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CARBON CREDIT MARKET IN THE MOBILITY SECTOR: OPPORTUNITIES IN THE BRAZILIAN CONTEXT

MERCADO DE CRÉDITO DE CARBONO NO SETOR DE MOBILIDADE: OPORTUNIDADES NO CONTEXTO BRASILEIRO

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RESUMO

O setor de transportes é um dos maiores emissores de gases de efeito estufa, contribuindo para alterações climáticas. Inúmeras iniciativas têm sido adotadas mundialmente para redução da emissão de tais gases, entre elas, o mercado de crédito de carbono. O objetivo deste estudo foi revisar e contextualizar sobre a mobilidade e os caminhos para transição para economia de baixo carbono. A pesquisa foi conduzida em bases de dados e órgãos nacionais e internacionais relacionados ao mercado de crédito de carbono. Foram selecionados estudos, relatórios e documentos atendendo aos seguintes critérios: Materiais relacionados à temática de mobilidade, sustentabilidade e crédito de carbono; em inglês, português ou francês até

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novembro/2022. A análise das informações identificou que as metodologias de cálculo para análise de ciclo de vida estão majoritariamente voltadas a natureza e pouco foi publicado sobre o setor de transportes. Empresas ainda necessitam agregar a gestão de sua performance ambiental pelo inventário de emissões de gases de efeito estufa e evoluindo para a análise de ciclo de vida de seus produtos e serviços. No cenário global, veículos rodoviários representam 77% das emissões globais de carbono do transporte (34% veículos pesados). Veículos pesados contribuem desproporcionalmente mais para o potencial de aquecimento devido a emissão de particulados. Em conclusão, não existe solução única para a descarbonização do setor de transportes no Brasil, a combinação da renovação da frota, biocombustíveis e melhoria na eficiência da frota circulante, como a eletrificação de segundo eixo de veículos pesados, são fundamentais para atingir as metas brasileiras.

Palavras-chave: gases de efeito estufa; mercado de carbono; mobilidade.

ABSTRACT
The transportation sector is one of the largest emitters of greenhouse gases, contributing to climate change. Numerous initiatives have been adopted worldwide to reduce the emission of these gases, including the carbon credit market. The objective of this study was to review and contextualize mobility and pathways for transitioning to a low-carbon economy. The research was conducted using national and international databases and organizations related to the carbon credit market. Studies, reports, and documents were selected based on the following criteria: Materials related to mobility, sustainability, and carbon credit themes; in English, Portuguese, or French up until November 2022. The analysis of the information identified that life cycle analysis calculation methodologies are predominantly focused on nature, with little published about the transportation sector. Companies still need to incorporate environmental performance management through greenhouse gas emission inventories and evolve towards life cycle analysis of their products and services. In the global scenario, road vehicles account for 77% of the global carbon emissions from transportation (34% being heavy vehicles). Heavy vehicles disproportionately contribute more to the warming potential due to particle emissions. In conclusion, there is no single solution for the decarbonization of the transportation sector in Brazil; a combination of fleet renewal, biofuels, and improvements in the efficiency of the existing fleet, such as the electrification of the second axle of heavy vehicles, are essential to achieve Brazilian goals.

Keywords: greenhouse gases; carbon market; mobility.

1 INTRODUCTION

The transportation sector is worryingly dependent on a single energy source: oil. Economic growth and the ongoing trend of an increasing middle class in developing countries and the United States (STATE OF THE UNION, 2022) will sustain high demand for passenger and cargo vehicles. On the other hand, over 90% of the global population lives in areas that do not meet minimal air quality standards (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2022). Addressing greenhouse gas (GHG) emissions alone doesn't fully encompass the environmental challenge of tackling rising fossil fuel consumption and demand for mined raw materials. Thus, conducting life cycle analysis (LCA) of products is crucial for a multifactor understanding of the environmental

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impact and environmental performance of production processes (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2022).

Since the industrial revolution in the 18th century, the concentration of GHGs has been increasing, leading to heat retention in the atmosphere and a rise in global temperature. According to a report from the World Meteorological Organization (WORLD METEOROLOGICAL ORGANIZATION, 2022), three main gases — Carbon Dioxide (CO2), Methane (CH4), and Nitrous Oxide (N2O) — have seen increases of 150%, 262%, and 123% respectively compared to pre-industrial revolution levels. Over the years, numerous initiatives have been internationally adopted because of the recognition of the climate urgency. Beginning with the Kyoto Protocol and currently enforced through the Paris Agreement, these efforts are consistently discussed during the Conferences of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC). These agreements and groups establish plans and targets to mitigate climate changes stemming from global warming, including the reduction of GHG emissions.

Joining forces with the primary goal of emissions reduction, regulated and voluntary carbon credit markets reward companies' climate efforts through CO2-eq inventories. The regulated market sets emission limits (caps) for entities through regulations, and those entities operating below the limit can trade emission allowances with entities exceeding their limit. The Voluntary Market functions as a trading mechanism for certifications of GHG emission reductions (offsets) (INTERNATIONAL CHAMBER OF COMMERCE, 2022).

The transportation sector is one of the largest GHG emitters following the sectors of i) energy, ii) agriculture and forestry, and iii) industry (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2022). However, the transportation sector significantly shapes energy demand. According to the Ministry of Mines and Energy (2022), energy consumption increased by 3.4% from 2020 to 2021, with the transportation sector advancing the most and regaining its position as the leading energy consumer in Brazil, surpassing the industrial sector. Considering the above, this article aims to review and contextualize mobility and its pathways to transition to a low-carbon economy, considering opportunities arising from carbon markets' implementation. Furthermore, this article seeks to elucidate the necessary steps for certifying a mobility product or project to facilitate carbon credit generation certification mapping within the mobility industry in the Brazilian context.

