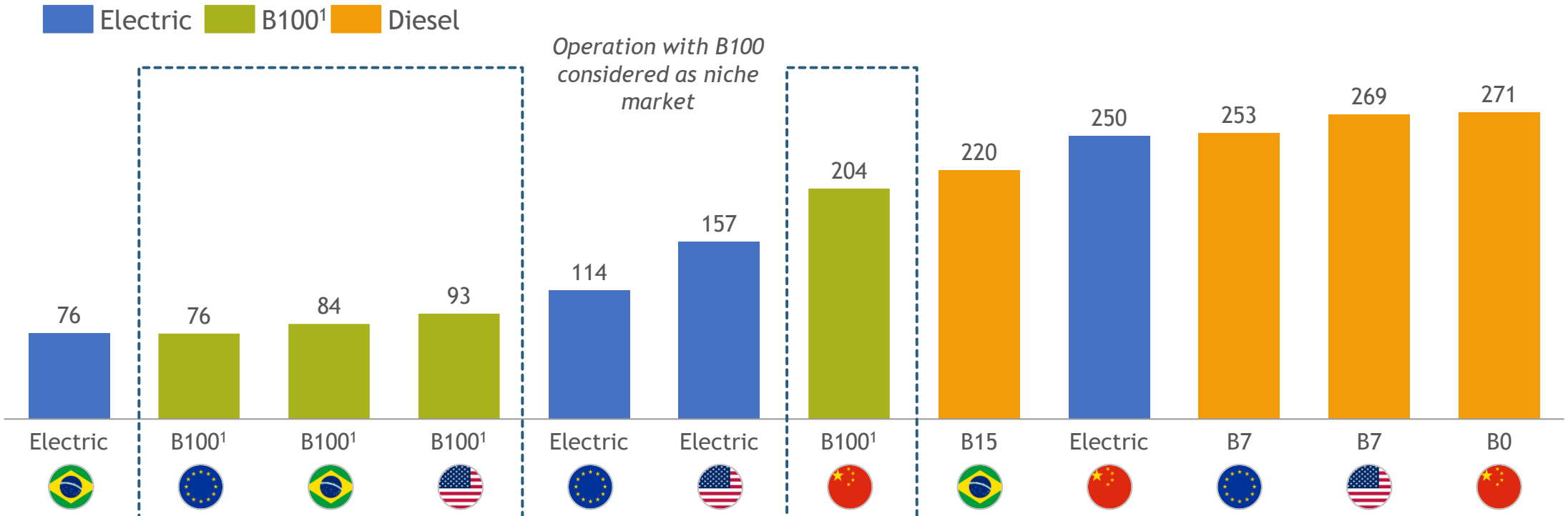


- Renewable energy matrix is a differentiator for Brazil, significantly reducing electric vehicle emissions
- Electric vehicles have the lowest emissions in all countries analyzed
- The higher the proportion of biofuel in diesel, the lower the carbon footprint (highlight for B15 in Brazil); however, scale requires guaranteed supply and compliance with quality specifications

Note: 1. Operation with B100: niche market. B15 = blend with 15% biodiesel, per Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the US. Biodiesel considered without ILUC, with the following emission factors (gCO_2e/MJ): Brazil: 28.4 (EPE); EU27: 25.1 (EEA); US: 31.4 (LCFS); China: 74.7 (academic literature). Diesel considered 100% fossil, without co-processing. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

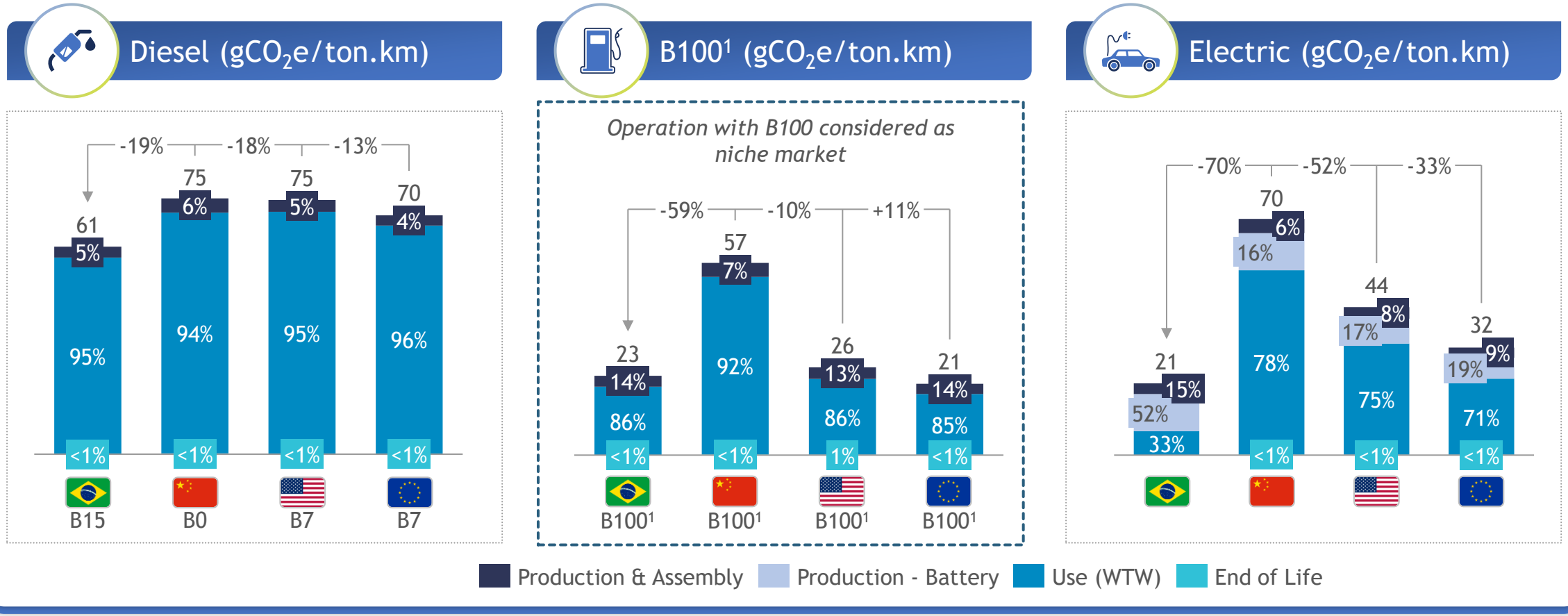
Urban Truck | B100 reduces emissions vs. diesel in most geographies, but application remains niche in the market

