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EXECUTIVE SUMMARY

THE MOST EFFICIENT TECHNOLOGICAL PATHWAYS TO MOBILITY DECARBONIZATION

Study prepared by LCA Consultores and MTempo Capital

MBCB

MOBILIDADE DE BAIXO CARBONO PARA O BRASIL

Summary

Facing the climate emergency by means of the implementation of decarbonization environmental goal is the most critical challenge humankind currently faces. Upon execution of the Paris Agreement, Brazil made the ambitious pledge to reduce its greenhouse gas emissions (GHG) by 37% by 2025, with an indicative contribution of an additional 43% emissions reduction by 2030, in each case relative to estimated 2005 levels. Subsequently, the country increased its GHG emissions reduction pledge to 48% by 2025 and 53% by 2030, again compared with 2005 levels.

Brazil, a middle-income country whose development trajectory has been halted for the past decade, urgently needs to resume its development agenda, even as it faces several environmental challenges. Fortunately, the country has special and unique conditions that enable effective responses to these challenges – given the diversity of its biomes, its abundant natural resources and its vast renewable-energy potential.

Consequently, it may be a leading actor and exemplary pioneer in the decarbonization of its economy. To this end, it must capture and competitively develop new emerging opportunities on the renewable energy and bioeconomy fronts. As we will discuss, rapid decarbonization of automotive mobility – if carried out with balance and wisdom, may harmonize the progress of new technological avenues with sustaining and creating jobs and income – reconciling social, environmental, economic and technological objectives.

Out of the various carbon-intensive industries, the transport industry answers for a significant share of CO2 emissions: in Brazil, the industry has contributed 13% of total CO2 emissions in 2018, as opposed to an average 17% for the set of countries with the most total emissions (United States, China, European Union and India).

The global goal of reaching net zero CO_2 emissions by 2050 has been driving the adoption of policy measures and actions on the part of national governments to encourage sustainable and low-carbon technology pathways.

Redirecting the incumbent model centered on combustion engines towards electrification has been mobilizing significant support in the shape of public funds and subsidies in a portion of the main countries, and will require a lengthy journey to reach the intended objective. Electrification, particularly in the United States, Europe and China, will only succeed if there is also a simultaneous transition of the respective energy and electricity matrices.

In this respect, Brazil enjoys extraordinary comparative advantages. Brazil's energy and electricity matrices are mostly clean and made up largely of renewable energy. In addition, we have already developed – decades ago – effective vehicle decarbonization alternatives through biofuels, and ethanol in particular.

The main reason why Brazil's transport sector emissions are proportionally lower is a result of the fact that the light vehicle fleet includes a large share of flex-fuel vehicles, which can run on either gasoline or ethanol. Flex fuel light vehicles hold the lion's share of domestic sales, with more than 83% of registrations in 2021-'23. Furthermore, the chain's development enabled the creation of solid and sophisticated industrial and agricultural sectors that hold proprietary technology leading to added value and local jobs.

On the other hand, the use of biofuels in heavy vehicles has been far less material, limited to the mixture of biodiesel into diesel, and still at relatively limited ratios. Given that freight transport in Brazil is dominated by the highway modal (70% of freight in 2021) and that approximately 95% of this runs on diesel, it is urgent to prioritize and accelerate the segment's decarbonization.

Automotive chain: government incentives and electrification in advanced countries

The automotive industry as a whole answered for an average 2.8% of the Brazilian economy's total added value between 2010 and 2021, and generated over 3 million jobs. In the same period, tax revenues from the industry were approximately BRL 80 billion annually. This bears witness to the industry's undeniable economic and social relevance.

According to Anfavea (National Association of Motor Vehicle Manufacturers), the Brazilian light vehicles fleet exceeds 43 million vehicles. In 2023, the segment's registrations were over 2.18 million vehicles, 83% of which flex fuel; 9.9% diesel; 2.8% gas, and 4.3% electrified (hybrid and flex). In addition, the total fleet also includes over 2.4 million heavy vehicles (trucks and buses); sales of new trucks and buses in 2023 exceeded 128 thousand units, of which 99.5% running on diesel, 0.4% electric, and 0.1% running on LPG.

Unlike countries like Norway, the United States, Germany and China, where light vehicle electrification has been gaining ground rapidly, the process remains incipient in Brazil, despite sharp recent growth. China has a large lead in the production and production chain for batteries and electric vehicles, in particular BEV; the USA and EU have been attempting to close the gap by supporting technological innovation, local production, the installation of charging infrastructure, and several programs to encourage the purchase of electric vehicles, with a large range of programs based on material subsidies.

Due to these conditioners and incentives, the progress of the light vehicle fleet's electrification in these countries has been remarkable: electric vehicles' share of total world sales went from 9% in 2021 to 14% in 2022. China dominates the trends, contributing almost 60% of new registrations. This growth is the product of almost a decade of early-adopter policy. Europe is the second largest electric vehicle market, contributing 25% of global sales, particular emphasis due on Norway, Sweden the Netherlands, and Germany. IN the US, electrified light vehicle sales were approximately 8% in 2022.

As they rapidly gain market share, electric cars shift the demand for internal combustion vehicles and modify the prevailing market structures. The rapid expansion depends on the creation of a comprehensive battery charging infrastructure and requires significant fixation of additional capital, adding to the demand for renewable electric energy – which remains a significant hurdle for many advanced countries, whose energy matrices remain highly dependent on fossil fuels: China derives approximately 61% of its electric energy from coal, gas and coal represent 58% of electricity production in the US and 42% in Europe.

Given this context, the main vector driving electrification in Europe and the United States has been a combination of tax incentives and favorable regulatory treatment. The table below compiles and categorizes the policies adopted by several of these countries:

Table 1 – Policies by category in different countries

Category	Policy	Norway	USA	Canada	China	Japan	Netherlands
Economic – fiscal and financial	Reduced registration tax[a]	✓	×	×	✓	✓	✓
	Reduced purchase tax[b]	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓
	Reduced annual licensing	✓	✓	×	-	×	✓✓
	Reduced tax on business-owned cars	-	×	×	×	×	✓✓
	Carbon emission taxation	✓✓	×	✓✓	×	×	✓
	Increased MCI circulation tax	×	-	-	×	×	×
	Insurance rebate	×	×	×	-	×	×
Regulatory	Zero-emission vehicle mandate	×	✓✓	✓✓	×	✓	×
	Exemption from gas emissions test exemption	×	✓	-	×	×	×
	Government fleets	×	✓	×	×	×	×
Charging infrastructure	Financial support for charging stations	✓	✓✓	-	✓	✓	✓✓
	Quick charging station	✓	×	×	×	×	✓
	Building regulations	×	×	✓	×	×	×
Urban and transport planning	Access to bus and HOV lane	✓✓	✓	-	✓	×	✓
	Parking rebate	✓	-	×	✓	✓	✓
	Toll rebate	✓✓	-	×	-	✓	✓

Source: Eclac (Economic Commission for Latin America and the Caribbean) (2020)[1].
Prepared by: LCA Consultores

Note: ✓✓ high impact, ✓low impact, - no impact, × not evaluated.
[a] Tax for vehicle registration in the owner's domicile region (state/country).

In Brazil, it is referred to as license-plate fee. [b] Includes discounts, credit rates and exemptions.

1 Cepal (2020), Big Push para a Mobilidade Sustentável: cenários para acelerar a penetração de veículos elétricos leves no Brasil. Available at: https://www.cepal.org/pt-br/publicaciones/45694-big-push-mobilidade-

Decarbonization measures

The greenhouse gas and other gaseous emissions measurement methodology is supremely relevant for the proper evaluation, diagnosis and regulatory discussion of the matter. Specialized literature has been underscoring the importance of fully examining the **product lifecycle**, from extraction of the ores used along the entire chain, through the manufacture of all parts and the vehicle itself, energy generation and consumption, use of land for biofuel production, all the way to the appropriate disposal of onboard products and materials.

The lifecycle methodologies most frequently used to evaluate vehicular performance may be divided into cradle to grave, which is more comprehensive well to tank, which analyzes only emissions generated during the energy or fuel production process; and tank to wheel, which measures exhaust emissions during use of the vehicle. The well to tank and tank to wheel stages can be combined to for the well to wheel concept.