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2 METHODS

The present study was conducted through a search in national and international databases and organizations related to the study's theme using keywords in English and Portuguese: Climate change, GHG, sustainability, mobility, Paris Agreement, decarbonization, carbon market, green bonds, carbon certificate, LCA, circular economy, and low-carbon economy. Thus, studies, reports, and documents were selected based on the following eligibility criteria: (1) Materials related to mobility, sustainability, and carbon credit themes; and (2) published online in English, Portuguese, and French until November 2022. Considering the search, the text was divided into two parts. The first introduces key concepts and projections concerning mobility and sustainability in Brazil and around the world, as well as regarding carbon credits in this context. The second part discusses the carbon credit trading environment, its certification, and opportunities in the Brazilian context.

3 RESULTS AND DISCUSSION

3.1 Worldwide mobility, in Brazil, and projections for the next years

In 2010, the global fleet of automotive vehicles amounted to 985 million, while in 2021, this number grew by approximately 45% (1.4 billion vehicles), and this number continues to increase each year. In 2010, Brazil had a fleet of 60.6 million vehicles, whereas in 2021, the fleet reached 111.5 million, representing an almost 85% growth (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2021). Currently, with 11% of the global fleet, Brazil holds a strategic market for automakers; the marketed fleet will substantially impact corporate environmental goals as regulatory trends are leaning towards considering not only vehicles sold but also the circulating fleet (INTERNATIONAL ENERGY AGENCY, 2022).

The transportation sector has many benefits from CO_2-eq emission calculations, which serve as a key parameter for informed decision-making. Eighteen out of the top twenty manufacturers have committed to increasing the supply of electric vehicles to meet the demand for zero CO2 emission vehicles in the private vehicle sector (INTERNATIONAL ENERGY AGENCY, 2022). In Brazil, with major companies committed to reduce GHG emissions, the trajectory is likely to follow a similar path, given that major automakers operating in Brazil have also committed to provide fewer polluting vehicles.

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3.2 Sustainability in the mobility scenario

The Brazilian Panel on Climate Change and the Intergovernmental Panel on Climate Change (IPCC) have unanimously attested that Brazil and South American countries are already experiencing climate change impacts (MINISTRY OF ENVIRONMENT, 2016): Increase of up to 2.5°C in Brazil's coastal regions between 1901 and 2012; rise in the number of days with 30 mm rainfall in Southeast Brazil; higher sea temperatures and changes in the salinity of the South Atlantic; increase in frequency, intensity, and influence of El Niño southern oscillation events on continental climate.

In a broader international context, the IPCC's climate change report serves as a guide for international agreements. The International Council on Clean Transportation (ICCT) focuses on enhancing environmental conditions and energy efficiency in land, marine, and air transportation to mitigate climate change and improve public health, in line with the IPCC's recommendations. The ICCT's Vision 2050 report, 2020, outlines actions in the transportation sector to achieve the goals of the Paris Agreement, which aims to limit temperature growth to 1.5°C under the best-case scenario. The conclusion suggests a trend toward all vehicles producing zero exhaust emissions and being fueled by carbon-zero solutions or renewable energy sources. Electric vehicles are the solution that, if applied individually, would have the greatest impact on decarbonizing the transportation sector. This is why several governments and companies have set official goals for reducing internal combustion engines (INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION, 2021).

In the 2022 IPCC report, it was identified that Latin America, in terms of CO2-eq emissions contribution, has its greatest share due to land-use change (LUC). Increasing land use with carbon-retaining crops is crucial to avoid global warming. For instance, sugarcane plantations, when grown on land previously used for pasture, might qualify for Carbon Credit Projects to capitalize on their environmental attributes. Certification and trading of Carbon Credits can support increased use of biofuels and contribute to a low-carbon economy. In the Latin America case, biofuels can help reduce emissions in two ways: by altering land use and by offsetting emissions from internal combustion engines, primarily due to the planting phase and utilization of residues. Moreover, increasing transportation efficiency will ensure compliance with the Paris Agreement. Therefore, complementary investments in hybridizing flex engines are strategic for decarbonization. Electrification technologies through the combination of electric machines alongside internal

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combustion engines, coupled with the use of biofuels, offer diverse efficiency benefits based on their installation position within the propulsion system, which may significantly curtail fuel consumption. The possibility of electrifying the existing fleet will also contribute by aligning the need for governments to take immediate action and directing private capital toward sustainable and profitable solutions (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2022).

Currently, the transportation sector is responsible for a quarter of global anthropogenic CO_2 emissions. In 2015, GHG emissions were equivalent to 10.9 billion metric tons of CO_2-eq (INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION, 2020). The four largest vehicle markets - the United States, China, the European Union, and India - account for 46% of global CO_2 emissions. These top four markets, along with aviation (10%) and maritime transport (11%), hold two-thirds of the total emissions in the transportation context. Globally, road vehicles represent about 77% of the global CO_2 emissions from transportation (43% from light vehicles, including 2 and 3-wheeled vehicles, and 34% from heavy vehicles, including buses). Heavy vehicles have significantly higher emissions of particulate matter (including black carbon), thus disproportionately contributing to the warming potential (INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION, 2020).

