

Circular Economy: an effective response to climate change

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Abstract

Climate change has affected all countries, generating great losses for the economy, the environment, and human lives. The circular economy is an effective way to address climate change, contributing to the potential reduction of carbon dioxide emissions. The objective of the study is to analyze the potential relationship between the reduction of carbon dioxide emissions and the recycling of urban solid waste by waste pickers' organizations. Quantitative and documentary research was developed based on data from the Recycling Yearbook (2020-2024). The results point to a positive relationship between potential CO₂ reduction as the number of organizations increases, from 1,829 in 2020 to 3,028 in 2024, associated with the expansion of the collection and correct disposal of recyclable materials, especially plastics, metals, and paper/cardboard, which together account for most of the reduction in carbon emissions. As contributions, it is highlight that waste pickers' organizations are the axis for the social inclusion of people in social vulnerabilities, women's empowerment, in addition to contributing to the reduction of water and energy consumption and lower impacts on the environment.

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Keywords: Circular economy. Solid Waste. Carbon Dioxide Gas. COP30. Climate Governance.

Resumo

As mudanças climáticas têm atingido todos os países gerando grandes perdas para a economia, meio ambiente e vidas humanas. A economia circular é o caminho efetivo para as mudanças climáticas, contribuindo para redução potencial de emissão de gás carbônico. O objetivo do estudo é analisar a relação potencial de diminuição das emissões de dióxido de carbono e a reciclagem de resíduos sólidos urbanos pelas organizações de catadoras e catadores. Foi desenvolvida uma pesquisa quantitativa e documental a partir dos dados do Anuário da Reciclagem (2020-2024). Os resultados apontam uma relação positiva entre potencial diminuição de CO₂ à medida que aumenta o número de organizações, de 1.829 em 2020 para 3.028 em 2024, associada à ampliação da coleta e destinação correta de materiais recicláveis, especialmente plásticos, metais e papel/papelão, que juntos respondem pela maior parte da diminuição das emissões de carbono. Como contribuições destaca-se que as organizações de catadoras e catadores são o eixo para inclusão social das pessoas em vulnerabilidades sociais, empoderamento das mulheres, além de contribuir para redução do consumo de água e energia e menores impactos ao meio ambiente.

Palavras-chave: Economia circular. Resíduos Sólidos. Gás dióxido de carbono. COP 30. Governança Climática.

1 Introduction

Sustainability is not a fad, but a complex action that depends on the involvement of all stakeholders (the public, civil society, governments, and business leaders) and is grounded in intergenerational ethics. This means that environmental and economic actions taken by people today should not reduce the chances of future generations enjoying equivalent levels of wealth, utility, or well-being (Meadowcroft, 2022).

Nature, as well as people and the structures that sustain nations, have been impacted by the COVID-19 pandemic (Soares; Pinto, 2020), in some cases irreversibly. The environment continues to undergo changes resulting from human intervention, whether direct or indirect, which creates additional challenges for achieving the 17 Sustainable Development Goals (SDGs). The 2030 Agenda is an initiative of the United Nations (UNESCO, 2019) that proposes a global pact for sustainable development. It aims to ensure human progress and meet the basic needs of individuals through economic, political, and social processes that respect the environment and the principles of sustainability.

Climate change is one of the most relevant global challenges, gradually highlighting inequalities between North and South and resulting in increasingly intense

impacts. The Paris Agreement, signed on December 12, 2015, represents a milestone in the multilateral process by establishing a treaty that encompasses all nations, intending to combat climate change and promote adaptation to its effects (United Nations Climate Change, 2015). International cooperation provides a global reach by imposing uniform core obligations through a minimum agreement, in addition to stimulating debates on inequalities related to vulnerability and the capacity for equitable coping (Oliveira, 2019). The Paris Agreement seeks to reach consensus on the stabilization of carbon dioxide in the atmosphere, aiming to keep the global average temperature at 1.5°C and reduce CO₂ emissions by 43% by 2030, contributing to the social and economic transformation of countries (United Nations Climate Change, 2015).

The 30th United Nations Climate Change Conference 2025, called COP30, will take place from November 10 to 21, 2025, in the city of Belém, Brazil, to mobilize the action agenda consisting of voluntary climate actions by civil society, companies, investors, cities, states and nations to more prominently support the reduction of emissions, adaptation to climate change and the transition towards sustainable economies in accordance with the Paris Agreement (COP30 Brazil).