Therefore, the **well to wheel** approach does not cover relevant states, such as the manufacturing chain of vehicles and their main parts. Evidence exists that the main difference between electric and internal combustion vehicles as concerns emissions lies in the battery production process, which is very fossil fuel-intensive. Therefore, the electric vehicles, CO_2 emissions range from zero (tank to wheel) to 13.3 gCO2/Km (well to wheel). Considering emissions in a wider sense (cradle to wheel, an adaptation of the "cradle to grave" method that leaves aside the disposal/recycling stage, for which no information exists), results will be close to 100 gCO2/km, bearing in mind that the battery manufacturing chain is intensive in greenhouse gas emissions, particularly where they are now made (largely concentrated in China).

We believe that the full lifecycle approach – **cradle to grave** – measuring the carbon footprint from the extraction of minerals to manufacture batteries and other vehicle parts to the disposal of onboard materials, **is the most appropriate methodology to measureemissions**, as it accounts for all relevant stages. Because it remains somewhat new, the method is not yet consolidated, be it

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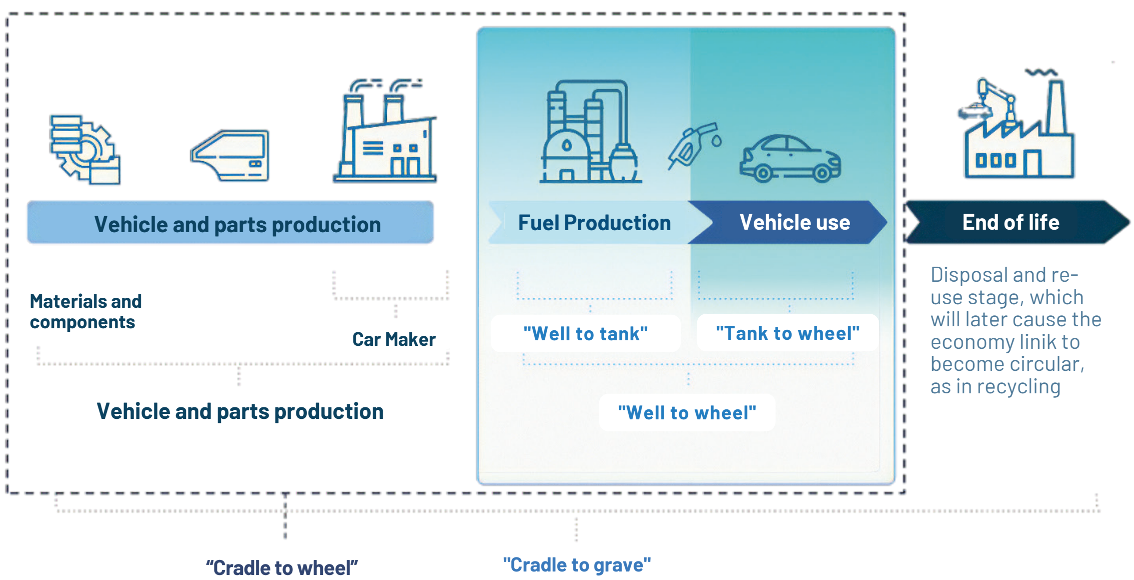
because of the variability of the results from recent studies, be it because of the absence of certain parameters (such as battery disposal or recycling).

The figure below summarizes the concepts:

Figure 1 – Lifecycle methodologies



Source: UNICA (Brazilian Sugarcane Industry and Bioenergy Association), edited by LCA Consultores.

For comparative purposes, the tables below show the estimated results of the of emissions of grams of CO2eq/km for the various light vehicle propulsion models found in the domestic market, using the "well to wheel" calculation rationale – according to the AEA[2] (Brazilian Association of Automotive Engineering) methodology –, plus the calculated results from Gauto et alli with the "cradle to wheel". concept

2 Available at: https://aea.org.br/inicio/wp-content/uploads/2022/11/AEA_CARTILHA-CALCULO-POCO-RODA.pdf

Table 2 – gCO_2/km emissions – "Well to wheel"

Flex	C Gas	Diesel	HEV (Flex)	Electric
91,0	143,4	202,8	75,4	13,3

Sources: EPE (Energy Research Office), AEA (Brazilian Association of Automotive Engineering). Prepared by: LCA Consultores.

Note 1: Calculations based on PBEV 2023 data (Inmetro) using representative vehicles, AEA (Brazilian Association of Automotive Engineering) –Well to wheel handbook light vehicles and EPE (Energy Research Office) (2022). Technical Note "Highway Transportation Industry Decarbonization – Carbon intensity of energy sources".

Table 3 – gCO_2/km emissions – "Cradle to Wheel"

Flex (E100)	A Gas	Hybrid (E100)	Electric
120,9	269,3	77,5	104,8

Source: Gauto et al. (2022). Prepared by: LCA Consultores.

Note 1: The study calculated the emissions of flex and hybrid vehicles using ethanol only.

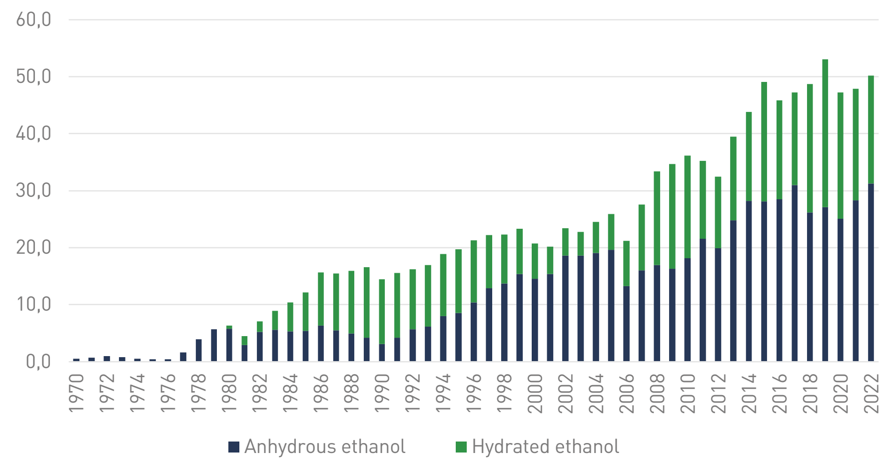
Technology pathways: biofuels

Biofuel production in Brazil dates back to the 1970s, with policies that aimed for increased energy independence by encouraging the substitution of ethanol for gasoline as a vehicle fuel by means of mandates (mixing ethanol into gas and biodiesel into diesel) and incentives to the production of ethanol burning vehicles to reduce Brazil's exposure to the high price of oil products and mitigate its impacts on inflation.

Thus, the demand for and production of ethanol in Brazil increased rapidly in the 1980s and '90s and reached new levels beginning in 2003, with the release of flex-fuel engines. According to Anfavea[3], flex-fuel technology was present in 80% of light vehicles sold in Brazil by 2005 and, more recently, answered for 83% of light vehicle registrations. The positive impact on CO_2 from the increased use of ethanol is material (see graph below).

3 Source: https://anfavea.com.br/site/o-que-foi-o-proalcool/. Viewed on 28/Sep/2023

Graph 1 – Estimated emissions avoidance from the use of anhydrous and hydrated ethanol (in $MtCO_{2EQ}$).



Source: EPE (Energy Research Office)[4]. Prepared by: LCA Consultores.

The sharp increment in ethanol production in recent decades raised concerns about the use of land and required massive investment in research, development and innovation to increased farming productivity. In sum:

(i) The farming activity regulation and control mechanisms that RenovaBio provides are quite strict and inductive to the sustainable use of the land in biofuel production;

(ii) Genomic developments achieved by the CTC[5], focusing on sugar cane, are expected to more than double ethanol supply over two decades, with no increase in tilled area; and

(iii) The area used to grow sugar cane in Brazil (approximately 8.3 million hectares) represents approximately 15% of the total farmed are at present and approximately 2% of the country's tillable area (CONAB, 2022). Furthermore, the area currently in use represents approximately 65% of degraded areas with potential for recovery as recently mapped by the Ministries of Agriculture and the Environment.

4 Source: https://www.epe.gov.br/sites-pt/publicacoes. Op. cit., See Note 49.

5 Centro de Tecnologia Canavieira (CTC) is a publicly trade corporation (Bovespa-Mais) focusing on science, technology and development. Its ownership structure includes bioenergy companies and BNDESPar (19%); its modern governance structure includes a Board of Directors with representatives from the shareholders plus three independent members; it features lean professional management and posts positive and sustainable financial results. See www.cct.com.br.