Biofuels are essential for short-term decarbonization, as the technological solution is already in place. An example in the Brazilian context is RenovaBio, which employs a risk management approach, penalizing when native vegetation is replaced by any other use. Therefore, it aligns with international expectations to prevent deforestation and encourages the expansion of carbon-retaining crops over areas with low carbon retention activity, such as pastures. There are numerous lessons learned from the implementation of RenovaBio and CBio; a review of these programs could benefit all stakeholders and provide better framework for market operations (MOREIRA; KIMURA, 2016).

Biofuels will be crucial to meeting the 2050 targets. Approximately 67% of bioenergy production (~15.5 million barrels per day) could be directed toward the transportation sector, with 79% of this being used for road transport. The highest potential for low-carbon biofuel production comes from cellulosic energy crops (MINISTÉRIO DE MINAS E ENERGIA, 2020, 2021). Comparing well-to-wheel CO_2 emission projections, it was revealed that by 2050, in the United States, parts of the European Union, Japan, and South Korea, projected CO_2 emissions will be lower compared to 2020. In other countries, there's still an increase, with significant variation in countries like China and Africa, where growth surpasses 100% (Ministry of Mines and Energy, 2020). In Brazil and Mexico,

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CO_2 emissions increase by over 50%, which can be attributed to these countries already having lower CO_2 emission solutions (MINISTÉRIO DE MINAS E ENERGIA, 2020). Conversely, the United States does not have a national requirement for ethanol content in gasoline, but on average, has a 10% ethanol content by volume. Thus, there's significant availability of flex-fuel vehicles and ethanol production, leading to greater relevance of biofuels in the Brazilian energy matrix compared to other countries (ASSOCIAÇÃO NACIONAL DOS FABRICANTES DE VEÍCULOS AUTOMOTORES, 2021).

3.3 Carbon credit history

Over the past decades, numerous intergovernmental initiatives have aimed to coordinate international actions to mitigate the threats of climate change. Since the inception of these agreements, Brazil has played a significant role in discussions initiated during the Rio92 summit. As a developing country, Brazil's historical contribution to the global climate change issue is much smaller than the emissions accumulated since the Industrial Revolution (post-1750 period). To build a fair global response, it's vital to establish a connection between the cause (anthropogenic emissions, i.e., GHG resulting from human activities) and the effect (temperature increase and climate change). Most of current GHG in the atmosphere result from emissions since the industrial revolution; today, we bear the cost of past interferences primarily caused by developed countries over the last two and a half centuries. Therefore, a country's autonomy to establish its own National Determined Contribution (NDC) is crucial for justice and equity (NATIONAL DETERMINED CONTRIBUTION, 2022).

The United Nations (UN) through the IPCC constructs policies in collaboration with nations to determine international cooperation and strategies to mitigate climate change. The outcome of this collaboration is agreements that amalgamate actions and commitments from each party. The Paris Agreement was adopted by 196 Parties at COP21 in Paris in 2015 and came into effect on November 4, 2016. Commitments are reviewed every 5-year cycle. Each country communicates its goals through the NDC, outlining actions it will take to reduce its GHG emissions to meet the targets set in the Paris Agreement. To monitor progress, each country has established an Enhanced Transparency Framework (ETF). Starting in 2024, parties will report actions and outcomes that feed into a global assessment of collective progress towards long-term climate goals (UNITED NATIONS, 2022). Additionally, it's important to note that some countries, while participating in the Paris

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Agreement, deem the use of the agreement and its mechanisms as unacceptable tools for creating barriers to social and economic development. Low-carbon solutions have become competitive across various economic sectors, a notably strong trend in energy and transportation sectors, creating numerous business opportunities.

Carbon pricing instruments (taxes and emissions trading systems - ETS) cover 23% of global GHG emissions. In 2022, there are 68 carbon pricing instruments (CPIs) worldwide. Global carbon pricing revenue totaled $84 billion, and revenues from high-performing ETS markets surpassed carbon tax revenues for the first time, marking a historic milestone. Despite macroeconomic challenges, the growing carbon pricing revenue can sustain economic recovery, finance broader fiscal reforms, and shield countries from turbulence (THE WORLD BANK, 2022). There is a continuous growth in carbon markets, with the voluntary carbon market (VCM) exceeding $1 billion annually for the first time, primarily driven by corporate commitments. The evolution of the Paris Agreement under Article 6 will guide the demand for carbon credit compliance. Currently, nature-based credits are experiencing high demand (forest and land-use transactions more than doubled between 2020 and 2021). This represents significant potential for the transportation sector to benefit from biofuels in combination with performance-enhancing technologies, such as electrification (THE WORLD BANK, 2022).

In Brazil, the *Projeto de Lei* 290/20 mandates a yearly reduction of 1.2% in GHG emissions from power generation by thermal power plants or the offset of this percentage through certified carbon credits. The bill will be conclusively examined by the committees on Mines and Energy, Environment and Sustainable Development, and Constitution and Justice and Citizenship (AGÊNCIA CÂMARA DE NOTÍCIAS, 2020). On May 19, 2022, the Carbon Market Decree was published in the Official Gazette of the Union. It establishes procedures for developing Sectoral Plans for Climate Change Mitigation, institutes the National System for GHG Emission Reduction, and amends Decree No. 11,003, dated March 21, 2022 (PRESIDÊNCIA DA REPÚBLICA, 2022).