Massuga *et al.* (2022) warn of the increased generation of plastic waste in coastal regions during the pandemic, especially from personal protective equipment. This scenario poses a prolonged environmental and social challenge due to the disruption of sustainable practices and the increased use of disposable plastics, requiring structural and behavioral responses to promote sustainability.

Consequently, solid waste generation has increased in recent years due to changes in people's lifestyles. However, without recycling these materials, carbon emissions into nature and greater impacts on the climate and health would increase (Bordim *et al.*, 2022). However, this increase in waste consumption generates income for people in social inequalities (Tizziani *et al.*, 2025) through the collection and selection of materials, in addition to expanding the cooperatives responsible for sorting (Carvalho *et al.*, 2025).

As a way of reducing the harm caused by environmental impacts and preserving lives, and the need to solve immediate social problems, it justifies the transformation of the economy with the concept of social innovation (Avelino *et al.*, 2019), emerging circular, creative, collaborative, shared, and multi-currency economies (Schinaider *et al.*, 2025).

In this study, we adopted circular economy as a production model that aims to recover the value of tangible commodities through a closed cycle, using resource reuse and restoration techniques to determine the performance of production systems (Ashby, 2018), such as the recycling process (Ribeiro *et al.*, 2014).

The circular economy has three dimensions: a) preserving and increasing natural capital, aiming to control finite stocks and balance the use of renewable resources; b) optimizing resource use in production, focusing on circulating products and materials with maximum use (technical cycle and biological cycle); and c) stimulating system efficiency by identifying and eliminating negative externalities in processes (Berardi; Dias, 2018). For full effectiveness, intersectoral collaboration is required, with the involvement of various private and public stakeholders to minimize energy consumption and reduce CO2 emissions.

Solid waste recycling is one of the pillars of smart and sustainable cities, as it guarantees income for the marginalized and social protection for cooperative members (Carvalho *et al.*, 2025), reduces environmental pollution and climate-related tragedies (Bordim *et al.*, 2022), and generates economic development and profits for companies through the carbon market (Zong *et al.*, 2019). Environmental disasters constitute an obstacle to economic growth and highlight the difficulties in reconciling economics with environmental conservation and health quality for people in certain areas (Pott; Estrela, 2017).

Considering the global impact scenario and its implications for the environment, the economy, human lives, and public health, the question arises: Can the circular economy contribute to the potential reduction of CO2 emissions? The objective of this study was to analyze the potential relationship between carbon dioxide (CO2) emissions reduction and the recycling of urban solid waste by waste picker organizations. A descriptive, quantitative, and documentary study was developed using data from the Recycling Yearbook (2020-2024).

To this end, quantitative and documentary research was conducted (Sá-Silva *et al.*, 2009), using secondary data from the yearbook. The theoretical framework adopted was based on studies on social innovation (Avelino *et al.*, 2019). The article's relevance is highlighted by its adherence to Sustainable Development Goal number eleven (SDG 11 - sustainable cities and SDG 13 - climate action) and, in the academic context, by its

contribution to the field of administration, evidenced by the fact that there are only twenty articles mentioning carbon in the article titles in the Scientific Periodicals Electronic Library (Spell) database, as of September 20, 2025. This study presents the direct relationship between urban solid waste circularity, waste picker organizations, and potential CO₂ emission reduction.

This article is divided into five sections, the first being the introduction, the second a literature review addressing the environment and the circular economy, the third the methodology, the fourth presenting the results, analysis, and discussion, the fifth the conclusions, and finally the references.

2 Literature review

2.1 Environment and the circular economy

According to Sena *et al.* (2016), environmental and climate change have a direct impact on public health, often going unnoticed and hindering action on the various determinants of health. These changes significantly influence the population's living conditions, especially regarding access to water, both in quality and quantity. For municipalities, adequate management of the effects of drought and its relationship with achieving the SDG targets requires the formation of strategic partnerships and investments in territorial infrastructure, aiming to mitigate processes related to health and disease (Sena *et al.*, 2016).