Heavy vehicle emissions over the lifecycle by production country and use (ton CO_2e/lifetime)



Note: 1. Operation with B100: niche market. B15 = blend with 15% biodiesel, according to Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the US. Biodiesel without ILUC considered, with the following emission factors (gCO2e/MJ): Brazil: 28.4 (EPE); EU27: 25.1 (EEA); US: 31.4 (LCFS); China: 74.7 (academic literature). Diesel considered is 100% fossil, without co-processing. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

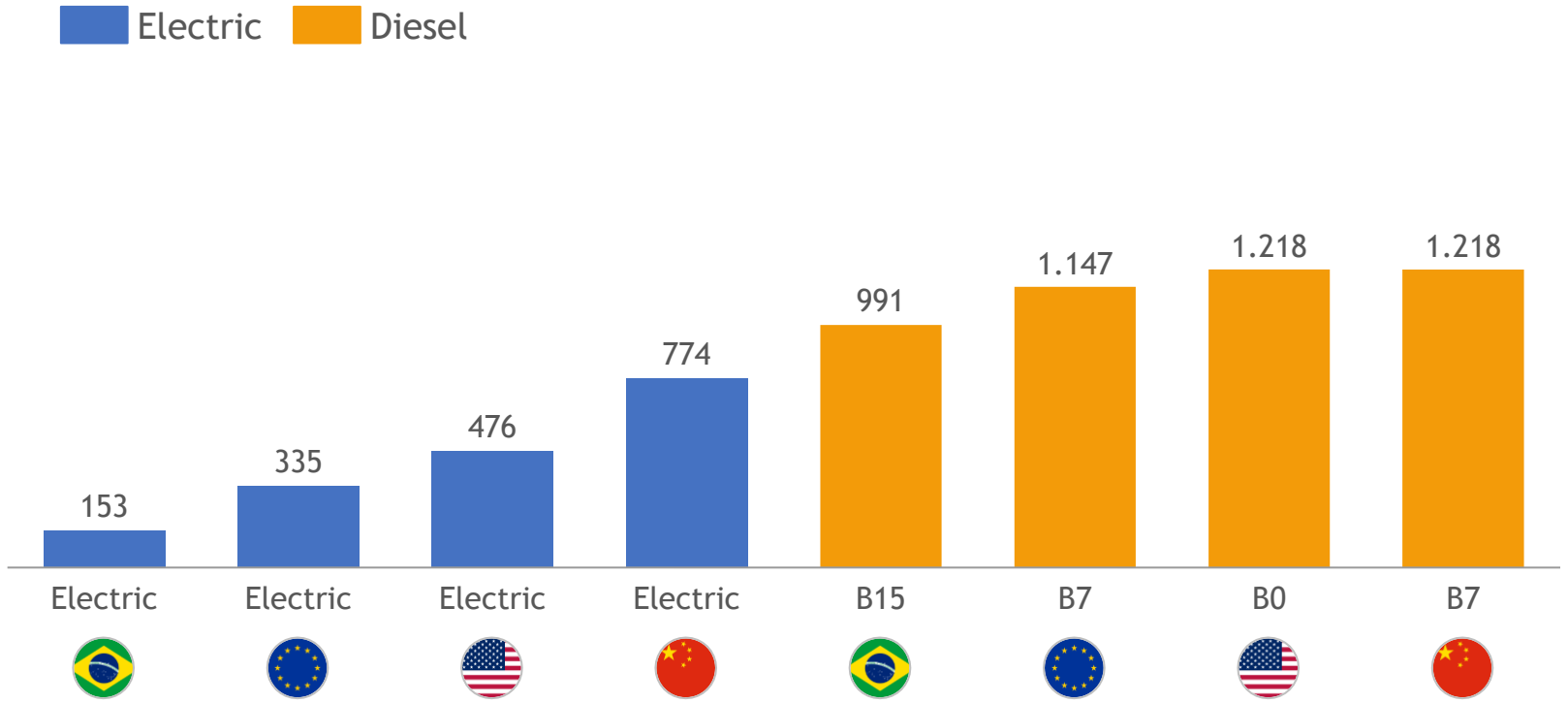
Urban Truck | WTW is the largest source of vehicle emissions, except for Brazilian electric vehicles due to the clean energy matrix



Note: 1. Operation with B100: market niche. B15 = blend with 15% biodiesel, according to Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the United States. Biodiesel is considered without ILUC, with the following emission factors (gCO2e/MJ): Brazil: 28.4 (EPE); EU27: 25.1 (EEA); USA: 31.4 (LCFS); China: 74.7 (academic literature). Diesel considered is 100% fossil, without co-processing. Assumes gross vehicle weight of 12 tons. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

Urban Bus | Electric in Brazil with lowest emissions, +50% below other powertrains and markets analyzed

Heavy vehicle emissions over the lifecycle by country of production and use (ton CO_2e/lifetime)