Decree No. 11,075 references Decree No. 9,578 of 2018, which consolidates regulatory acts issued by the federal Executive Branch concerning the National Climate Change Fund established by Law No. 12,114 of December 9, 2009, and the National Policy on Climate Change established by Law No. 12,187 of December 29, 2009. The main considered projects are efficient collection and use of biogas, urban mobility (added by Decree No. 10,143 of 2019), low-carbon urban mobility and efficient transportation (added by Decree No. 10,143 of 2019), and pollution control and air quality

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monitoring (added by Decree No. 10,143 of 2019). It's also important to note Decree No. 11,075 of 2022, which establishes Sectoral Plans for Climate Change Mitigation and institutes the National System for GHG Emission Reduction (SINARE) and amends Decree No. 11,003, dated March 21, 2022. Considering the current scenario of carbon market implementation in Brazil can be identified. There is still much work to be done to secure Brazilian diplomatic interests, sectoral decarbonization plans, and the effective implementation of credit trading environments.

3.4 Carbon credits and their importance in the mobility landscape

The Brazilian NDC is one of the most ambitious in the world, with few others adopting commitments not only for 2025 but also for 2030. The second cycle of the National Adaptation Plan will strengthen the management of 55 policies across sectors for broad coherence, efficiency, and synergy considering the Sustainable Development Goals (SDGs). For instance, the Low Carbon Agriculture Plan (ABC+ Plan) allocated $17 billion to implement a wide range of mitigation actions (land restoration, nitrogen fixation, soil carbon accumulation, agroforestry, and reforestation). The Brazilian NDC employs a Tier 2 methodology, Global Warming Potential over 100 years (GWP-100) as per the IPCC 5th assessment report and follows the Global Temperature Potential (GTP) methodology for greater accuracy in accounting for the contribution of different gases (EMPRESA DE PESQUISA ENERGÉTICA, 2018).

Brazil has committed to reduce its GHG emissions by 37% in 2025 compared to 2005, and additionally, by 50% in 2030 compared to 2005. Its long-term goal is to achieve climate neutrality by 2050 (BRASIL, 2022). The National Adaptation Plan aims to reduce vulnerability in terms of water, energy, food, social, and environmental security, but it needs to be updated as it was initiated in 2013 and published in 2016, and it does not encompass the evolution of the debate on carbon markets and electrification (MINISTRY OF ENVIRONMENT, 2016). The AdaptaBrasil system (developed by the Ministry of Science, Technology, and Innovation and maintained with support from the National Institute for Space Research and the National Research and Education Network) consolidates information about the impacts of climate change in Brazil. Brazilian statistics indicate the need to ensure economic growth while simultaneously improving the population's standard of living (MINISTRY OF ENVIRONMENT, 2016; MINISTÉRIO DE TRANSPORTES, 2013). Significant advancements are still needed in the development of sectoral plans to ensure that regulated entities

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in the regulated market and companies participating in the voluntary market are truly engaged in climate change mitigation actions.

Brazil possesses abundant natural resources and the potential to manage its transition from a net energy importer to a net energy exporter (MINISTÉRIO DE MINAS E ENERGIA, 2020). This expansion should be carried out sustainably, to maintain its renewable indicators: nearly 45% of renewable sources in the energy matrix and almost 85% in the electric matrix. The National Energy Plan 2050 (PNE 2050) compiles studies from the Energy Research Company to guide the decisions of the Ministry of Mines and Energy. The policy outlined in PNE guides long-term strategies, with revisions every 5 years. One of the focuses of PNE 2050 is carbon mechanisms that can contribute to a low-carbon economy and collaborate in designing technological pathways for decarbonization. In the medium term, one of the conclusions is that by 2030, 75% of the domestic energy supply will come from oil, hydropower, sugarcane, and biogas. The energy transition aims for matrix decarbonization, providing Brazil with a strategic competitive advantage to benefit from international carbon offset markets. Achieving this scenario will require a review of legal and regulatory structures to favor the natural attributes of energy resources, such as Renewable Energy Certificates, Green Bonds, and Carbon Pricing (MINISTÉRIO DE MINAS E ENERGIA, 2020). RenovaBio is a mechanism to make biofuels accessible compared to fossil fuels. Notably, RenovaBio is the only sectoral transport mitigation mechanism listed in the Brazilian NDC as an action already implemented for decarbonization (CLIMATE WATCH DATA, 2022).

3.5 Carbon credit trading platforms

There are two major carbon trading markets: the Regulated Market and the Voluntary Market. The former derives from commitments and targets set in the NDC under the Paris Agreement. For its implementation, the regulatory framework establishes a maximum limit of GHG emissions (cap), and regulated entities that emit below this cap can trade their emission allowances with those emitting above the established limit. The emission allowance is an allocation of a right granted to a regulated entity. The regulated market can be international, national, or regional in scope. The UNFCCC has already implemented the international regulated market, initially in force through the Kyoto Protocol and since 2015 governed by Article 6 of the Paris Agreement, in which the targets are referred to as NDCs (BRASIL, 2022).

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The Voluntary Market generates carbon credits based on reductions or removals of GHG emissions. These credits are traded between companies and individuals seeking to achieve voluntary corporate or individual goals, and they undergo verification by a third party with knowledge of the calculation methodologies for each activity segment. Credits generated in the voluntary market can be traded in the regulated market as a partial means of achieving targets, thus creating an interaction where credits (offsets) can be directed from the voluntary market to the regulated market, but not the other way around (INTERNATIONAL CHAMBER OF COMMERCE, 2022).