Therefore, several innovations are under way based on research that has been developing and maturing in recent years to improve productivity and the future supply of biofuels, particular emphasis due on CTC projects focusing on ethanol, which have the potential to more than double productivity at the agricultural end in the next two decades, on three fronts:

(i) Improved genetics and adoption of new, more resistant, plant varieties with higher sugar concentration and faster growth;
(ii) Addition of transgenic seeds, which will save area (currently set aside for developing plants) and enable better adjustment of varieties to soil characteristics and conditions; and
(iii) Adaptation of mechanization to seeds, which will greatly expedite the planting process.

Despite the slow pace of application of new techniques, sufficient degraded area exists to cover any need for new spaces to be used um compliance with RenovaBio requirements. If necessary, the use of these new areas is feasible eve if it implies additional soil-recovery costs.

The use of ethanol in Brazil is almost entirely limited to light vehicles, and no ethanol burning engine options exist for heavy automotive vehicles. For this category the alternative to launch the decarbonization process has been mixing biodiesel into diesel, in much the same way that anhydrous ethanol is mixed into gas for light vehicles.

Biodiesel production in Brazil takes place my means of a reaction between triglycerides and fatty acids, on the one hand, and ethanol, on the other.[6] The main raw materials for biodiesel production include soy oil, fatty materials, bovine fat, and others.

According to National Energy Policy Council (CNPE) Resolution No. 16, the percentage of biodiesel mixed into conventional diesel fuel increased to 12%

6 Source:https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/Paginas/Nota-T%C3%A9cnica-Descarbonizacao-do-Setor-de-Transporte-Rodoviario-Intensidade-de-carbono-das-fontes-de-energia.aspx . Viewed on 03/Oct/2023

from April 1st, 2023. In addition, the document provides for a gradual increase of the admixture to 14% in March 2024 and 15% in 2025, anticipating the schedule originally stipulated in the previous resolution by one year[7]. Therefore, the market for biodiesel is expected to increase in the coming years.

On the other hand, the production of biogas and biomethane in Brazil has been growing significantly. In 2022, production of biogas for energy purposes was 2.88 billion Nm^3/year, up 22% YoY. According to certain sectoral institutions, Brazil has a theoretical long-term production potential equivalent to 84.6 billion Nm^3/year. A remarkable aspect of biomethane from vinasse is its potential for carbon reduction in ethanol production, in addition to the synergy emerging from circular economy.

Biomethane may be used as a distributed energy source (such as fuel for isolated electricity generators) and as a green fuel for trucks. In the latter case, the engine and tanks must be replaced, which requires additional capital and/or appropriate funding. The main direct benefit of biomethane lies in the potential to replace diesel as a fuel, particularly for trucks, including vehicles used internally on farms and in ethanol mills for transportation. This may produce quite a relevant indirect effect insofar as such an **internal replacement of diesel with biomethane will even further and significantly reduce the ethanol chain's carbon footprint**.

Low-carbon hydrogen may also become a relevant element in our decarbonization strategy. Brazil enjoys important advantages for the local production of low-carbon hydrogen ("H2BC") due to the availability of renewable energy at a competitive generation cost, and has been attracting a significant number of companies with feasibility study projects involving the production using the water electrolysis pathway. Notwithstanding, studies indicate a competitiveness gap when the entire cost chain is considered, including transmission costs (TUST), taxes, sectoral charges electric energy, and cost of capital, among others[8]. Furthermore,

7 Source: https://www.gov.br/mdic/pt-br/assuntos/noticias/2023/dezembro/cnpe-aprova-antecipacao-do-b14-para-marco-de-2024-e-b15-para-marco-de-2025-incentivando-a-producao-de-biocombustiveis-e-a-transicao-energetica. Viewed on: 26/Dec/2023.

8 In Brazil, a single small project is under construction in Bahia (Unigel plant in Camaçari, with capacity at thousand annual tons of H_2 e and mil thousand annual tons of ammonia). However, several projects exist in EVTEA phase, most of which consider the main and dominant production pathway, through water electrolysis, which consists in separating H_2 and O molecules. A means to navigate the accumulated logistics, contributions and charges costs on

subsidies granted to similar plants in regions such as the USA, EU, Middle East and China generate significant decreases in end prices, creating a competitiveness gap for local projects.

Other potential pathways exist with different prospects. Emphasis is due on RCGI-USP's development of low-carbon emission hydrogen production technology based on ethanol using the reform-vapor method: the combination of ethanol and water under temperature (700^{0}C) and pressure conditions to enable the separation of ethanol molecules (C_2H_6O) into Hydrogen, Oxygen and biogenic CO_2.[9] This innovation may be produced in small distributed stations, solving the great challenge of long-distance hydrogen transportation and contributing to the advance of fuel-cell vehicle motorization, applicable to both heavy and light vehicles. There is also the possibility of replacing natural fossil gas with biomethane for the production of low-carbon hydrogen, which is technically feasible due to the gases' similar chemical properties.

The Brazilian regulatory framework and its Science, Technology and Innovation support system are expected to provide incentives capable of closing the competitiveness gaps that favor early entrants and pioneering projects, for a certain time and subject to monetary limits, as a means to expedite the respective development phases and lend scale to the ensuing pilot plants.

As a result, competitive solutions are expected to be mature and ready to operate by 2030, enabling Brazil to catch up to countries like China, the USA and Europe, which have been making significant investments in new and sustainable low-carbon technologies.

Existing Policies

On the existing policies front, emphasis is due on the MOVER, RenovaBio and Future Fuel Programs. MOVER ("Mobilidade Verde", or "Green Mobility"), approved by Law No. 13.755/2018 and renewed in 2023, is the successor to the Inovar-Auto Program, which was in force from 2013 to 2017. Its main goals **boosting the**

the end price of H_2 might be built in the shape of intra-company, locally integrated projects.

9 https://revistapesquisa.fapesp.br/brasil-tera-planta-piloto-pioneira-para-produzir-hidrogenio-a-partir-de-etanol/

competitiveness of locally manufactured vehicles, reducing greenhouse gas emissions, and fostering the progress of vehicle safety by means of the adoption of new technologies.

RenovaBio's **purpose is to increase the production and use of biofuels in the Brazilian energy matrix**. To this end, the policy considers the connection between energy efficiency and decreased greenhouse gas emissions to support the decarbonization of the Brazilian transport matrix in such a manner as to ensure national energy security by means of market predictability. The program operates based on government-mandated national targets for greenhouse gas emissions from the fuels matrix, so that these national targets can be broken down into mandatory annual targets for fuel distributors. RenovaBio's key instruments may be divided into three axes: (i) Greenhouse gas emission reduction targets; (ii) Biofuel production certification; and (iii) Decarbonization credits.

The Future Fuel Program was enacted by CNPE Resolution No. 07, of April 20,[10] converting into a bill placed before Congress in September 2023 (PL 4516/2023). Its main purpose is **to expand the use of sustainable and low-carbon fuels**.

The program's five main axes may be described as follows: (i) National Sustainable Aviation Fuel Program ("Programa Nacional de Combustível Sustentável de Aviação" – ProBioQAV); (ii) National Green Diesel Program ("Programa Nacional do Diesel Verde" – PNDV); (iii) Synthetic fuel regulation; (iv) Geological capture and storage of carbon dioxide (CO_2) e (v) New limits for anhydrous mixture into gas.

Geopolitical aspects

Geopolitical matters involving national security imperatives and economic and technological priorities have been driving central countries' energy transition strategies.

These strategies – in the US, EU and Asia (China in particular) – combine decarbonization targets, re-industrialization (or reshoring), and the pursuit of the technology lead.

10 Source: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/combustivel-do-futuro. Viewed on: 21/Sep/2023.

They are fostered by industrial policy and large scale programs, supported by subsidies, government procurement and massive support to research and development into new technologies to create advantages for the respective science and technology ecosystems.

The Brazilian case shows certain unique opportunities for the development of products and processes that answer to the tripod mentioned above: decarbonization, re-industrialization, and innovation based on proprietary technology. From among this palette of opportunities, renewable biofuels illustrate how the pioneering construction of comparative advantages through lengthy learning processes and public- and private-sector investment, enable the country to clear paths to international protagonism. Some illustrative possibilities include: 2nd generation ethanol, biomethane, biodiesel from various sources, new synthetic fuels for various uses, and low-carbon hydrogen.