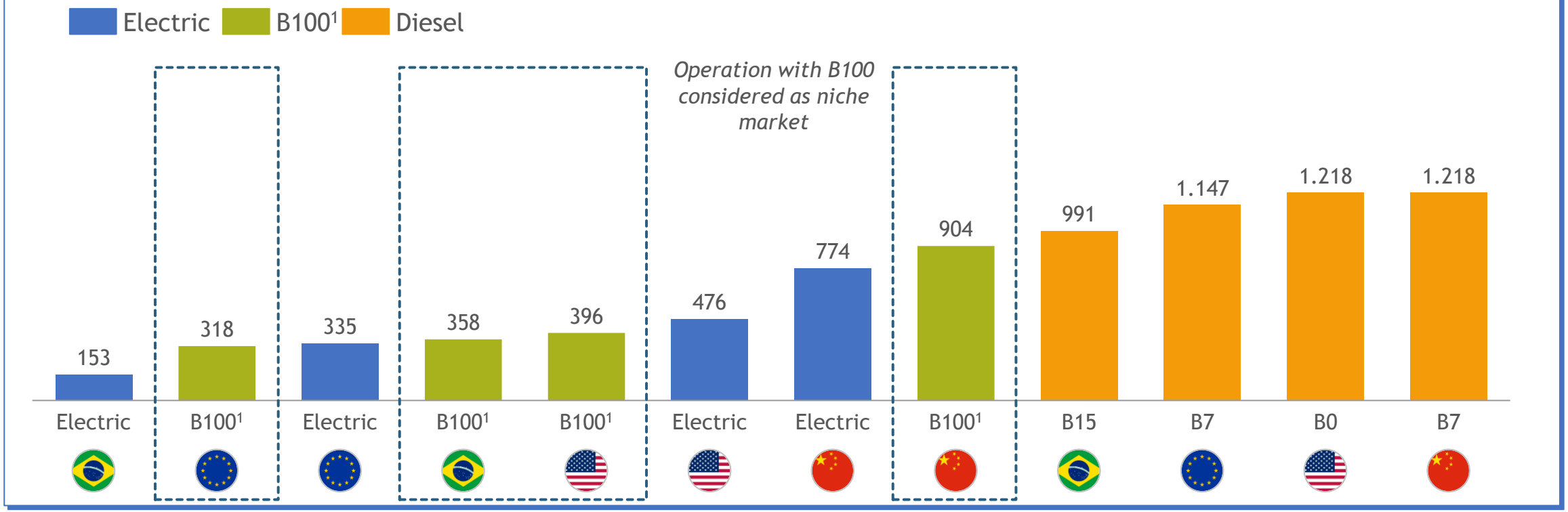


- Use dominates emissions in the bus lifecycle, especially with 700,000 km of useful life
- Production and use of electric heavy vehicles in Brazil have the lowest lifecycle emissions from markets analyzed — more than 50% below other options
- More biodiesel, lower emissions — Brazilian B15 stands out compared to lower blends from other countries; however, scale is only viable with supply security and guaranteed technical specifications

Note: 1. Operation with B100: market niche. B15 = blend with 15% biodiesel, following Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the US. Biodiesel assumed without ILUC, with the following emission factors (gCO2e/MJ): Brazil: 28.4 (EPE); EU27: 25.1 (EEA); USA: 31.4 (LCFS); China: 74.7 (academic literature). Diesel assumed to be 100% fossil, with no co-processing. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

Urban Bus | Lower emissions with B100 compared to diesel in most markets; however, use remains restricted to niches

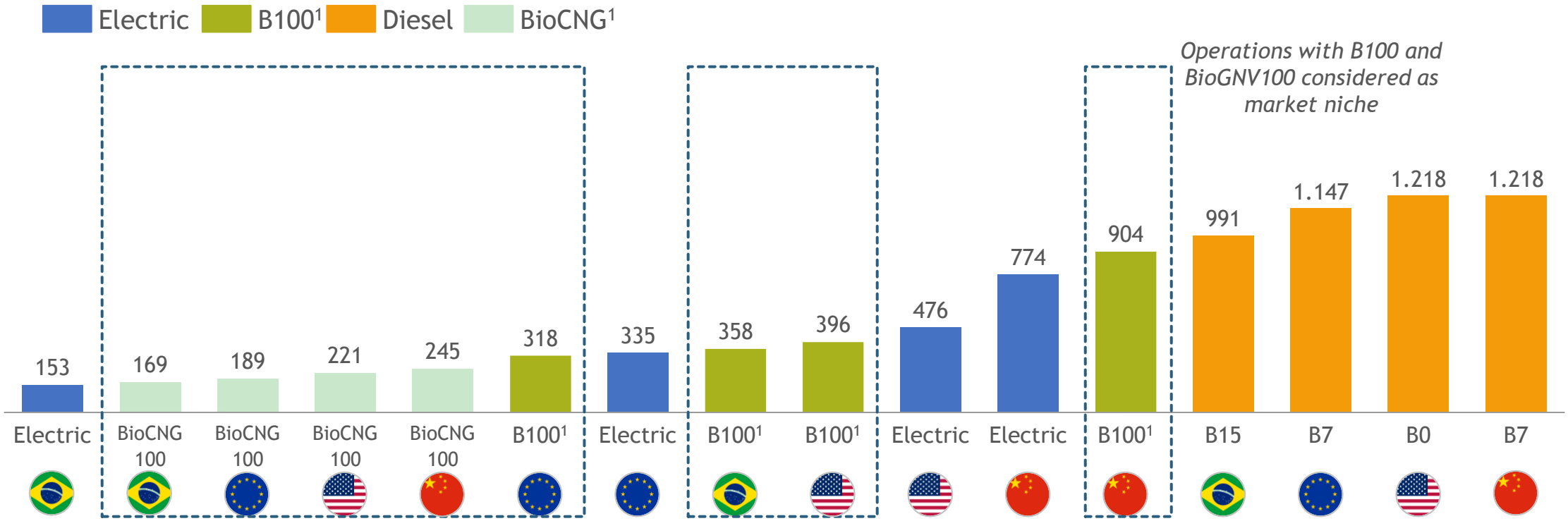
Heavy vehicle emissions over the lifecycle by country of production and use (ton CO_2e/useful life)



Note: 1. Operation with B100: niche market. B15 = blend with 15% biodiesel, in accordance with Future Fuel Program guidelines; B7 = average 7% mandate in EU27 and the US. Biodiesel is considered without ILUC, with the following emission factors (gCO_2e/MJ): Brazil: 28.4 (EPE); EU27: 25.1 (EEA); US: 31.4 (LCFS); China: 74.7 (academic literature). Diesel is considered 100% fossil, without co-processing. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

