GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 13, n. 88, 2025

Sustainable management of municipal solid waste: Environmental education, circular economy and public policies in Brazil

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Submissão: 22/05/2025
Aceite: 16/07/2025
CRUZ, Uilmer Rodrigues Xavier da; GARCIA, Ricardo Alexandrino; DÍAZ, Martín Andrés. Gestão sustentável de resíduos sólidos urbanos: Educação ambiental, economia circular e políticas públicas no Brasil. **Revista Nacional de Gerenciamento de Cidades** , *[S. l.]*, v. 13, n. 88, 2025. DOI: 10.17271/2318847213882025574 8. Disponível em: https://publicacoes.amigosdanatureza.org.br/index.php/gerenciamento_de_cidades/article/view/5748.

GC Revista Nacional de Gerenciamento de Cidades
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Gestão sustentável de resíduos sólidos urbanos: Educação ambiental, economia circular e políticas públicas no Brasil

RESUMO

Objetivo - A gestão de resíduos sólidos urbanos (RSU) tem se tornado um dos maiores desafios ambientais no Brasil, devido ao crescimento populacional, à urbanização acelerada e ao modelo de consumo linear. A Política Nacional de Resíduos Sólidos (PNRS), instituída pela Lei nº 12.305/2010, visa transformar a maneira como o país lida com o lixo, promovendo a redução, reutilização e reciclagem. No entanto, sua implementação enfrenta obstáculos, como a falta de participação efetiva da sociedade e a deficiência em práticas educativas e sustentáveis nas comunidades. Este estudo busca investigar as abordagens e práticas utilizadas na gestão dos RSU, com foco em educação ambiental, economia circular e a integração dessas práticas nas políticas públicas brasileiras. O objetivo geral é analisar a implementação da PNRS e identificar metodologias pedagógicas e modelos econômicos sustentáveis que possam contribuir para a gestão eficiente de resíduos. Como objetivos específicos, pretende-se (i) explorar as metodologias pedagógicas eficazes para promover a educação ambiental, (ii) analisar a aplicação da economia circular e (iii) avaliar os avanços e desafios na implementação da PNRS.

Metodologia - A metodologia adotada foi uma revisão bibliográfica de artigos e estudos empíricos sobre o tema.

Originalidade/relevância - A justificativa para a pesquisa está no crescente impacto ambiental dos resíduos sólidos e na necessidade de alternativas sustentáveis, que envolvam tanto políticas públicas quanto práticas educativas.

Resultados - O estudo contribui para uma melhor compreensão dos desafios e soluções possíveis, visando uma gestão de resíduos mais inclusiva e sustentável.

PALAVRAS-CHAVE: Resíduos Sólidos Urbanos. Educação Ambiental. Economia Circular. Políticas Públicas.

Sustainable management of urban solid waste: Environmental education, circular economy and public policies in Brazil

ABSTRACT

Objective – The management of urban solid waste (USW) has become one of the biggest environmental challenges in Brazil due to population growth, rapid urbanization, and the linear consumption model. The National Solid Waste Policy (PNRS), established by Law No. 12.305/2010, aims to transform the way the country handles waste by promoting reduction, reuse, and recycling. However, its implementation faces obstacles such as the lack of effective societal participation and the deficiency of sustainable and educational practices in communities. This study aims to investigate the approaches and practices used in USW management, focusing on environmental education, circular economy, and the integration of these practices into Brazilian public policies. The general objective is to analyze the implementation of the PNRS and identify pedagogical methodologies and sustainable economic models that could contribute to the efficient management of waste. Specific objectives include (i) exploring effective pedagogical methodologies to promote environmental education, (ii) analyzing the application of the circular economy, and (iii) evaluating the advances and challenges in the implementation of the PNRS.

Methodology – The methodology adopted will be a bibliographic review of articles and empirical studies on the topic.

Originality/Relevance – The justification for this research lies in the growing environmental impact of solid waste and the need for sustainable alternatives that involve both public policies and educational practices.

Results – The study contributes to a better understanding of the challenges and possible solutions, aiming for a more inclusive and sustainable waste management system.

KEYWORDS: Urban Solid Waste. Environmental Education. Circular Economy. Public Policies.

Gestión sostenible de resíduos sólidos urbanos: Educación ambiental, economía circular y políticas públicas en Brasil

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RESUMEN

Objetivo – La gestión de residuos sólidos urbanos (RSU) se ha convertido en uno de los mayores desafíos ambientales en Brasil debido al crecimiento poblacional, la urbanización acelerada y el modelo de consumo lineal. La Política Nacional de Residuos Sólidos (PNRS), establecida por la Ley Nº 12.305/2010, tiene como objetivo transformar la forma en que el país maneja los residuos, promoviendo la reducción, reutilización y reciclaje. Sin embargo, su implementación enfrenta obstáculos, como la falta de participación efectiva de la sociedad y la deficiencia de prácticas educativas y sostenibles en las comunidades. Este estudio tiene como objetivo investigar los enfoques y prácticas utilizadas en la gestión de RSU, con énfasis en la educación ambiental, la economía circular y la integración de estas prácticas en las políticas públicas brasileñas. El objetivo general es analizar la implementación de la PNRS e identificar metodologías pedagógicas y modelos económicos sostenibles que puedan contribuir a la gestión eficiente de los residuos. Los objetivos específicos son (i) explorar metodologías pedagógicas efectivas para promover la educación ambiental, (ii) analizar la aplicación de la economía circular y (iii) evaluar los avances y desafíos en la implementación de la PNRS.