Given that the innovation process requires continuous progress, in addition to the need to expand the market into new regions, three points are relevant for the country's strategic positioning on the global scenario:

(i) Connecting the biofuel industry with the rest of the world requires Brazil to place an active and cooperative role defining and standardizing at a global level fuels for various uses: trucks (green diesel, biomethane), aircraft (SAF) and ships (green bunker) to serve the global market;

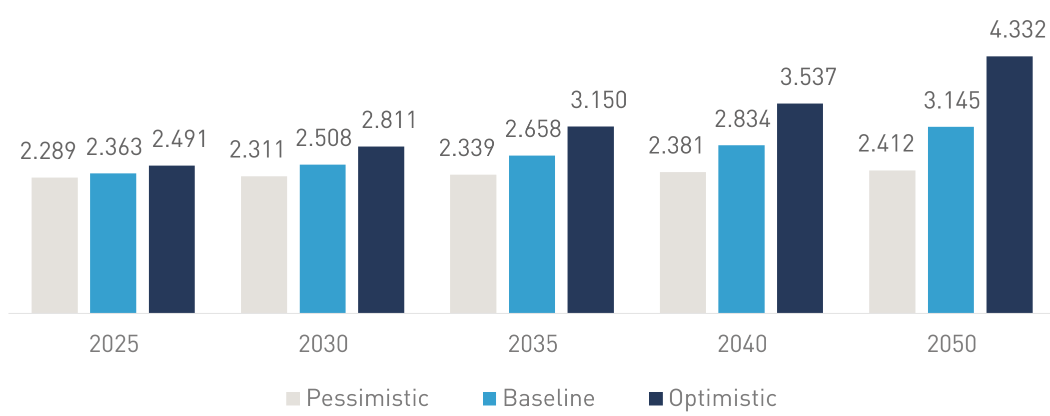
(ii) Countries exist with the capacity for or an interest in developing the **ethanol pathway** for mixed use in internal combustion engines or hybrid vehicles (such as USA, Mexico, India, Indonesia, Colombia and Panama, among others), have interesting room exists for cooperation in areas where Brazil has mastered the relevant technologies and processes, such as flex-fuel engines and parts and ethanol-burning hybrids (HEV and PHEV);

(iii) The trend for automotive mobility electrification is global and part of the strategy of almost all car makers. The fact that Brazil has been able to attract direct investments from a foreign car maker for local production of electric vehicles enables fostering and learning from the internalization of the respective production chain of parts, components and technology to increase local content and exports. This experience may create opportunities to serve the Latin America market from such a subsidiary (and any subsequent ones), to foster competitive niches, including for services, along the supply chain, and to develop new technological cooperation channels.

Electrification scenarios and environmental impacts Light vehicles

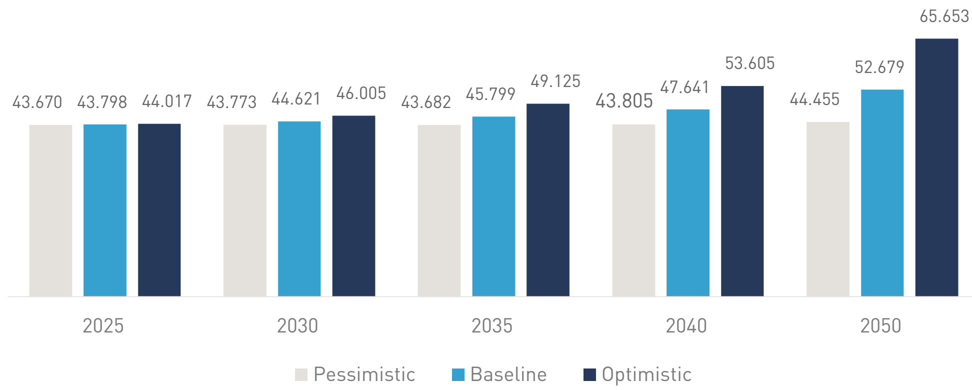
To understand the impacts of each technological pathway, as well as the effects of the transport industry decarbonization policies, the study estimated results in terms of CO2 emissions of the light vehicles fleet in certain scenarios and attempted to assess the respective economic impacts in terms of jobs and income generation. Calculating the evolution of total light vehicle emissions requires forecasting the fleet for the study's relevant years, that is 2025, 2030, 2035, 2040 and 2050 for which Brazil has committed to neutral emissions. Fleet evolution clearly depends on the incorporation of new vehicles and the disposal of old ones. New registrations and fleet size were estimated based on econometric tools, pursuing adherence to historical data, macroeconomic conditioners, consumer preferences and other sectoral aspects. The graphs below dhow the results for vehicle registrations and fleet evolution.

Graph 2 – Light vehicle registrations (thousands of units) – Comparative Scenarios.



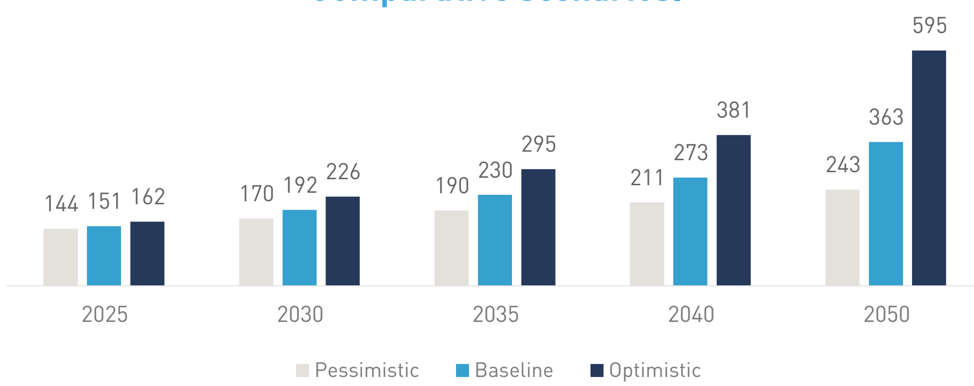
Source: LCA Consultores.

Graph 3 – Forte de Light vehicles (thousands of units) – Comparative scenarios.



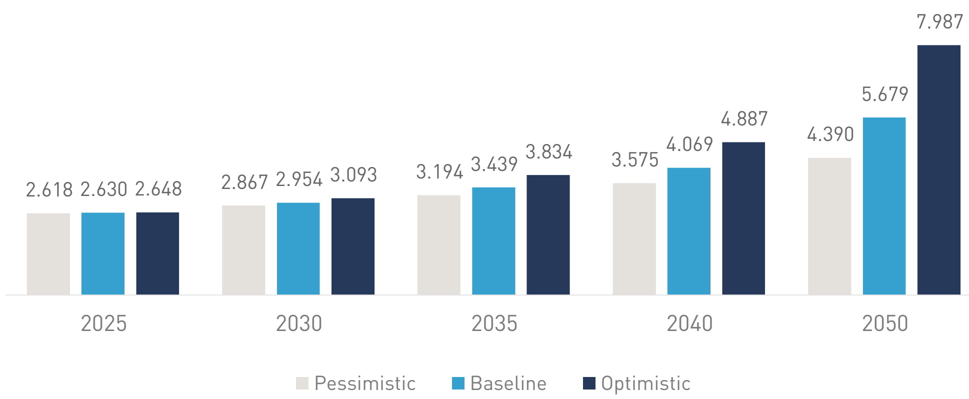
Source: LCA Consultores.

Graph 4 – Heavy vehicle registrations (thousands of units) - Comparative scenarios.



Source: LCA Consultores.

Graph 5 – Heavy vehicle fleet (thousands of units) – Comparative scenarios.



Source: LCA Consultores.

Comparative Emissions

For **light vehicles**, we initially simulated scenarios for **well to wheel**, a method enshrined by industry institutions, and “**cradle to wheel”** cycles, based on Gauto et al.[11](2023). It is worth mentioning that little data and parameter convergence exists so far to enable a full lifecycle (cradle to grave) assessment, which is why we chose the most comprehensive method possible out of those available.

Based on the methodologies above, the study simulated difference scenarios as concerns the evolution of the electrification of the Brazilian vehicle fleet, as follows: 1) status quo, 2) global convergence – hybrids, and 3) global convergence - electric. In every case, the baseline scenario was adopted to forecast new registrations and total fleet.

The first scenario maintains the existing registrations and fleet configuration (same percentage sales of electrified vehicles as seen in January 2024), as this is merely a hypothetical control scenario where no structural changes occur. In the other two scenarios, the fleet converges on the global electrification pattern: in the second scenario, **hybrid vehicles** prevail (scenario 2) and in the third one, electric vehicles prevail (scenario 3). This establishes hypotheses that enable estimating the fleet’s breakdown on the relevant years.