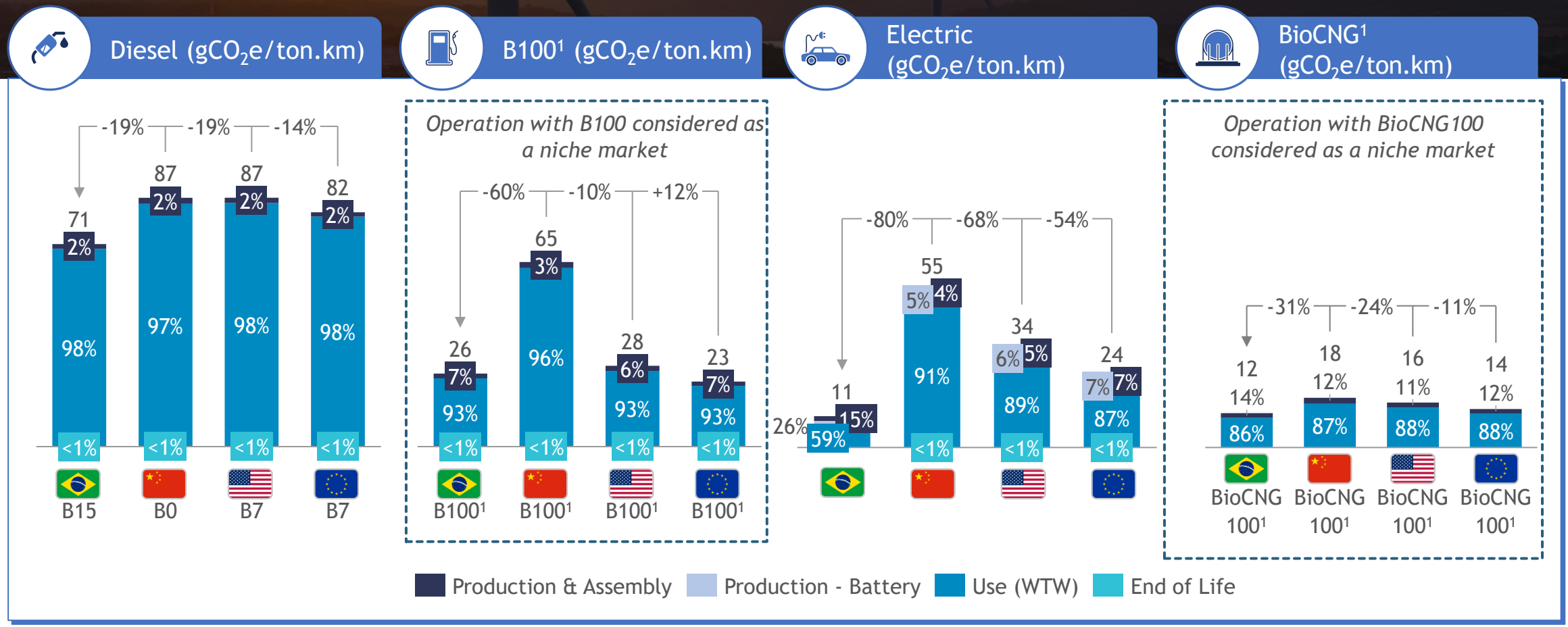
Urban Bus | BioCNG100 with emissions similar to the Brazilian electric vehicle, with significant reduction compared to other powertrains

Heavy vehicle emissions over the lifecycle by country of production and use (ton CO_2e/useful life)



Note: 1. Operation with B100 and BioCNG100: market niche. B15 = blend with 15% biodiesel, according to Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the USA. Biodiesel is considered without ILUC, using the following emission factors (gCO_2e/MJ): Brazil: 28.4 (EPE); EU27: 25.1 (EEA); USA: 31.4 (LCFS); China: 74.7 (academic literature). Diesel is considered 100% fossil, without co-processing. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

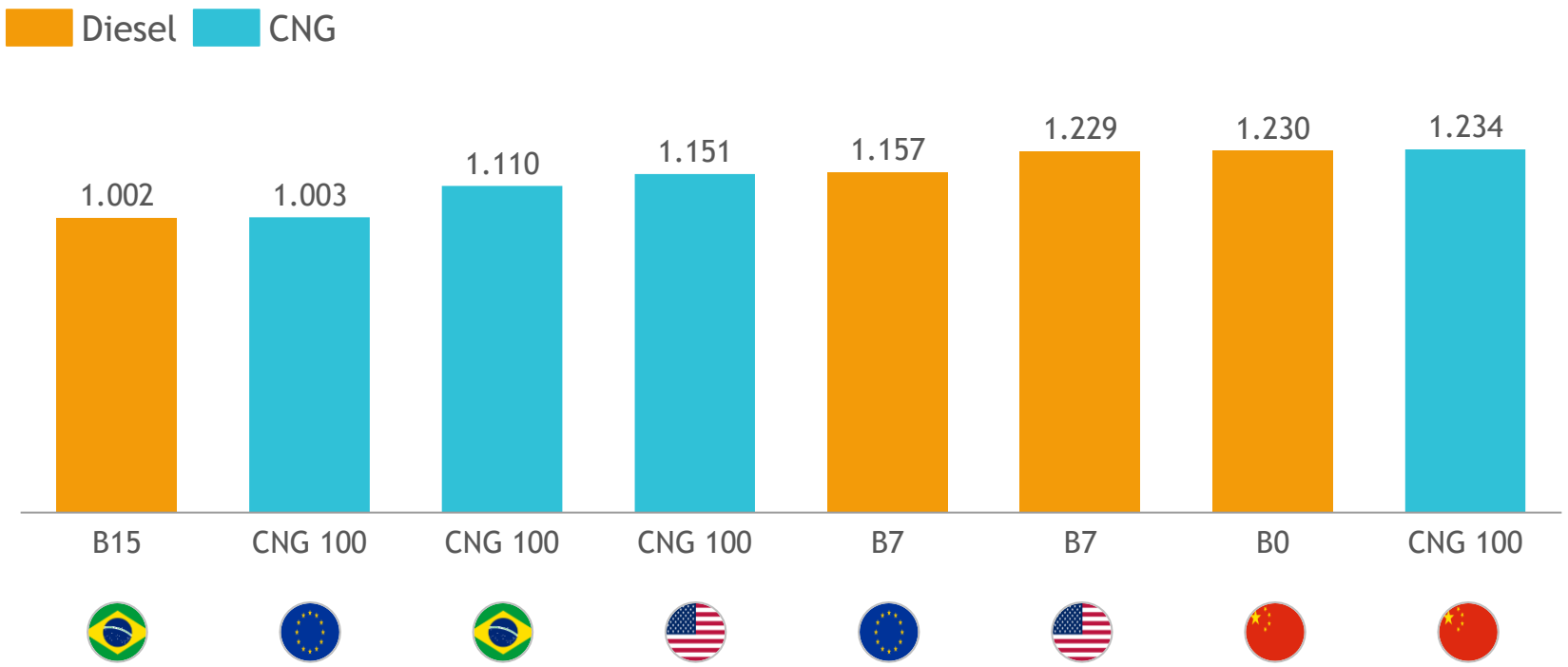
Urban Bus | In combustion technologies, emissions are primarily well-to-wheel, whereas for electric vehicles, production gains relevance