There are three major carbon credit trading environments: i) the United Nations Framework Convention on Climate Change (UNFCCC) market (regulated market), ii) National or Regional Emission Trading Systems (ETS) (regulated market), and iii) the Voluntary Market. Article 6 of the Paris Agreement outlines the regulated market, specifying under Article 6.2 that countries can trade credits generated by emission reduction and removal projects to achieve their targets with each other. Article 6.4 outlines that private entities can trade project credits with countries and other private companies. The regional market aims to reduce emissions according to policies that define goals for a group of regulated entities, and the results of these reductions can be traded with another country if it surpasses the commitments adopted in its NDC (INTERNATIONAL CHAMBER OF COMMERCE, 2022). Ensuring the quality of credits generated in the voluntary market is crucial for effective contributions to environmental objectives and accurate pricing of these assets in the regulated market. Nature-linked credits, such as GHG Reduced Emissions from Deforestation and Forest Degradation (REDD+) credits, which consider the role of conserving forest carbon stocks, sustainable forest management, and increasing forest carbon stocks, hold high value in the market due to their ability to guarantee the quality of methodologies and the credibility of GHG mitigation calculations (CHERUBIN et al., 2021).

The implementation of the carbon market should establish a clear framework for interactions between entities and incentivize the trading of these assets, which still require a well-defined accounting perspective. Although there is no consensus yet on the accounting classification of carbon credits, there is a tendency to classify them as intangible assets. The implementation of the RenovaBio policy through Law 13,576 recognized new fuels and generated experience for the carbon credit market with CBIOs: Decarbonization Certificates. However, RenovaBio does not address tax issues. Thus, the implementation of the carbon market will still be inhibited by the general tax regime. The Federal Revenue also needs to be involved in the implementation of the voluntary

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market. CBIOs and Carbon Credits differ, as the latter must be acquired for retirement since the goal is emissions abatement. The most widely accepted classification currently is that Carbon Credits are a currency, an optional and fungible means of payment. There is a backing to the certificate with the weight of the CO_2-eq not emitted into the atmosphere, essentially making it a type of Green Bonds. Nevertheless, the lack of regulation leads to legal and tax uncertainty, hindering broader adoption. Regarding CBIOs, currently there is no PIS/COFINS tax on sales; however, it remains uncertain how carbon credits will be categorized and whether these taxes, IOF, or others will apply (MARTIN; MOSER, 2016; SOUZA et al., 2020).

Thus, promoting a trading environment with clear, efficient, and effective regulations will enable companies to drive energy efficiency and promote renewable energy. With this encouragement, the transportation sector (which largely dictates demand for fossil and renewable energy sources) will, together with the energy sector, have numerous opportunities to promote efficiency and facilitate new technologies through the monetization of their credits. It will also interact with the forestry sector, given the potential for applying credits and incentives for biomass and bioproducts. The role of the transportation industry is critical in defining strategies to develop more efficient, connected, and electrified modes of transportation. The transportation industry can increasingly interact with the agricultural sector, exploring the environmental potential of biofuels and carbon sequestration in soil through Land Use Change (LUC). In the field, tractors and trucks have easy access to refueling points for biogas, biomethane, ethanol, and potentially hydrogen. OEMs are paying attention to the use of new technologies and fuels and their environmental benefits (PEREIRA et al., 2022; INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION, 2020; CHERUBIN et al., 2021).

3.6 Certification for carbon credit generation

The implementation of the voluntary market is essential to sustain the demand for credits from the regulated market and to promote a culture and incentives for sustainable practices. The voluntary market will allow companies to purchase emission credits from projects that reduce or remove GHGs from the atmosphere. In this market, key actors exist to set goals, develop projects, provide credibility, and trade these credits (SUSTAIM, 2022).

The trading price per ton of CO_2 varies based on the project type and region. However, projects of the same nature and region can have different pricing due to the quality of the credit, which is the

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project's ability to effectively demonstrate the verifiability of the calculation methodology with real emissions (SUSTAIM, 2022). Unlike the regulated market, there won't be a central entity issuing emission permits. In theory, project developers can issue their own carbon credits and methodologies or standards. This presents a vulnerability as it could lead to overvaluation of mitigated emissions and double counting. Therefore, Verifiers or Certifiers become important to validate fundamental project characteristics (SUSTAIM, 2022):

- **Additionality**: Without income from credit trading, the project becomes unfeasible. Emission reductions or removals cannot occur within activities already legally required or common practices in the project area.
- **Inventory**: The reductions or removals of GHGs must correspond to the quantity of credits generated by the projects.
- **Perennial:** The positive impact of projects must be enduring.
- **Double Counting:** Reductions or removals of GHG emissions can only be accounted for in one project, including proof of credit retirement according to project maturity. A credit has its positive environmental effect when retired (recognized as an offset). Therefore, certifying companies must maintain a record of all projects.
- **Environmental and Social Benefits**: Projects must comply with legal requirements of their region and promote social benefits in accordance with the United Nations' Sustainable Development Goals (SDGs).

The main issue is that project certification is costly and financially renders small projects unfeasible. Currently, a project becomes viable starting from 15,000 tCO_2-eq (GOLD STANDARD, 2021; VERRA, 2021) (Table 1).

Table 1 – Costs for carbon credit certification.

Information	Value
Cost of project documentation development	Depends on each project
Minimum annual reduction potential for financial viability (tCO_2e) (US$)	15,000
Validation cost (US$)	30,000 to 40,000
Bank Account Opening (US$)	500,000

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Registration Fee (US$)(1)	10,000 + annual fee
Verification Fee (US$)(2)	20 to 30 mil
Monitoring Cost (3)	Depends on each project
Credit Emission Costs (US$/credit)(4)	US$ 0,025 to 0,30 depends on program, period, and quantity

Source: International Chamber of Commerce, 2022. Notes: (1) Maximum value; (2) For forestry projects recommendation of 5-year re-validation; (3) Value per project; (4) One credit corresponds to 1 tCO_2-eq.