Using the automotive industry’s emissions calculation methodology and public data on the carbon intensiveness of energy sources and vehicle efficiency, we built assumptions to estimate CO_2 emissions according to the **well to wheel** method; The study used representative vehicles for each propulsion model. This, based on fleet quantities, the share of each model in fleet propulsion, and emissions by representative vehicles, we estimated emissions for the light vehicle fleet in the three scenarios. We present, below, the assumptions made and the emissions results for the three scenarios[12].

11 Gauto, Marcelo Antunes, et al. "Hybrid vigor: Why hybrids with sustainable biofuels are better than pure electric vehicles." Energy for Sustainable Development 76 (2023): 101261.

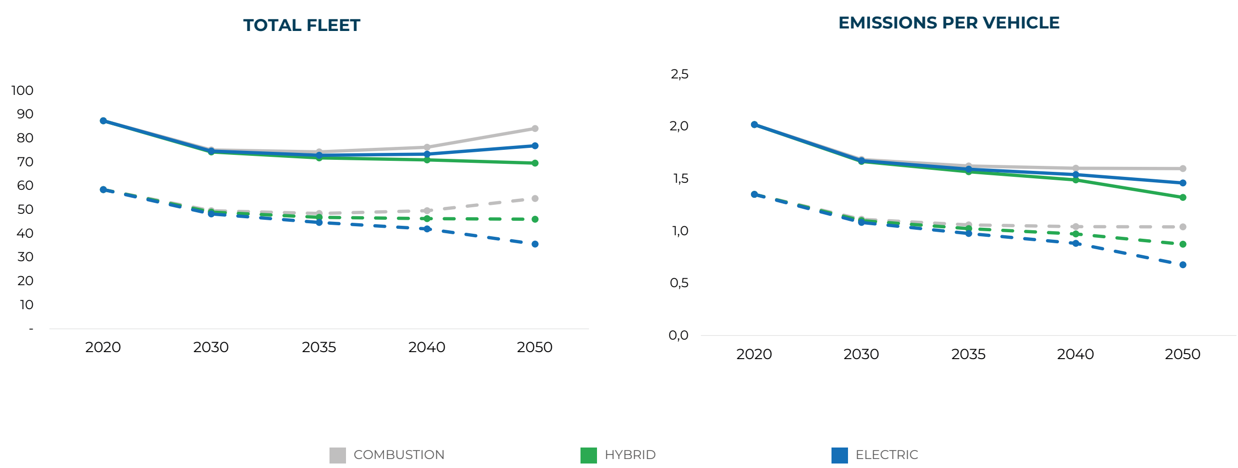
12 The methodologies, as well as the variables used for calculations, such as carbon intensity and usage factor are discussed in detail in the report.

Beyond these estimates, we have run a scenario using the **cradle to wheel** methodology, which covers a larger number of lifecycle phases and therefore tends to produce higher emissions. We adopted the method based on the hypotheses in Gauto et al.(2023)[13] for the same scenarios.

The Graph below shows emissions results for the three scenarios according to the **cradle to wheel** and **well to wheel** methodologies.

Graph 6 – CO_2 Emissions – “Cradle to wheel” x “Well to wheel”(Mt/year)

Cradle to Wheel (Solid Lines) vs Well to Wheel (Dashed Lines)



Source: LCA Consultores.

Because of the previously discussed methodological differences, estimation results also differ significantly. By considering a shorter cycle (well to wheel), without calculating emissions from the battery production chain, **the electric prevalence scenario generates lower CO_2 emissions**. However, for a lengthier lifecycle analysis (cradle to wheel), **the hybrid convergence scenario** generates **the least CO_2 emissions, assuming exclusive ethanol use**.

13 It is worth noting that, in the study at hand, calculations were conducted for hybrid and flex vehicles aloe using ethanol n(E100). As such the calculations were probably conducted regarding the vehicle as mono-fuel, with no need to include the usage factor variable.

In addition to these methodologies, we ran an additional simulation considering growing participation of biofuels. In this simulation (**biofuel prevalence**), we maintained the **well to wheel** methodology, but changed the *ethanol usage factor* variable over the years: **we start out from 38% ethanol in 2030** and stipulated, for the purposes of the analytical exercise, **increasing this factor to 64% by 2050**, as the table below shows:

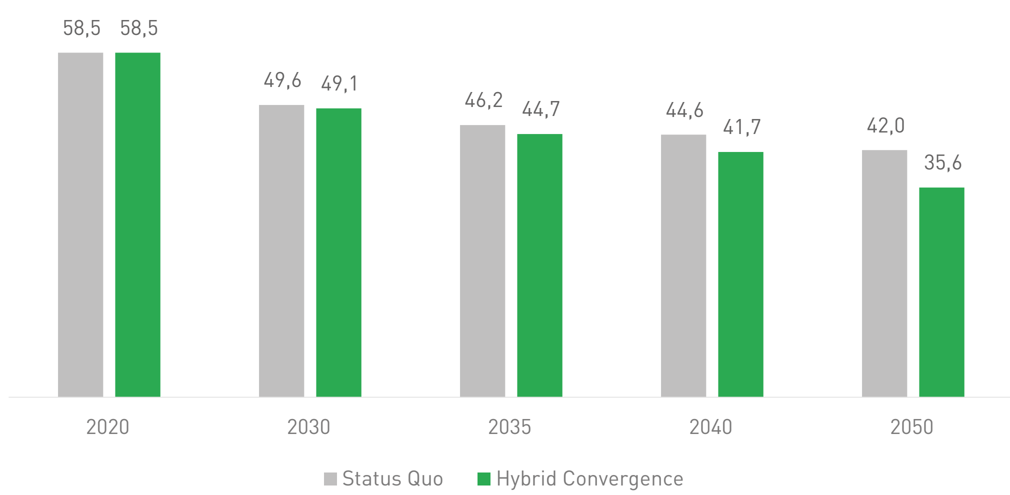
Table 4 – Usage factor – Biofuel prevalence

	2020	2030	2035	2040	2050
Usage factor	0.28	0.38	0.43	0.49	0.64

Source: LCA Consultores.

Using the fleet breakdown from the previous breakdown for the *status quo* and *hybrid convergence* scenarios associated with this hypothetical ascending ethanol usage trend, we calculated CO_2 emissions for the light vehicle fleet. The Graphs below show the exercise's results:

Graph 7 – Vehicle fleet emissions Mton CO_2/year –Status Quo and Hybrid Convergence scenarios under biofuel prevalence.



Source: LCA Consultores.

Assuming these hypotheses and the "well to wheel" concept, the final CO_2 emissions from hybrid (HEV) and electric (BEV) vehicles would be similar, at around 35.6 MmtonCO_2/year.

These results raise interesting questions. Given the Brazilian fleet's structure, with a very relevant share of flex-fuel vehicles, **a hypothetical increase in the ethanol usage factor would lead to an immediate decrease in emissions**, which might take place should to shoulder with the fleet electrification process. In other words, because a complete and disseminated biofuels usage structure already exists, this modification would lead to an immediate decrease in emissions.

In sum, analysis of light vehicle emissions in the **well to wheel** cycle shows that electric vehicles stand as an important and more effective decarbonization vector. However, when the cycle is expanded to **cradle to wheel**, which considers emissions from the battery manufacturing chain (which currently has a large carbon footprint), **hybrid vehicles show more satisfactory results**. On the other hand, if it becomes economically and technically feasible to make significant and rapid gains to decarbonize the battery manufacturing chain, this relative disadvantage could be overcome. Similar results would emerge in a similarly hypothetical scenario if it became technically and economically feasible to manufacture batteries in Brazil, using renewable energy. Finally, in the expanded biofuel usage factor scenario, light-vehicle decarbonization would be immediate and significant.

Heavy vehicles

A feature of the heavy vehicle class is more heterogeneous models, cargo capacity and applications. Therefore, the technological pathways available must be compatible with these characteristics, and also economically, financially and environmentally feasible.

Diesel vehicles, with their high carbon emissions, dominate the market because of the fuel's high energy efficiency. Decarbonization therefore requires a paradigm change from today's massive dominance of diesel.