Note: 1. Operation with B100 and BioCNG100: market niche. B15 = blend with 15% biodiesel, according to Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the US. Biodiesel is considered ILUC-free, with the following emission factors (gCO2e/MJ): Brazil: 28.4 (EPE); EU27: 25.1 (EEA); US: 31.4 (LCFS); China: 74.7 (academic literature). Diesel considered is 100% fossil, no co-processing. Assumes gross vehicle weight of 20 tons. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

Long-Haul Truck | High emissions from long-haul transport vehicles reinforce the need for lower emissions alternatives

Emissions of heavy vehicles over the lifecycle by country of production and use (ton CO_2e/useful life)

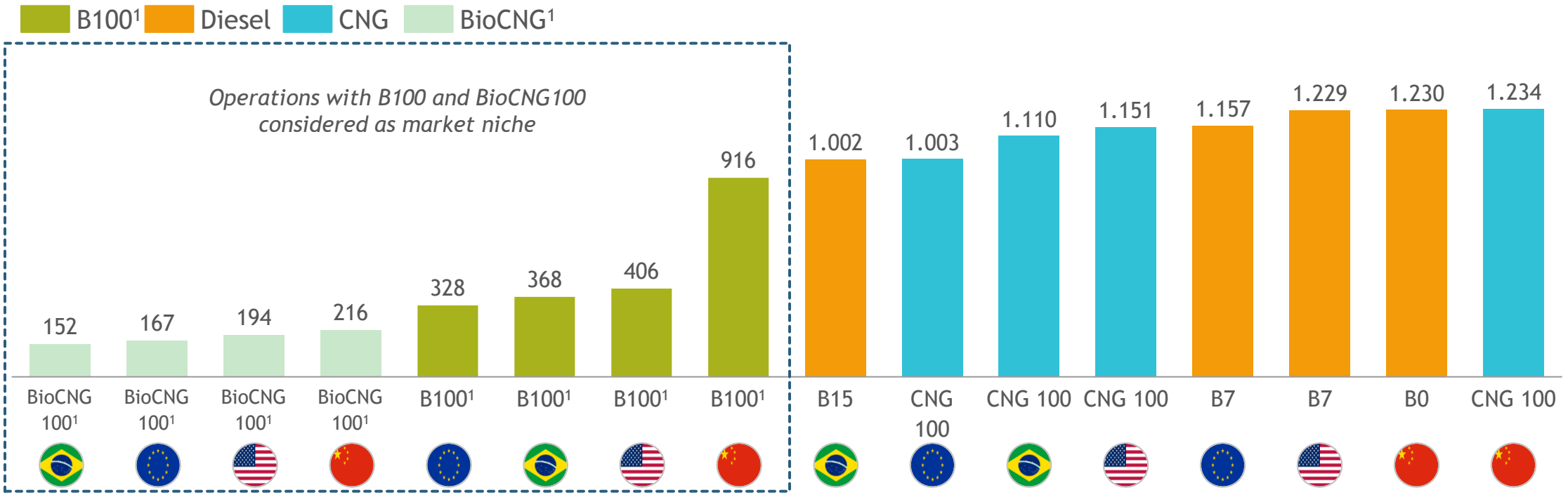


- CNG and diesel have very similar and high emission profiles in all countries, reinforcing the need for lower carbon alternatives for long-haul transport

Note: 1. Operation with B100 and BioCNG 100: niche market. B15 = blend with 15% biodiesel, according to Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the US. B100 = 100% biodiesel. BioCNG100 = 100% biomethane. CNG100 = 100% natural gas. It is considered biodiesel and biomethane without ILUC, with the following emission factors (gCO_2e/MJ): Biodiesel – Brazil: 28.4 (EPE); EU27: 25.1 (EEA); US: 31.4 (LCFS); China: 74.7 (academic literature); Biomethane – Brazil: 8.35 (EPE); EU27: 9.61 (estimated); US: 11.26 (LCFS); China: 12.35 (estimated). Diesel is considered to be 100% fossil, without co-processing. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China," European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

Long-Haul Truck | Emissions from vehicles with biofuels can represent 10% of the emissions of diesel or CNG vehicles

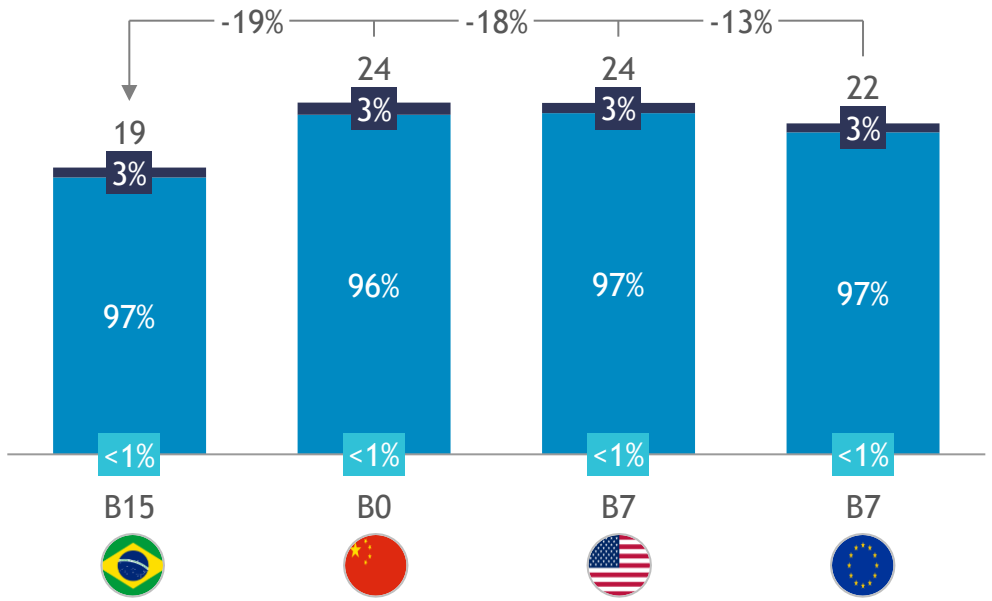
Emissions from heavy vehicles over the lifecycle by country of production and use (ton CO_2e/useful life)