In the transportation sector, Europe has been engaging in high-level discussions about Vehicle LCA (EUROPEAN COMMISSION, 2020), which serves as a foundation to scientifically substantiate the methodology for quantitatively analyzing the total emissions involved in all stages of a product's life cycle. The transportation market is undergoing a significant transformation, innovating, and increasingly incorporating the use of data. These data will require governance and robustness to ensure smart contracts in a market that is becoming more complex due to the growing number of stakeholders. According to the National Energy Plan 2050 (PNE2050) (MINISTÉRIO DE MINAS E ENERGIA, 2020), the natural gas market will involve the trading of molecules from various sources, with different degrees of flexibility, contract liquidity, and a diversity of stakeholders. Biogas can be directly injected into the natural gas pipeline, enabling access for numerous new players in this market.

3.7 LCA as a tool to assess the environmental performance of the transportation industry

The need to combat climate change is leading more and more countries to adopt carbon neutrality trajectories. In Europe, the Green Deal (2019) and the Fit-for-55 legislative package (2021) take an environmentally based approach grounded in Life Cycle Assessment (LCA). Although there is currently no mandatory LCA requirement in Europe, the dynamics of analysis are present: CO_2 emission regulation for tailpipes will require a methodology for assessing the entire life cycle compatibility starting from 2023. The LCA methodology for batteries will also be regulated, obliging carbon footprint disclosure from 2024. In China, similar regulation is under development (GIRARD; RICHET, 2022).

Most of Original Equipment Manufacturers (OEMs) employ the LCA approach. The results feed communication actions with stakeholders and support strategic decision-making for companies. The

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entire value chain benefits from this approach, which is gaining increasing importance. The goal is to introduce the market and different LCA and carbon footprint standards to better guide methodological choices: databases, units, benchmarks, end-of-life considerations, and more (GIRARD; RICHET, 2022).

LCA is a methodology that assesses the environmental impact of a product throughout its life cycle, from raw material extraction to disposal. The LCA methodology is characterized by being multi-stage (covering all stages of the product life cycle), multi-criteria (considering a wide range of environmental impacts), multi-component (evaluating product impacts and derivatives such as transport, packaging, associated product use, etc.), and functional (comparative analysis based on the service provided by the product, represented by a functional unit) (GIRARD; RICHET, 2022). For the mobility industry, both LCA (product-centered) and Carbon Footprint Inventory (company's industrial activity-centered) are important tools for guiding decisions. It's important to differentiate between these two methodologies. LCA is a multi-criteria methodology focused on the product, quantifying various environmental impacts and the product's impact throughout the value chain, with the main international standard being ISO 14.040/44. On the other hand, Carbon Footprint focuses on GHG emissions resulting from a company's activities across three scopes: 1) direct industrial activity emissions, 2) indirect emissions from energy sources for operations, and 3) emissions generated by third parties in manufacturing, use, or disposal of a component; the main standard is ISO 14 067. One of the most widely used standards is the GHG Protocol by WRI (GIRARD; RICHET, 2022). Both methodologies, LCA and Carbon Inventory, use a variable that connects them, the Global Warming Potential (GWP), which allows calculating the carbon footprint. Currently, most analyses use GWP100 as a reference for the global warming potential over 100 years (GIRARD; RICHET, 2022).

These methodologies can be applied within different boundaries. Therefore, it's essential to define the boundary of the analyses: which system is being assessed. It can be focused on just a part of the life cycle, such as the cradle-to-gate system, which considers only the carbon footprint of manufacturing and transportation to the point of sale. This scope is primarily used between OEMs and suppliers where raw material exchange occurs. On the other hand, the cradle-to-grave system is the most comprehensive approach for LCA and includes the entire life cycle: manufacturing, transportation, use, and disposal of the product (GIRARD; RICHET, 2022).

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The GWP indicator is representative for calculating the carbon footprint and is a major focus of current studies. However, it's important to maintain the multi-criteria focus of LCA, which is likely to be the primary form of analysis. As governments adopt emissions reduction targets towards carbon neutrality, companies will increasingly need to master LCA for their products and Carbon Footprint Inventory for their activities. For climate change mitigation to be effective, these measures must be accurate, scientifically proven, and therefore require standardized methodologies segmented by product category. LCA offers this solution and must be regionally developed based on scientific foundation to reflect real emission patterns. OEMs already adopt this methodology at an institutional level and influence decisions as regulations and recommendations are conceived, necessitating discussions with key stakeholders. Therefore, OEMs need to technically influence the criteria to be adopted in legislation to effectively reflect the product being evaluated (GIRARD; RICHET, 2022):

1. LCA methodologies for vehicles and components should be provided, identifying key assumptions and relevant data for the automotive value chain.
2. Influence regulatory bodies' decisions by providing relevant and accurate LCA data for mobility products.
3. Ensure consistency between various regulations focused on environmental impacts (e.g., batteries).
4. Model a vehicle throughout its life cycle, highlighting key sources of emissions.
5. Ensure result compatibility for the mobility industry.