Some applications, such as the cases of last-mile vehicles, operating within city limits, and city buses, whose predictable routes enable charging, tend to be viable for the purposes of the electric model. As for the longer routes covered by heavy and super-heavy trucks, low-carbon diesel, biomethane (as a replacement for NVG, which can be used as a transition fuel) and even the hydrogen electric with fuel cells solutions, may become viable. Biodiesel and renewable diesel stand as low-carbon solutions that show synergies with the existing infrastructure, with no need for additional investments to create or modify the established fueling infrastructure.

Each of these pathways features more complex implementation and mass adoption challenges than the light vehicle case. In the case of electric heavy vehicles, the charging infrastructure, the ensuing increase in electric energy supply, and the high production costs all demand significant investments. In the case of natural gas and biomethane, for shorter distance applications, a more comprehensive network of pipelines is required. In addition, the biomethane case requires a regulatory framework to incentivize expansion of fuel production nationwide.

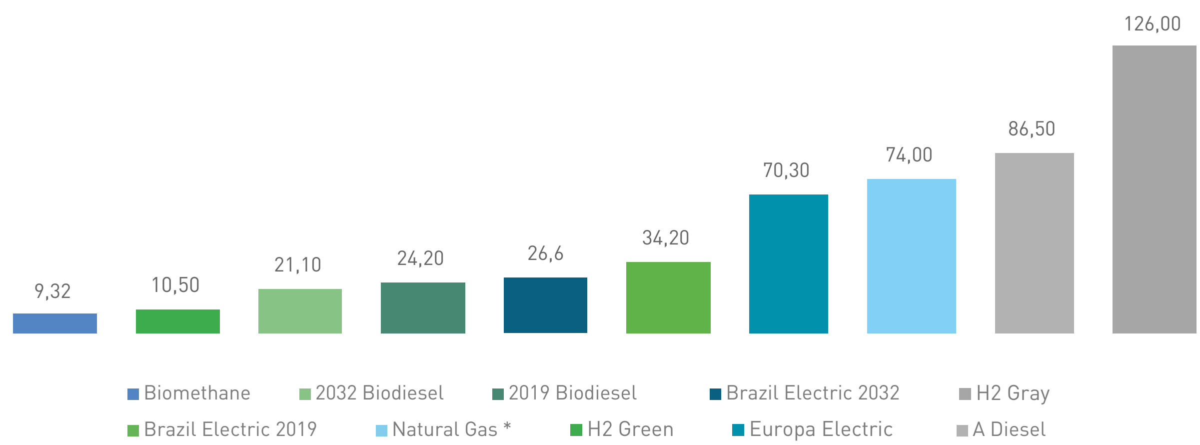
Biodiesel and renewable diesel still face technical hurdles, such as the ceiling ratio of biodiesel mixture into diesel, and certain productive constraints, such as the higher production cost vis-à-vis conventional diesel. As for low-carbon hydrogen, studies indicate a need for temporary incentives to early entrants until the industry shows material scale gains.

From the environmental angle, greenhouse gas emissions from heavy vehicles are under the influence of several factors, such as cargo type, highway conditions and route topography, number of axles, engine type, tires used, transmission system, and more. The wide array of variables to be considered estimating emissions make the task challenging and hampers generalization around a single specific mathematical model. In this respect, difficulty stipulating each model's emissions magnitude has a direct impact on the feasibility of developing greenhouse gas reduction targets.

Therefore, a necessary and crucial step forward towards efficiently regulating heavy-vehicle decarbonization involves implementation of a computerized measurement model: VECTO. VECTO is a tool that the European Commission developed as the official instrument for monitoring heavy vehicles' CO_2 emissions and fuel consumption.

Although no model exists in the Brazilian market to measure heavy vehicles' greenhouse gas emissions, it is a known fact that the use of less carbon-intensive fuels leads to fleet decarbonization. The table below provides details on the carbon intensiveness (in CO_2/MJ) of certain fuels at the heart of the technological pathways towards decarbonization.

Graph 8 – Carbon intensiveness of certain energy sources (in gCO_2/MJ).



Source: EPE[14] (Energy Research Office) and UNICA (Brazilian Sugarcane Industry and Bioenergy Association). Prepared by: LCA Consultores.

Source: Reuters[15] and Roland Berger. Prepared by: LCA Consultores.

Note. Natural gas intensiveness used a correction factor based on data provided by EPE (Energy Research Office).

Therefore, **heavy vehicle decarbonization will depend on a match of economic, financial and environmental feasibility between the various technological pathways and the respective applications.** For the harmonization to be implemented and correctly monitored by regulations, the Brazilian market must make progress developing a tool (VECTO) to establish CO_2 measurement standards so that credible targets can be set and attained.

14 Available at: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-708/NT-EPE-DPG-SDB-2022-03_Intensidade_de_carbono_Transporte_Rodoviario.pdf

15 Available at: https://www.reuters.com/markets/commodities/europes-top-economies-slash-carbon-intensity-electricity-2023-12-12/

Finally, it is important to emphasize that the CO_2 calculation methodology for heavy vehicles must also evolve to the **cradle to wheel** cycle and, as soon as possible, to the **cradle to grave** lifecycle. The latter is clearly more comprehensive as it considers all forms of GHG emission in every stage, including the origin of energies, inputs, parts and components, of manufacturing processes throughout the production chain, and of the emissions coefficients associated with vehicle usage and, finally, of the disassembly and disposal process for parts, components and, above all, batteries.

Social and economic impacts of electrification scenarios (based on the Input-Output Matrix)

As seen thus far, the decarbonization of automotive mobility in Brazil is privileged to have at hand a range of opportunities and technological pathways. But, by consummating these opportunities, a strategy must reconcile the environmental, social and economic dimensions – realizing that policy choices will bring about different consequences not only for national decarbonization efforts, but also for economic and social development.

It is therefore necessary to assess the expected socio-economic impacts of changes in the automotive industry arising from the introduction of hybrid and electric vehicles in Brazil. To this end, we estimated a demand stimuli multiplier Model based on the Input-Output Matrix (IOM). The Input-Output Model, or Matrix (IOM), is an “economic snapshot of the economy itself”[16], based on the realization that an industry’s output depends on inputs provided by others, creating a complex network of consumption and production relationships[17] These inter-relations enable determining the magnitude of the impact of one relevant industry on others the others (including the segment itself through autofeedback), and can be captured by means of technical coefficients and of the Leontief matrix.

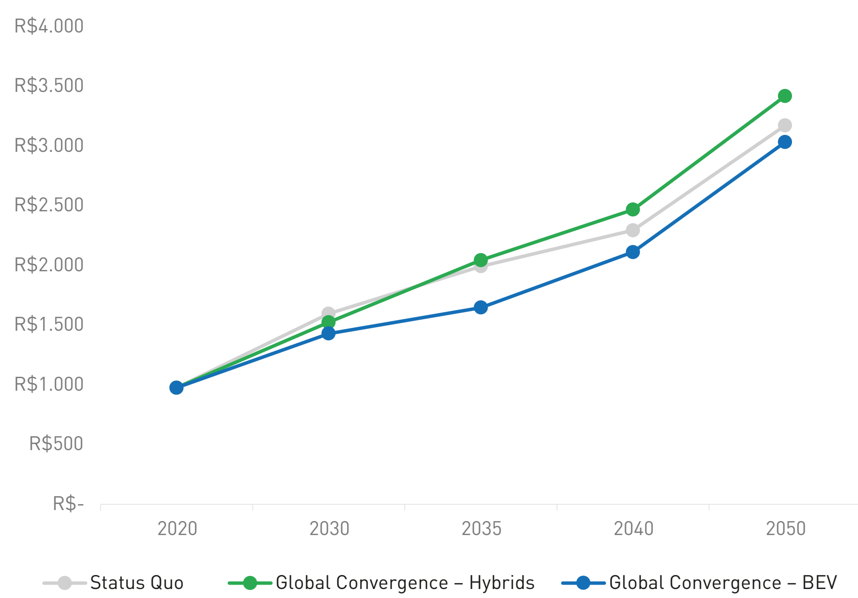
16 Guilhoto, Joaquim José Martins and Guilhoto, Joaquim José Martins, Input-Output Analysis: Theory and Foundations (Análise de Insumo-Produto: Teoria e Fundamentos) (August 1, 2011). Available at: SSRN: https://ssrn.com/abstract=1900073 or http://dx.doi.org/10.2139/ssrn.1900073

17 Considering direct and indirect ties, it can me said that each industry’s output depends on the inputs provided by ALL other economic segments. For example, the production of cotton requires mineral extraction, even if a miner is not a direct supplier to a farmer, as the minerals extracted will be used as raw materials by the steel industry, whose product will be used as an input by manufacturers of machinery and equipment, which, by their turn, will produce the machinery and equipment directly employed in cotton production.