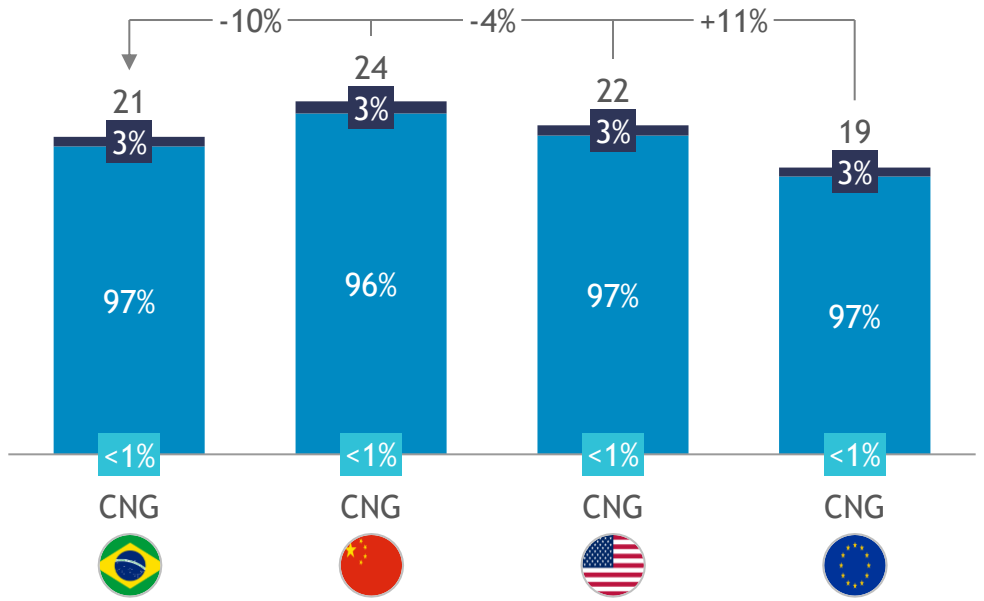
Note: 1. Operation with B100 and BioCNG100: niche market. B15 = 15% biodiesel blend, according to Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the USA. B100 = 100% biodiesel. BioCNG100 = 100% biomethane. CNG100 = 100% natural gas. Biodiesel and biomethane are considered without ILUC, with the following emission factors (gCO2e/MJ): Biodiesel - Brazil: 28.4 (EPE); EU27: 25.1 (EEA); USA: 31.4 (LCFS); China: 74.7 (academic literature); Biomethane - Brazil: 8.35 (EPE); EU27: 9.61 (estimated); USA: 11.26 (LCFS); China: 12.35 (estimated).Diesel considered is 100% fossil, without co-processing. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

Long-Haul Truck | Well-to-wheel in the largest source of emissions in combustion vehicles, with lower values for diesel in Brazil and CNG in EU27

Diesel (gCO_2e/ton.km)



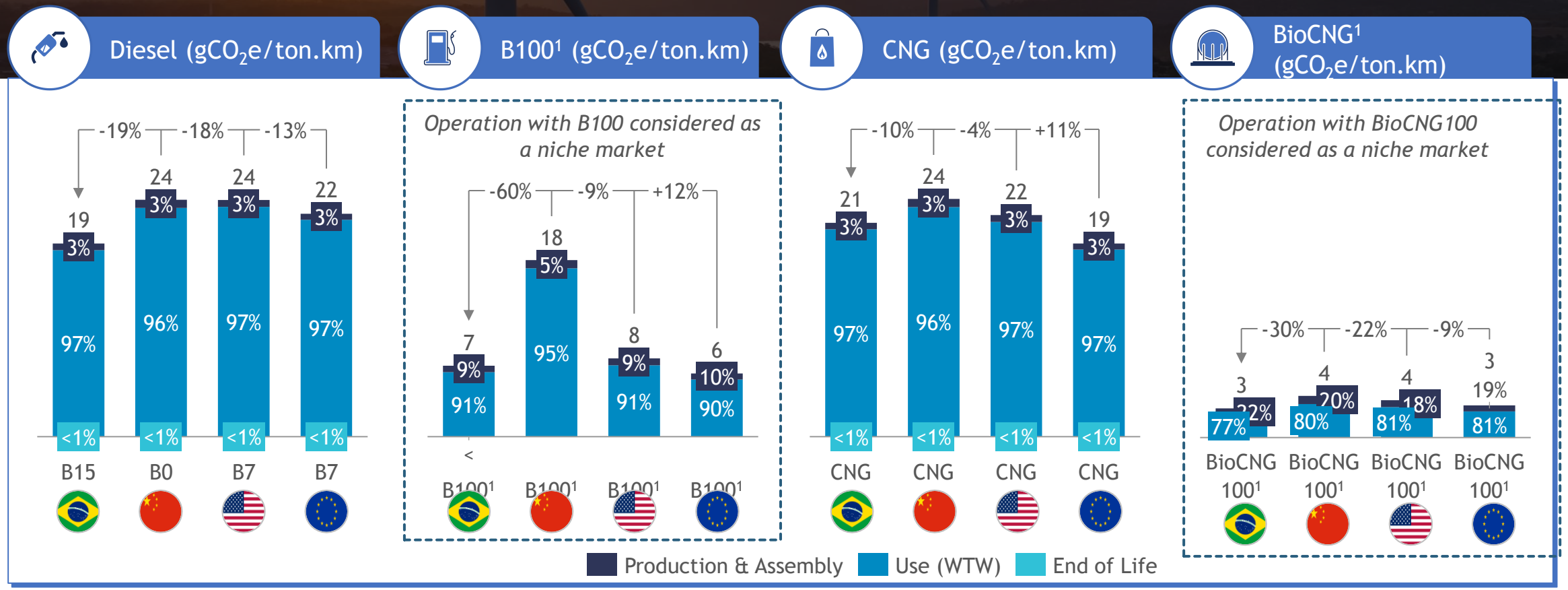
CNG (gCO_2e/ton.km)