It is necessary to deepen into the concept of Carbon Footprint and LCA of a vehicle to better understand both concepts. In 2021, the Emissions Inventory of the Renault Group indicated that on average, 29.8 tCO_2-eq/vehicle are emitted when considering the well-to-wheel scope. In this context, the driving phase, which represents the actual use of the vehicle, accounts for 80% of the emissions. Improvements in the vehicle's production process continue to evolve and reduce its carbon footprint during the manufacturing phase of the product. However, efficiency improvements in the driving phase hold the greatest potential for reducing the carbon footprint in the transportation sector. From the OEMs' perspective, Corporate Average Fuel Economy (CAFE) goals are likely to be achieved as the sales mix becomes increasingly electrified, naturally lowering the emissions average. However, the need for an environmental response commensurate with the challenge requires more ambitious goals (GIRARD; RICHET, 2022).

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The complexity resulting from the combination of various elementary flows demands databases that compile a repository of factors that can be applied. In the automotive context, up to 1,300 indicators can be found. This is a significant difference between the complexity of LCA and Carbon Footprint Inventory, as the former analyzes multiple criteria, while the latter focuses on analyzing GHG emissions (GWP). There are other sources of complexity for the Carbon Footprint Inventory, such as choosing the company's footprint accounting method and minimizing double counting (WORLD RESOURCES INSTITUTE, 2004).

Analyzing the environmental impacts of tire production, different software yields distinct results due to the use of different databases and the modeling and compilation of complex elementary flows. The main differences in environmental impacts between GaBi and SimaPRO lie in natural rubber. When conducting comparative analyses, ensuring the use of the same tool and database is essential, and this compatibility is especially crucial when negotiating between companies (from cradle to gate when targeting the supply chain) (GIRARD; RICHET, 2022).

3.8 Hypotheses and sensitivity

LCA requires a series of foundational assumptions to conduct a comparative study, and each segment will have its specificity. Initially, all vehicle categories used the same reference lifespan of 150,000 km. However, as different segments possess varying characteristics and usage capacities, the trend is to adopt mileage values consistent with the actual usage of each product. Each segment thus attains a more representative mileage figure. This differentiation is crucial as it directly impacts comparative analysis (RICARDO, 2022). As a result, efforts are made to demonstrate that different methodologies and software yield substantially discrepant results.

Another example of assumption harmonization is the Well-to-Tank scope, where the country's energy and electricity matrix must be taken into consideration. Projecting the evolution of these matrices is also necessary to comprehend trends and support decision-making. The International Energy Agency (IEA) has already produced a reference basis for these studies, advocating the Sustainable Development Scenario (SDS) aimed at reducing global warming well below 2°C – an ambitious scenario. IEA also provides the Stated Policies Scenario (SPS). Normalizing assumptions and methodologies for precise decision-making is of paramount importance (INTERNATIONAL ENERGY AGENCY, 2022).

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Another relevant theme is end-of-life assessment, as the circular economy benefits both the initial (cradle) and end-of-life (grave, Cradle-to-Grave) phases. The use of recycled materials during the manufacturing phase reduces the product's environmental footprint. Proper disposal promotes the reuse and recycling of materials, reducing the need for raw material extraction. Care must be taken to avoid double counting and accurately evaluate recycling benefits. The European Joint Research Center (JOINT RESEARCH CENTER, 2019) developed a specific methodology called the Circular Footprint Formula (CFF) in 2014. This methodology introduces an allocation factor that balances the benefits of the upstream and downstream phases of the value chain, favoring the circular economy.

With an impact of up to 80% on emissions and the LCA of a vehicle, monitoring the usage phase becomes necessary for accurately accounting for avoided emissions (RICARDO, 2022). In the Verra methodology VM0019 (Fuel Switch from Gasoline to Ethanol in Flex Fuel Vehicle Fleets), techniques for direct and indirect measurement of these emissions are proposed, with a minimum of 3 years of measurement recommended. Various opportunities, including fleet managers, exist to conduct direct measurement of the variables to be controlled. For instance, a fleet monitoring system rather than manual estimates (such as Excel spreadsheets) (VERRA, 2012).

LCA has demonstrated how technologies compare in terms of CO2 footprint from lowest to highest: Electric Vehicle < Electric Hybrid Vehicle with Ethanol < Ethanol Vehicle < Electric Flex Hybrid Vehicle < Gasoline Hybrid Vehicle < Flex Vehicle < Gasoline E22 Vehicle < Natural Gas Vehicle < Gasoline E10 Vehicle < Diesel Vehicle (EMPRESA DE PESQUISA ENERGÉTICA, in press). From this information, it's evident that pure ethanol engines have a better environmental efficiency than Flex HEV vehicles. The type of fuel significantly impacts the vehicle's environmental footprint over its lifespan. Three factors are crucial for environmental impact: type of powertrain, geographic area (energy matrix), and decarbonization routes (PEREIRA et al., 2022).

Stakeholders in the automotive value chain will invariably need to focus studies on specific scopes. For instance, OEMs, when identifying priority decarbonization routes, will seek to strengthen efforts alongside certain suppliers that hold the greatest potential for mitigating environmental impacts. To achieve a comprehensive analysis of component lifecycles, the European Union aims to establish allocation factors for vehicle use attributed to each component (EUROPEAN COMMISSION, 2020).

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Valeo has been working on formulating a systematic approach to mitigate the environmental impact of its products, which seems simple and effective by applying 3 steps:

1. Inventory emissions by scope (Scope 1, Scope 2, Scope 3 upstream, and Scope 3 downstream) using the GaBi software or Valeo's internal tool.
2. Identify key offenders, be it raw materials or products.
3. Evaluate cost-benefit ratio: gain versus the cost of a mitigation action.