Operationally, IOM analyses take place through monetary shocks to one or more relevant industries that then disseminate cumulatively throughout the economy, supporting economic planning and public policymaking (additional details can be found in the full Report.

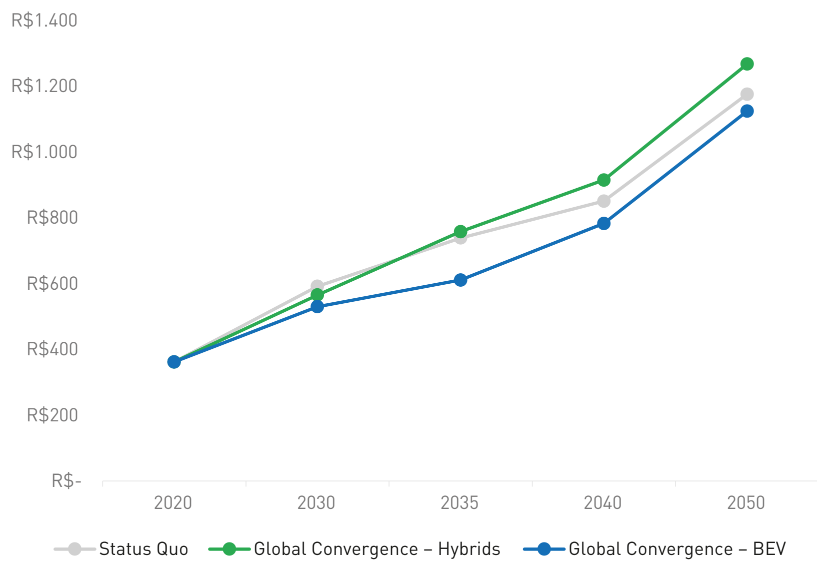
We estimated the effects of demand shocks to the automotive industry on the economy, measuring ensuing effects for the as-of date 2020 and the years 2030, 2035, 2040 and 2050. The Graph below summarizes our analyses' results:

Graph 9 – Total Output (BRL Billion)



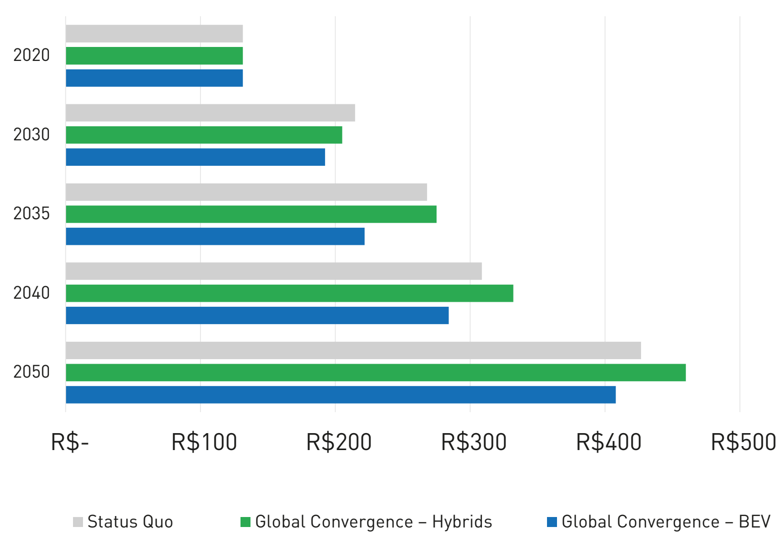
Source: LCA, with data from Anfavea, Abraciclo (Brazilian Association of Manufacturers of Motorcycles, Mopeds, Scooters, Bicycles and Similar), Car Makers. Prepared by: LCA Consultores

Graph 10 – Added Value – GDP (BRL Billion)



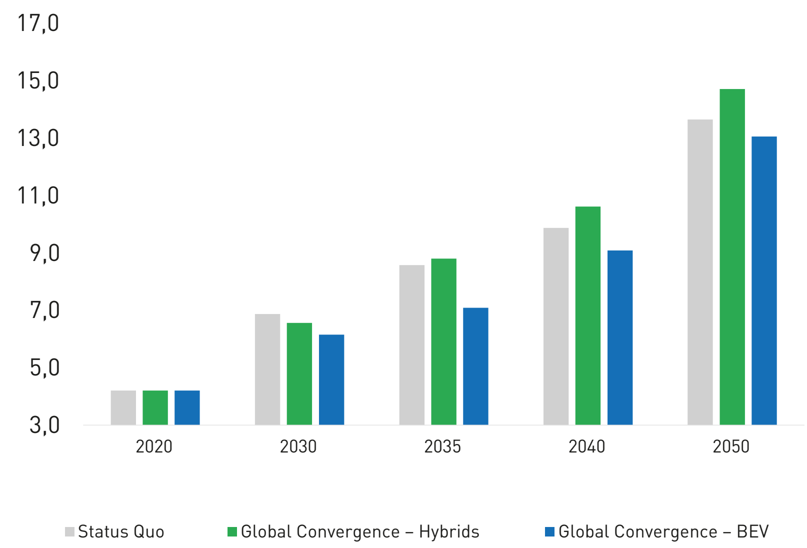
Source: LCA, with data from Anfavea, Abraciclo, Car Makers. Prepared by: LCA Consultores

Graph 11 – Taxes (BRL Billion)



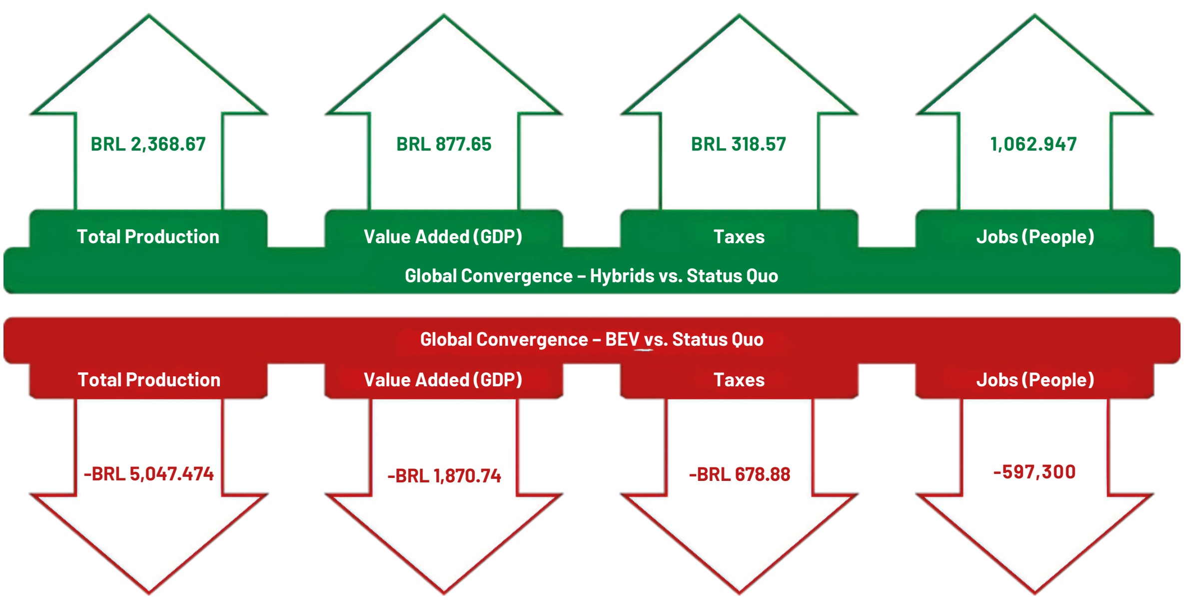
Source: LCA, with data from Anfavea, Abraciclo, Car Makers. Prepared by: LCA Consultores

Graph 12 – Employment (Millions of Workers)



Source: LCA, with data from Anfavea, Abraciclo, Car Makers. Prepared by: LCA Consultores

Figure 2 – Summary of Accumulated Economic Impacts (2020-2050)



Source: LCA through MIP/IBGE (Input-Output Matrix/Brazilian Institute of Geography and Statistics), with data from Anfavea (National Association of Motor Vehicle Manufacturers, Abraciclo, Car Makers. Prepared by: LCA Consultores.