Production & Assembly | Use (WTW) | End of Life

Note: 1. Operation with B100 and BioCNG100: niche market. B15 = blend with 15% biodiesel, according to Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the US. B100 = 100% biodiesel. BioGNV100 = 100% biomethane. GNV100 = 100% natural gas. Biodiesel and biomethane considered without ILUC, with the following emission factors (gCO2e/MJ): Biodiesel - Brazil: 28.4 (EPE); EU27: 25.1 (EEA); US: 31.4 (LCFS); China: 74.7 (academic literature); Biomethane - Brazil: 8.35 (EPE); EU27: 9.61 (estimated); US: 11.26 (LCFS); China: 12.35 (estimated). Diesel is considered 100% fossil, without co-processing. Assumes gross vehicle weight of 74 tons. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

Long-Haul Truck | Well-to-wheel is the largest source of emissions in combustion vehicles — reduction depends directly on biofuel



Note: 1. Operation with B100 and BioCNG 100: market niche. B15 = blend with 15% biodiesel, as per Future Fuel Program guidelines; B7 = average mandate of 7% in EU27 and the US. B100 = 100% biodiesel. BioCNG100 = 100% biomethane. CNG100 = 100% natural gas. Biodiesel and biomethane considered without ILUC, with the following emission factors (gCO2e/MJ): Biodiesel - Brazil: 28.4 (EPE); EU27: 25.1 (EEA); US: 31.4 (LCFS); China: 74.7 (academic literature); Biomethane - Brazil: 8.35 (EPE); EU27: 9.61 (estimated); US: 11.26 (LCFS); China: 12.35 (estimated). Diesel considered is 100% fossil, without co-processing. Assumes gross vehicle weight of 74 tons. Sources: PROCONVE, CONAMA, GREET (Argonne National Laboratory), ICCT, IEA, EPE, JOANNEUM RESEARCH (2022), Steel Benchmarking Report, Aluminum Benchmarking Report, ABAL, Green NCAP, International Copper Association, Future Fuel Program, LCFS, "Energy consumption and GHG emissions of six biofuel pathways by LCA in the People's Republic of China", European Environment Agency, China Products Carbon Footprint Factors Database, BCG analysis.

Heavy Vehicles | Key Comments

Use is the main driver of emissions in heavy-duty vehicles

The majority of emissions come from use, which reinforces the importance of reducing the carbon intensity of the fuels adopted

For long-distance vehicles, electrification still faces technological limitations

Electrification faces challenges to achieve the required range and charging infrastructure; low-emissions biofuels are a suitable alternative to fossil diesel

For trucks and buses used for shorter distances, electrification also enables significant emission reductions

Countries with predominantly renewable power grids, such as Brazil, show low overall carbon emissions in electric vehicles— although adoption is still incipient

Combination of renewable pathways enables greater impact on emission reductions

Different solutions (biofuels and electrification) complement each other depending on the type of application and the energy context of each region

Contents |

Decarbonization Pathways for the Automotive Sector in Brazil: A Lifecycle Perspective

General context and perspectives for the automotive sector

Lifecycle methodology for measuring emissions in the automotive supply chain

Results of the comparative analysis of the Brazilian supply chain versus other regions

Scenario development for potential impacts on vehicle emissions in Brazil

We compare Brazil's cradle-to-grave emissions with other regions for different vehicle types

Light Vehicles

Heavy Vehicles

We will now analyze how variables can contribute to pathways for Brazil's decarbonization

We mapped the **emissions profile** of light-duty and heavy-duty vehicles in Brazil, covering all lifecycle stages and comparing various technologies and segments with the US, EU27, and China

Automotive lifecycle emissions in Brazil are comparatively low - due to the use of biofuels and a lower-emissions electricity matrix

The analysis **reflects the 2024 ecosystem** and does not fully capture the effects of industry commitments, technology advances, and regulatory changes

In this context, next we explore **scenarios across the vehicle life cycle**, simulating potential future trajectories and testing how changes in these vectors may affect Brazil's footprint

We built multiple scenarios with potential emission impacts to enable Brazil to advance along automotive decarbonization pathways

Production

Green Production: What is the impact on emission reductions if steel and aluminum production followed lower carbon routes, with a 15% reduction, in line with the Industrial Climate Plan targets?

Low carbon Batteries: What is the impact on emissions if batteries used in Brazil were produced using technologies up to 44% lower emissions, according to the Green NCAP study?

EV Efficiency: What is the impact on emissions if vehicle's energy efficiency improves by 20% (with proportional reduction in battery capacity), according to ICCT projections?

Upstream (Scope 3)

Assembly

Electric Matrix: What is the impact if Brazil achieves its announced commitments for the electricity matrix, according to IEA scenarios[1]? And in other countries?

Scopes 1 and 2

Use

Engine Efficiency: What is the impact on emission reductions with a 12% increase in energy efficiency, in line with Mover program targets?

Biofuels: What is the impact of expanding and improving the efficiency of biofuels in Brazil, according to guidelines from the Future Fuel Program and the 2024 Anfavea & BCG study?

Downstream (Scope 3)

End of Life

Battery Recycling: What is the additional impact on emission reductions from recycling up to 15% of batteries, according to Transport & Environment projections?

Material Recycling: What is the impact of increasing recycled content from 2% to 50%, according to National Solid Waste Plan targets?

Downstream(Scope 3)

Light Vehicles Heavy Vehicles

Note: 1. IEA scenario considers the evolution of the power grid through 2035, in line with the announced decarbonization pledges. Source: Industrial Climate Plan, Mover Program, Fuel of the Future Program, National Solid Waste Plan, EPE, IEA, Green NCAP, ICCT, Transport & Environment, Anfavea & BCG, BCG analysis.