Azevedo and Resende (2025) add that sanitation is a human right that is the responsibility of governments, and that many governments do not consolidate public policies that guide universalization and equity of access to sewage, generating more inequalities in addition to impacting the environment.

Therefore, building a sustainable world requires a broader vision, recognizing ecosystems in balance and prioritizing collective well-being through collaboration between people, organizations, and governments. Partnerships and behavioral transformations are essential to underpin a new development paradigm (Berardi; Dias, 2018; Sena *et al.*, 2016), where changes in business dynamics, especially in the steel, chemical, and port industries, are crucial.

One of the challenges of climate change is energy consumption and CO₂ emissions, particularly for the steel industry. In China's case, the potential for carbon

dioxide reduction in 2020 will be 541.75 million tons and 856.68 million tons in the long term (Wang; Lin, 2016). Another area that contributes to high CO₂ emissions is port activities, but some ports are already aware of their carbon footprint and how they replicate it, in addition to the need to consider emissions from waste treatment operations and employee commuting (Azarkamand *et al.*, 2020).

The steel industry needs to adopt resource-saving practices, such as reverse logistics and material reuse. This not only extends product lifespans and reduces costs, but also expands companies' reach and boosts profitability. Decarbonizing the sector, recognized as one of the largest emitters of CO₂, proves strategic for ensuring business sustainability while also contributing to mitigating environmental impacts and advancing toward a low-carbon economy (Circular Economy of the Brazilian Steel Sector, 2025).

Akiama and Spers (2024) point out that the circular economy in the steel industry in Brazil is linked to global circularity trends in the steel chain but still needs to improve in some areas to meet Agenda 2030, such as increasing the reduction of CO₂ emissions, having good waste management, and financial and regulatory incentives aiming at a more efficient circular economy.

In this context, the circular economy emerges as an innovative model that permeates the entire production chain, proposing new ways of thinking and acting. According to the Organization for Economic Cooperation and Development (OECD), the five main circular business models are: product as a service, circular inputs, resource recovery, life extension, and sharing (Ekins *et al.*, 2019). These models point out the way to overcoming the multiple forms of violence against people, animals, and the climate itself, promoting a virtuous cycle of environmental protection and social justice (Ekins *et al.*, 2019).

Figueiredo (2024) argues that adapting the chemical industry to sustainability challenges involves replacing oil, coal, and natural gas with renewable raw materials, fostering the concept of biorefineries with the production of synthetic fuels from biomass, and providing platform molecules that replace traditional base chemicals such as fossil fuels. Plastic recycling is not only about reducing environmental contamination and CO₂ emissions from plastic incineration, because non-recyclable plastics constitute a waste of valuable material. Recycling can be mechanical, the best known, but other methods include chemical recycling, such as thermochemistry and depolymerization.

Circularity in the chemical industry, focused on carbon dioxide gas, refers to the application of carbon as a raw material and transformed into methanol and liquid hydrocarbons, generating hydrogen from water through electrolysis and renewable electricity, resulting in green hydrogen (Figueiredo, 2024).

Luiz and Suski (2019) state that there is a direct influence between urban solid waste management and global warming due to the reduction of carbon dioxide gas through waste decomposition and the reuse of materials, thus preventing some significant parts of the production processes from (in)directly emitting gases that favor the increase in the greenhouse effect. Maia (2020) demonstrates that the recovery and recycling of solid waste from an association of waste pickers in Montes Claros achieved savings of enough water and energy to supply a population of 4,434 inhabitants for 20 days. Carvalho *et al.* (2025) warn about the increase in household solid waste generation in Minas Gerais, especially paper and cardboard, which reinforces the need for systemic interventions for waste management.

Vital (2018) emphasizes that the Paris Agreement imposed a condition for reducing greenhouse gas emissions, thus creating a global market for carbon trading. At the same time, the Chinese experience described by Zong *et al.* (2019) shows that efficient carbon emissions management can be a powerful tool for competitiveness and sustainability by creating tradable credits, encouraging clean development, and expanding the use of renewable energy in the global context.

Therefore, building smart and sustainable cities based on the premises of the circular economy depends on the coordination of public policies, governments at the micro, meso, and macro levels, business engagement, and the active participation of civil society. The circular economy, as a social innovation, is an effective response to climate change. Only through this joint effort will it be possible to advance toward SDG11 and its intersections with all the other SDGs, promoting prosperity, inclusion, and environmental balance for present and future generations.