Socio-economic impacts will vary depending on the prevailing technological pathway. If the Brazilian vehicle fleet's electrification occurs mainly through hybrid vehicles (HEV vehicles, Global Convergence – Hybrids scenario), our analyses indicate significant positive impacts. On the other hand, if BEV vehicles prevail (Global Convergence: BEV), analyses indicate potential losses for the Brazilian economy.

The positive results found in the Global Convergence – Hybrids are mainly due to a high level of local content in HEV vehicle manufacture and their higher average value relative to IC vehicles. However, hybrid vehicles sport a local content rate relatively However, hybrid vehicles have a lower local content percentage than the current internal combustion models, because of electric propulsion components – batteries in particular. In the future, it is possible that the nationalization of the production of battery inputs and components – metals mining and refining, and energy cell manufacturing chains for subsequent battery assembly – will magnify the positive effects seen in the Global Convergence – Hybrid scenario.

The economic losses arising from the Global Convergence: Battery-Powered Electric Vehicles, BEV, arise from the smaller local content of vehicles in this category compared with internal combustion vehicles, which are prevalent in the *Status Quo* scenario. This is specifically due to the absence of a battery manufacturing chain and, furthermore, to the exclusion of internal combustion engines and gearboxes, which are intensive in basic inputs, components, parts and pieces.

We find that these effects can be observed even in consideration of the fact that BEV vehicles have the highest average price of all motorization types analyzed. However, it is key to emphasize that our estimations and scenarios only consider existing production processes.

Due to methodological limitations, this analysis cannot incorporate the technological evolution of manufacturing systems that new motorization standards are expected to induce, nor, and mainly, the possible increase in local content of BEV electric vehicles, in particular the manufacture of the cells that make up batteries – which answer for 50-80% of the total battery value and 25-40% of the price of the vehicle, depending on model and power.

However, should power-cell manufacture and battery assembly become increasingly localized in Brazil, we expect the negative economic impact associated with BEV vehicles to be partly mitigated. This mitigation may be more relevant if the entire production chain upstream develops, including mining, processing and refining of the required metals.

Public policy recommendations

Based on an assessment of policies, both under discussion or in force, and on simulations of the evolution of motorization in Brazil and its impacts **on GHG emissions and social and economic conditions**, we emphasize relevant public policy themes and points for improvement, with the purpose of accelerating decarbonization and consolidating environmentally sustainable socio-economic development.

This study values the neutrality of policy action and definition, which implies not to discriminate against or privilege specific industries, but **to reduce GHG emissions and generate economic and technological development vectors for Brazil**. We indicate, next, the main actions that align with these objectives.

First off, there must be technical harmony and regulatory scope so that laws and regulations are consistent and mutually convergent.

In this sense, we recommend expanding the GHG emissions calculation paradigm to include stages such as metals mining and processing, battery production, farming and changes in land use (upstream stages); parts, components and materials disposal, re-use and recycling (downstream stages) – by adopting the **Cradle to grave** concept. To reduce GHG emissions, the law is expected to incentivize investments in decarbonization at all stages of the lifecycle of the products along the mobility chain, with advantages of the technological routes that generate the least environmental impact.

Regulatory matters exist that may negatively affect the evolution of consolidated solutions and interfere with the competitiveness conditions of biofuels. Such is the case of PROCONVE: designed to regulate the limits of pollutants emissions by car maker over time, the introduction of Phase 8 of the Light Vehicles Program

(L8) from 2025 will negatively affect ethanol-powered vehicles because of an excessively strict standard for non-methane organic cases – which tend to be higher in ethanol compared with gasoline due to the selected measurement criterion –, which will require making heavy investments that may make ethanol-burning engines, including hybrid ones, non-viable.

Therefore, automotive policies intended to reduce pollutant emissions under the Proconve must align with policies intended to reduce GHG emissions, considering their environmental, economic and social impacts along the production chain.

Matters concerning vehicle efficiency – MOVER in particular – generally consider hybrid vehicles as a single category, without distinction by efficiency level. Whatever the capacity of the electric system and its effective efficiency, all members of the "hybrid" category are afforded the same treatment. Given the recent approval of MP 45 (Tax Reform), assurance will be required that the IPI reduction benefits will remain under the new regime, but **preferably as differentiating tax rates associated with the effective efficiency gain associated with new motorizations**.

It is also necessary to ensure the competitiveness of biofuels and of low-carbon hydrogen nationwide, overcoming logistical bottlenecks and automatically implementing the favored tax regime, and stimulating ethanol consumption in markets where their cost currently exceeds that of fossil fuels.

Still in connection with light vehicles, policy must ensure balance between the available motorization alternatives, and that the benefits of IPVA reduction or exemption are extended to vehicles rated as low GHG emission by the Inmetro (AEA concept).

Similarly, as discussed for light vehicles, a database and a method must be established for measuring heavy vehicles' CO_2 emissions, where characteristics require a heterogeneous set of parameters, preventing the estimation of emissions based on averages. In this sense, a definitive calendar must be built for the **implementation of Vecto** in Brazil, to correctly measure heavy vehicles' CO_2 emissions for their purposes of the RenovaBio.

It is also recommended to update heavy-vehicle weight and size regulations in line with decarbonization goals, enabling the consideration of new low-carbon technologies that require an increase over the permitted front-axle weight. Examples include: facilitating biomethane by permitting 7 tons on the front axle, and 9 tons in the case of electric motors. This will require a plan to revise highway concessions to cover investments in reinforcements so that the pavement will not negatively influence GHG emissions.

Also in connection with heavy vehicles, **special financing lines must be create to renovate the truck and heavy machinery (agricultural and construction) fleet**, and there must be assured exchange of old models for new ones with minimal emissions, under the management of environmental regulation authorities and the supervision of the Ministry of Development, Industry and Commerce – MDIC. Policies in support of fleet renewal tend to accelerate and anticipate the effects of decarbonization.

As for the biofuel chain, in particular those for fuels made form sugar cane, Brazil clearly has the potential to become a global producer of a range of key products for the transport chain's decarbonization: from light vehicles (ethanol) to heavy ones (biomethane, biodiesel and green diesel; low-carbon hydrogen, and ammonia), including heavy farming and construction machinery (biomethane, ammonia), as well as aviation (SAF); shipping (ammonia and green methanol), and railway transportation (ammonia and methanol).

The incentives regime that RenovaBio provides for with the CBios has proven important to the expansion of biofuel production, and has been enabling remarkable productivity gains based on new technologies mapped by its R&D centers (CCT and EMBRAPA). However, relevant questions remain that require attention, such as:

i. Ensuring the approval of amendments to PL 4.516/2023 concerning the **National Biomethane Program**, which are key to providing regulatory safety to the market and ensuring investments to increase supply as demand grows;

ii. Supporting **investments in secondary gas pipeline branches** interconnecting the biofuel and low carbon hydrogen production sites with existing branches (TAG, TBG, TSB, GOM e NTS);

iii. Ensuring **appropriate material reinforcements** so that the gas pipelines will stand a significant amount of low-carbon hydrogen (LCH2) and **encouraging the development of ethanol pipelines**, in particular the central pipeline from Minas Gerais to the Center-West region;

iv. Ensuring special financing lines (BNDES, Fundo Clima, Plano Safra) by means of specific energy transition funding for **investments in the production of biofuels (biodiesel, biomethane, SAF, HVO, etc.), low-carbon hydrogen, battery and battery cell assembly and customization;**

v. Creating mechanisms to certify the availability and compliance of biofuels to ensure the issuance **Green Seals**, so that actors anywhere may provide the gas to be used at outtake sites;

vi. Extending special financing programs intended for electric buses to their peers running on biomethane (or VNG as a transition fuel), ethanol or low-carbon hydrogen, whether hybrid or not;

vii. Adding to the General Tenders Law a **provision enshrining sustainability as a criterion for fuels procurement, or setting aside a minimum procurement percentage to the purchase of biofuels by public administration**.

viii. Reinforcing science and technology development programs between Universities, ICTs and private-sector businesses by means of FINEO and BNDES lines, for **advanced biofuel projects**: low-carbon hydrogen, fuel cells, SAF, green bunker, minerals processing and battery cell production, development of automotive and clean recycling processes for new materials used in mobility, particular emphasis due on batteries.

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to Mobility Decarbonization

LCA Consultores and MTempo Capital

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