While computational models are widely accepted, many of them rely on projections. There is little literature on effectively measuring consumed raw materials and externalities like the type of energy used during production for accurate emission reduction calculations, as will be discussed below. As the next step towards Net-Zero, using primary data brings greater accuracy and traceability to vehicle LCA calculations, allowing for precise measurement of environmental impacts of materials used, including energy consumption and associated products and services. Challenges exist, such as monitoring and monitoring costs. Technologies associated with Industry 4.0, IoT, and machine learning can contribute. Another challenge is ensuring information integrity over time. For long-life-cycle products, maintaining traceability and information immutability is crucial. Technologies like Blockchain facilitate such solutions but face the current lack of methodology and legislation for this control (VERRA, 2012).

3.9 Practical applicability for the carbon market

Studies like the one presented by Renault at the International Automotive Engineering Symposium (SIMEA 2022 – São Paulo, Brazil) support the need for initiatives that accelerate the achievement of carbon neutrality goals. According to the study by Pereira et al. (2022), three pillars are essential for achieving carbon neutrality in the Brazilian mobility sector by 2050: i) fleet renewal, ii) a mix of renewable and non-renewable energy use (fossil fuels, biofuels, and electricity), and iii) new technologies with high energy efficiency.

Institutions worldwide are increasingly aligning themselves intrinsically with societal demands and climate impact to underpin investment and financing decisions. In Brazil, the Central Bank positions the country at the forefront of sustainable finance and leads a robust agenda. As of December 1, 2022, five BC norms will come into effect (BCB No. 139, BCB No. 140, CMN Resolution 4943, 4944, and 4945), standardizing the management of social, climate, and environmental risks

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for financial institutions. Seeking the effectiveness of climate actions, the Central Bank implemented Resolutions 4,943, norms aligned with the Taskforce on Climate-Related Disclosures (TCFD), launched in 2015 under the Paris Agreement, defining parameters to quantify the impacts of climate change on businesses. Companies will be required to uniformly disclose the Social, Environmental, and Climate Risk and Opportunity Report (GRSAC Report) (MINISTÉRIO DA ECONOMIA, 2022a).

The industry needs to comprehend how climate goals can be fully integrated into the nature of operations and across the scope of impacts. In the case of the automotive industry, internal combustion engine vehicles generate much more emissions (well-to-wheel) during usage than during production. Therefore, consumer goods industries, when conducting emission inventories, will identify numerous opportunities in Scope 3 to invest in product development to achieve decarbonization goals. The potential for applying more technology to products (Scope 3) should be decided considering the possibility of investment in manufacturing processes (Scope 1 and 2). Ensuring equity and interchangeability between international markets is extremely important to enable the widespread trade of carbon credits globally.

Analyzing business performance, it's possible to note that companies need to consider both the lifespan of their products, where mastery of LCA is essential, and need to inventory emissions across the three scopes. LCA is a much more comprehensive quantification due to its multifactorial nature. To achieve an effective environmental response and enable GHG mitigation projects, companies first need to adopt a culture of governing environmental impacts, and opportunities in both regulated and voluntary carbon credit markets will encourage a more circular economy.

There are numerous opportunities in the carbon market driven by systematic implementation demands. National certifiers are needed to foster carbon quantification methodologies that correspond to the Brazilian reality. Currently, Verra (Washington, DC) holds almost the entire market for Brazilian carbon projects from agriculture, forestry, and other land uses (AFOLU). Tax certainty is also required for companies to widely adopt this market. New businesses seeking to reduce fleet emissions can also become viable with income from carbon credit trading. Great opportunities in the carbon credit market exist for all actors.

State governments responsible for collecting the IPVA (Tax on Motor Vehicle Ownership) could impose taxes on less efficient vehicles and provide discounts for more efficient ones. The trucking sector still lacks a Proconve labeling system. Currently, when purchasing a passenger vehicle, the

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labeling system promotes consumer awareness of environmental performance (MINISTÉRIO DA ECONOMIA, 2022b,c; EMPRESA DE PESQUISA ENERGÉTICA, 2022).

For a real reduction in carbon footprint, advocating for the transition from fossil fuels to renewable sources like Biogas, Ethanol, or even 100% electric is fundamental. There is no one-size-fits-all solution for decarbonizing the Brazilian transportation sector; a combination of fleet renewal, the use of biofuels (PEREIRA et al., 2022), and improving the efficiency of the circulating fleet, such as electrifying the second axle of heavy vehicles, is a crucial combination to achieve the Brazilian NDC and allow more carbon credits to be traded in the international market, thus providing a clear direction for Brazilian diplomatic relations in this field.

4 CONCLUSION

The international debate has overcome the incredulity about climate change and has reached the maturity of implementing the economic agenda of sustainable development. Mobility sector has mapped different decarbonization routes for promoting circular economy. Nevertheless, LCA methodologies are mainly focusing on AFOLU, and little has been published about transportation. Brazil has a strategic advantage due to its abundancy of natural resources and use of renewable energy with special potential of producing biofuels.

The regulation of carbon markets in Brazil will allow companies to be more efficient. In the other hand, the private sector needs to have a cultural change and add its environmental performance to decision making. The first step is to make one's GHG inventory and scale to LCA of its products and services. This global movement towards sustainability creates big opportunities for new businesses, especially in Brazil. Companies in the vanguard of this transition are strategically positioned for new opportunities: from the enhancement of its processes, products and services until the governance and monitoring of environmental performance indicators and trading of green bonds.

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