We highlights that the Brazil has high potential in the role of transition to a low-carbon circular economy through global mobilization, with commitment, action and political initiatives such as the National Circular Economy Policy according to Bill No. 1,874 of 2022 (Brasil, 2022) and the National Circular Economy Plan that was approved on May 8, 2025 to establish goals and actions for the implementation of circularity in the

economy over the next 10 years (Mont'Alverne; Holanda, 2025) with five axes: normative environment, innovation and education, waste reduction, financial instruments and interfederative articulation (Brasil, 2025).

3 Methodology

Quantitative and documentary research adopted (Sá-Silva *et al.*, 2009; Sousa *et al.*, 2007). Quantitative research involves the analysis of numbers to answer the research questions or hypotheses (Sousa *et al.*, 2007). Documentary research allows the analysis of primary and secondary data according to the following narrative and is based on extracting data and making interrelations with other data and literature:

The use of documents in research must be appreciated and valued. The wealth of information that we can extract and retrieve from them justifies their use in various areas of the human and social sciences because it makes it possible to broaden the understanding of objects whose understanding requires historical and sociocultural contextualization (Sá-Silva *et al.*, 2009, p.2 tradução nossa).

This method was chosen to analyze secondary data from a socioeconomic and environmental perspective, providing a broad and organized approach to the recycling process across Brazil. The data source used was the Recycling Yearbooks (2020 to 2024), which contain updated information on the recycling sector in Brazil.

Data extracted from the Recycling Yearbooks for the years 2020 to 2024 refers to the years 2019 to 2023. Quantitative data is presented in tables and graphs and tabulated using Excel software. The variables analyzed were: number of organizations, number of waste pickers in the organizations, quantity collected and destined for recycling by the organizations (in tons) and potential for carbon (CO₂) reduction in thousands of tons by type of material, energy savings by type of material (in millions of MWh), and virgin raw material savings by type of material, according to the availability of annual numerical data.

4 Results: analysis and discussion

Figure 1 shows the number of waste picker organizations in Brazil in absolute numbers from 2020 to 2024. There is exponential growth in the number of organizations above 65%, rising from 1,829 in 2020 to 3,028 in 2024. The average participation rate

during this period was 2,329. This increase not only reveals greater waste collection capacity in urban areas, covering households, businesses, and public agencies, but also results in reduced environmental contamination and reduced disasters. Furthermore, it reflects greater opportunities for waste pickers to be included in organizations, accompanied by greater social protection (Carvalho *et al.*, 2025; Bordim *et al.*, 2022), a gradual reduction in social inequality (Tizziani *et al.*, 2025), and for companies contributing to better financial performance by contaminating the environment less (Vital, 2018; Zong *et al.*, 2019).

Figure 1 - Number of waste picker organizations in Brazil (2020 to 2024)



Source: Recycling Yearbook (2020 to 2024).

Table 1 shows the number of waste pickers in the organizations that agreed to participate in the annual survey. The variation in the number of recycling workers over these five years is evident. Women predominate in recycling organizations. In 2020, they had a total of 10,413 waste pickers. The COVID-19 pandemic saw a reduction in the number of waste pickers. In 2023, participation was high (86,878 waste pickers) and decreased in 2024 (70,608).

This does not mean that the number of waste pickers has decreased, but fewer organizations agreed to participate in the survey. The year 2023 refers to 2022 data, and there was a reduction in paper and cardboard disposal in the metal industries due to COVID-19, bringing other implications for the environment (Massuga *et al.*, 2022; Soares; Pinto, 2020). The predominance of female waste pickers is due to sexism and racism in Brazilian society, creating social inequalities and hindering their entry into the formal labor market. Another factor is that this activity corresponds to a social role, as it leads to social inclusion and empowerment for these women. Most are heads of households, and this role is a way to ensure family food security (Deiga Ferreira *et al.*,

2023). They are the group most affected by the effects of climate change and its impact on health (Sena *et al.*, 2016).