Scenarios to advance on the auto industry decarbonization

Light Vehicles

Heavy Vehicles

Combination of potential decarbonization pathways can reduce cradle-to-grave emissions in Brazil by ~25% for ICEV/HEV and ~60% for BEVs

GHG Cradle-to-Grave Emissions Scenarios of Light-Duty Vehicles in Brazil (Ton CO2e/vehicle)

	Current Context	1 Biofuels[6]	2 Engine Efficiency	3 Electric Transition[4]	4 Low carbon Batteries[5]	5 EV Efficiency	6 Material Recycling	7 Green Inputs	8 Battery Recycling
ICEV[1]	28.4	-3.7 (-13%)	-2.6 (-9%)	-0.2 (-1%)	-	-	-1.0 (-3%)	-0.4 (-1%)	-
HEV[2]	22.1	-2.6 (-12%)	-1.8 (-8%)	-0.3 (-1%)	-0.1 (-1%)	-	-1.1 (-5%)	-0.4 (-2%)	<0.1 (<1%)
BEV[3]	14.2	-	-	-5.1 (-36%)	-3.4 (-24%)	-2.0 (-14%)	-1.0 (-7%)	-0.4 (-3%)	-0.4 (-3%)
Scenarios reference:		*Fuel of the Future; EPE's Technical Note (2025); Anfavea & BCG (2024)*	*Mover Program*	*IEA (World Energy Outlook 2024-APS, 2025 update)*	*Green NCAP (Life Cycle Assessment Methodology and Data; 2022)*	*ICCT (A Comparison of the Life-Cycle Greenhouse Gas Emissions; 2023)*	*National Solid Waste Plan*	*Industrial Climate Plan*	*Transport & Environment (From waste to value; 2024)*

< 5% reduction 5-10% reduction > 10% reduction

1. Considers Brazilian Average ICEV (flex-fuel cars); 2. Considers Brazilian Average HEV (flex-fuel cars); 3. Battery assumed to be sourced from China, with a production emission factor of 131 $kgCO_2e/kWh$.
4.Includes reduction of emissions from China-sourced batteries based on announced pledges for electric grid transition in China by 2035; 5. Considers incremental gain versus new Chinese baseline. 6. Includes reduction of emissions by reducing carbon intensity of ethanol, according to EPE projections.
Considers only Otto cycle engines. For light-duty vehicles, emissions over a useful life of 160,000 km (PROCONVE).
Source: Industrial Climate Plan, Mover Program, Fuel of the Future Program, National Solid Waste Plan, EPE, IEA, Green NCAP, ICCT, Transport & Environment, Anfavea & BCG, BCG analysis.

Scenarios to advance on the auto industry decarbonization

Light Vehicles

Heavy Vehicles

Combination of potential decarbonization pathways can reduce heavy-duty vehicle life cycle emissions by ~10% for ICEV and ~70% for BEVs

Cradle-to-Grave GHG Emissions Scenarios for Heavy-Duty Vehicles in Brazil (Tons CO2e/vehicle)

	Current Context	1 Bio-fuels[3]	3 Electric Transition[1]	4 Low carbon Batteries[2]	5 EV Efficiency	6 Material Recycling	7 Green Inputs	8 Battery Recycling
Urban Diesel Truck	220	-23 (-10%)	-	-	-	-3 (-2%)	-1 (-1%)	-
Urban BEV Truck	76	-	-36 (-47%)	-17 (-22%)	-13 (-17%)	-3 (-5%)	-1 (-2%)	-2 (-3%)
Truck HDV Diesel	1,002	-106 (-11%)	-	-	-	-10 (-1%)	-4 (<1%)	-
Truck HDV CNG	1,110	-96 (-9%)	-	-	-	-10 (-1%)	-4 (<1%)	-
Urban Diesel Bus	991	-106 (-11%)	-	-	-	-6 (-1%)	-2 (<1%)	-
Urban Electric Bus	153	-	-92 (-60%)	-17 (-11%)	-26 (-17%)	-6 (-4%)	-2 (-2%)	-2 (-1%)
Scenarios reference:		*Fuel of the Future; EPE's Technical Note (2025); Anfavea & BCG (2024)*	*IEA (World Energy Outlook 2024-APS, 2025 update)*	*Green NCAP (Life Cycle Assessment Methodology and Data; 2022)*	*ICCT (A Comparison of the Life-Cycle Greenhouse Gas Emissions; 2023)*	*National Solid Waste Plan*	*Industrial Climate Plan*	*Transport & Environment (From waste to value; 2024)*

< 5% reduction | 5-10% reduction | > 10% reduction

Note: For urban trucks, lifetime emissions over 300,000 km; for urban buses and long-haul trucks, 700,000 km (PROCONVE). 1- Includes reduction of emissions from batteries imported from China based on the announced pledges to transition the Chinese power grid by 2035; 2- Considers incremental gain versus new Chinese baseline; 3- Includes emissions reduction with reduction of carbon intensity in biodiesel, according to EPE projections. For CNG, considers only Otto cycle engines. Source: Industrial Climate Plan, Mover Program, Fuel of the Future Program, National Solid Waste Plan, EPE, IEA, Green NCAP, ICCT, Transport & Environment, Anfavea & BCG, BCG analysis.

Key Messages

Brazil starts from a unique position: a predominantly renewable electricity mix and ample supply of biofuels already ensure comparatively lower automotive lifecycle emissions in Brazil than in other markets—even with low electric vehicle penetration

Combination of efforts will be key to maximizing results: ethanol, biodiesel, and biomethane enable emission levels close to electric vehicles and allow decarbonization of the existing fleet in the short term

- **Light vehicles:** electric vehicles tend to be the lowest emission pathway in Brazil with lower emissions energy sources and batteries; in the short term, different levels of electrification and ethanol offer comparable emissions profile and could be used as complementary solutions
- **Heavy vehicles:** in the short-medium term, electrification will be more viable on urban routes, while biofuels remain an essential and scalable option for long distances

Decarbonization requires action from the entire auto industry chain of Production, usage and supply (Scope 1, 2 and 3): including participation of sectors with high emissions intensity, Investments in technological Evolution, quality and availability of biofuels, infra of recharge and recycling

Anfavea