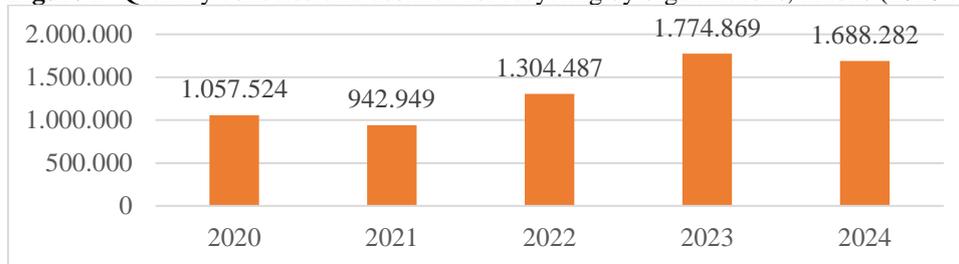
Table 1 - Number of waste pickers by gender from 2020 to 2024

Nº (%) of collectors by gender/Year	2020	2021	2022	2023	2024
Women	5.719 (55%)	5.287 (54%)	5.483 (54%)	46.519 (53,5%)	38.280 (54,2%)
Men	4.694 (45%)	4.467 (46%)	4.371 (44%)	40.359 (46,5%)	32.328 (45,8%)
Total	10.413	9.754	9.854	86.878	70.608

Source: Recycling Yearbook (2020 to 2024).

Figure 2 shows the quantity collected and destined for recycling by organizations, in tons (2020 to 2024), and the year 2023 stands out with the largest quantity of tons of materials for recycling and a potential estimate of a greater reduction in CO2 emissions when compared to the year 2021. This also reflects greater adherence to the National Solid Waste Policy post-pandemic and the importance of mitigating damage to nature (Carvalho *et al.*, 2025; Ribeiro *et al.*, 2014; Luiz; Suski, 2019) with the potential circular economy (Ekins *et al.*, 2019; Figueiredo, 2024; Maia, 2020).

Figure 2- Quantity collected and destined for recycling by organizations, in tons (2020 to 2024)



Source: Recycling Yearbook (2020 to 2024).

Table 2 shows the potential for Carbon (CO2) reduction in thousands of tons by material type over the last 5 years.

Table 2 - Carbon (CO2) reduction potential in thousands of tons by type of material

Materials	CO2 reduction potential (thousands of tons)					Total per year	% by material type
	2020	2021	2022	2023	2024		
By yearbook type/year							

Paper/cardboard	22,8	20,5	23,4	108,6	71,70	247,0	8,6
Plastic	87,8	77,2	112,8	472,3	660,00	1.410,1	48,9
Glasses	1,2	0,5	0,9	2,3	351,8	356,7	12,4
Metals (aluminum and other metals)	63,0	55,0	145,3	293,1	313,00	868,9	30,1
Total	174,3	153,2	282,4	876,3	1.396,5	2.882,7	100

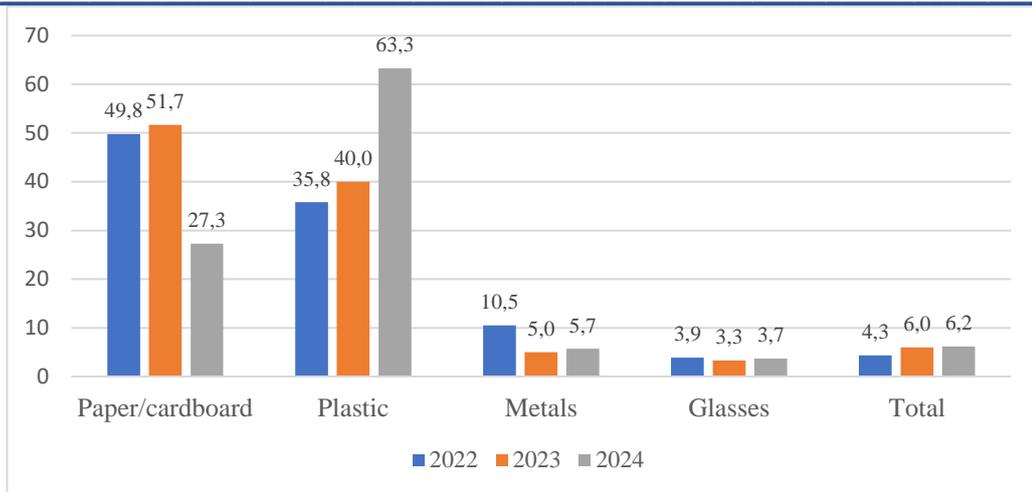
Source: Recycling Yearbook (2020 to 2024).

The material that contributed most to the potential for emissions reduction was plastic (48.9% fewer emissions into the atmosphere) due to the amount collected. As Figueredo (2024) states, plastic recycling prevents the waste of valuable material, reduces environmental contamination, and lowers CO2 emissions caused by incineration. The second material that contributed the least CO2 to nature was metal waste (30.1%), due to the high energy level expended in the production of virgin raw materials. In total, almost three million tons of materials were prevented from contaminating the environment and offset the generation of gases naturally emitted during the decomposition of solid waste, in this case, paper/cardboard and metals. Consequently, there was a lower production of virgin materials (plastics, metals, and glass) (Carvalho *et al.*, 2025; Ribeiro *et al.*, 2014).

There is a direct relationship between organizations, waste pickers, and recycled production that enables CO2 emissions to be reduced. Therefore, this marginalized political group needs to be valued, because without their involvement in the circular economy, climate change would be more severe and solar warming would increase.

Figure 3 shows the energy savings by material type, in millions of MWh, between 2022 and 2024. There was a percentage increase in plastics in the total materials collected and sold by waste picker organizations, triggering an increase in energy savings in 2024 compared to 2023. There was a decrease in the total amount of materials collected and sold, except for paper/cardboard. The recovery and recycling of solid waste leads to savings not only in energy but also in water, as Maia (2020) points out, the reduction in energy and water consumption was enough to supply 4,434 people for 20 days.

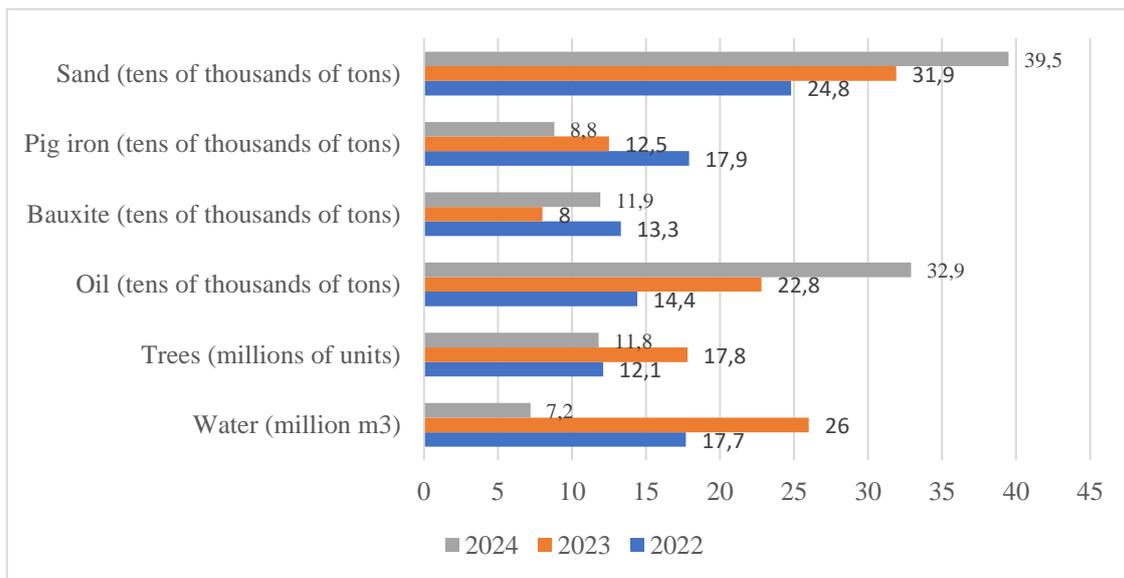
Figure 3 - Energy savings by material type, in millions of MWh, between 2022 and 2024



Source: Recycling Yearbook (2024).

Figure 4 shows the savings in virgin raw materials by type of material during the period from 2022 to 2024.

Figure 4- Savings in virgin raw materials by type of material, between 2022 and 2024



Source: Recycling Yearbook (2024).

The actions of waste picker organizations influenced the amount of raw material savings. There was an increase in the savings of oil (32.9) and sand (39.5) in 2024, and in 2023, the savings of sand (31.9), oil (22.8), trees (17.8), and water (26.0) increased. The growth in the oil economy was due to the increase in plastic in the total materials and

the reduction in its role in saving water and trees. These data, despite the low participation of waste picker organizations, demonstrate that Brazil is committed to reducing CO₂ and the environmental impacts resulting from climate change, and the chemical and steel industries and the population have contributed to this savings in raw materials (Akiama; Spers, 2024; Circular Economy of the Brazilian Steel Sector, 2025; Ekins *et al.*, 2019; Figueiredo, 2024).

5 Conclusions

Analysis of data from the Recycling Yearbook (2020-2024) highlights a direct relationship between the growth in the number of waste picker organizations and the increased potential for reducing CO₂ emissions from urban solid waste recycling. The expansion of these organizations, which jumped from 1,829 in 2020 to 3,028 in 2024, is associated with the increased collection and proper disposal of recyclable materials, especially plastics, metals, and paper/cardboard, which together account for more than half of the reduction in carbon emissions.

Plastics stand out, representing 48.9% of the potential for emission reduction, followed by metals (30.1%) and paper/cardboard, reinforcing the strategic role of these materials in mitigating environmental impacts. Strengthening associations and the circular economy, in addition to promoting environmental gains, contributes to reducing social inequalities, especially by guaranteeing income and prominence to women waste pickers, who make up more than half of these organizations. On the other hand, simply trading carbon credits can discourage the effective adoption of circular practices by creating a false sense of environmental commitment without addressing the underlying causes of the problem. It is essential to prioritize policies that value the closed material cycle and the leading role of cooperatives in a sustainable urban context. On the other hand, the carbon market favors economic growth.

Among their contributions, it is worth highlighting that waste picker organizations are a key driver for the social inclusion of socially vulnerable people, the empowerment of women, and the reduction of water and energy consumption, which reduces environmental impacts.

Climate change affects women and men differently, with women being more impacted due to being more vulnerable due to low access to resources, education, land, technology, and participation in political and economic decisions resulting from historical

patriarchy. Therefore, it is necessary to promote gender equality, making it possible to obtain greater effectiveness of climate change mitigation and adaptation strategies, as women and men play diversified roles and responsibilities in relation to the environment and their needs. To face the complexity of climate challenges, plural and transversal solutions are urgent (Matos *et al.*, 2023).

The patriarchal consequences in Brazil still guarantee the subordination of women in the domestic space and exclusion in the formal labor market that mainly requires education, mastery of technologies, making it impossible for women, especially black women, who suffer the intersectionality of sexism, racism, classism, generating social and racial inequalities and imputing to black women survival at the base of the social pyramid, because poverty is a black female stronghold (Ferreira; Carvalho, 2025).

It is necessary to reduce gender and race inequalities in the circular economy by a criterion of social and climate justice, and for this, public policies for the empowerment of women, especially black women, who are the majority because of the crossing of oppressors of race, gender, and social class, are fundamental. Matos *et al.* (2023) point out the need to promote a symbolic relationship between climate justice and social justice, as one contributes to the other, because climate effects are increasingly intense and affect the most vulnerable populations and those on the margins of society. This group has no active voice in decision-making and faces low opportunities and basic resources that can guarantee protection and the ability to react in the face of severe weather events.

The limitations lie in the fact that this is secondary data and corresponds to the organizations that agreed to participate in the survey. To provide a more realistic picture of recycling, all registered organizations should be encouraged to participate, enabling the identification of barriers and challenges to the circular economy.

Suggestions for future research include investigating why organizations do not participate in the surveys, whether they have difficulty understanding the terms for investing in training and development for all interested parties, and having public financial action that can encourage participation and show how much Brazil has the potential to reduce CO2 emissions to the world and thus increase credits to boost other SDGs such as SDG 1 (no poverty), SDG 2 (fighting hunger), SDG 3 (health and well-being), SDG 4 (quality education), SDG 9 (industry, innovation, infrastructure), SDG 10 (reduction of inequalities), SDG 11 (sustainable cities and communities), SDG 13

(climate action) and SDG 17 (partnerships for the means of implementation) (UNESCO, 2019).

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