Metodología – La metodología adoptada será una revisión bibliográfica de artículos y estudios empíricos sobre el tema.

Originalidad/Relevancia – La justificación de esta investigación radica en el creciente impacto ambiental de los residuos sólidos y la necesidad de alternativas sostenibles que involucren tanto políticas públicas como prácticas educativas.

Resultados – El estudio contribuye a una mejor comprensión de los desafíos y las posibles soluciones, con el objetivo de lograr una gestión de residuos más inclusiva y sostenible.

PALABRAS CLAVE: Residuos Sólidos Urbanos. Educación Ambiental. Economía Circular. Políticas Públicas.

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1 INTRODUCTION

In recent years, urban solid waste (MSW) management has become one of the biggest challenges for municipalities globally, especially in developing nations. Accelerated urban growth, population growth and the persistence of a linear consumption model have generated growing volumes of waste, the negative impacts of which on the environment and public health are increasingly evident. In Brazil, the National Solid Waste Policy (PNRS), established by Law 12.305/2010, proposes a new management paradigm, emphasizing reduction, reuse, recycling and shared responsibility. However, the implementation of this policy still faces significant obstacles, particularly with regard to social participation and the integration of sustainable practices in communities.

As such, this study seeks to gain a deeper understanding of the factors that influence the implementation of the SWNP, with a critical focus on the pedagogical practices of environmental education, waste management strategies and the application of sustainable economic models, such as the circular economy. Based on this problem, there is a need to analyze approaches, methodologies and policies that can contribute to building a more efficient, equitable and sustainable waste management system in Brazil. The central argument of this work lies in the premise that the theoretical density and critical articulation between the conceptual axes are fundamental for an in-depth and propositional analysis.

The general aim of this work is to investigate the main approaches and practices used in urban solid waste management, with a focus on critical environmental education, the circular economy and the integration of these practices in the context of Brazilian public policies. The specific objectives are: (i) to identify the most effective pedagogical methodologies for promoting transformative environmental education in schools and communities; (ii) to analyze the implementation of the circular economy in Brazil, with special attention to the limits imposed by territorial inequality and the role of waste picker cooperatives; (iii) to evaluate the challenges and advances in the implementation of the National Solid Waste Policy, problematizing the tensions between waste management models and the effectiveness of public policies in Brazil, with a focus on social participation and shared responsibility.

The methodology adopted in this study is based on a critical and systematic literature review, aimed at deepening understanding of urban solid waste (MSW) management, environmental education and the circular economy in the Brazilian context. The literature was selected by searching recognized academic databases such as SciELO (Scientific Electronic Library Online), Google Scholar and the CAPES Journal Portal, using combinations of key terms such as "urban solid waste management", "critical environmental education", "circular economy Brazil", "public waste policies" and "dumps". To ensure the relevance and timeliness of the information, priority was given to works published in the last 15 years (2010-2025), although classic and fundamental works for understanding the key concepts were also considered, regardless of the year of publication. The inclusion criteria included peer-reviewed scientific articles, books, theses, dissertations and official documents from government bodies and research institutions that explicitly addressed the articulation between the conceptual axes proposed, with a focus on theoretical and empirical studies that illustrated the complexities and potential of waste management in the national scenario. Approximately 10 to 15 studies were

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selected which were considered to be the most representative and the most theoretically dense for the construction of the argument, seeking to identify best practices and propose ways of overcoming the challenges of solid waste management in Brazil.

The justification for this study lies in the growing need for practical and innovative solutions for solid waste management in the country, given the magnitude of the problem and its socio-environmental and economic impacts. By analyzing the intersection between critical environmental education, public policies and circular economy practices, this work aims to contribute to the construction of a more efficient, inclusive and fair waste management model, capable of involving society as a whole and promoting a change of mentality in relation to the disposal, reuse and recovery of materials, considering the specificities and challenges of Brazilian territorial inequality.

2 SUSTAINABLE URBAN SOLID WASTE MANAGEMENT: A THEORETICAL AND CRITICAL APPROACH

The theoretical framework of this study is structured around three main axes, which complement each other in the analysis of municipal solid waste (MSW) management, the circular economy and public policies, seeking a critical and in-depth articulation. The first axis deals with general theories on waste and management, which are fundamental to understanding the socio-environmental context of solid waste, with a problematization of the challenges imposed by the Brazilian reality. The second strand focuses on environmental education, exploring its pedagogical approaches and the need for a critical perspective that promotes awareness and the transformation of attitudes towards the environment. The third axis analyzes practical models and public policies aimed at the circular economy and waste management, with an in-depth discussion of the tensions between management models and the effectiveness of public policies in Brazil, as well as the limits of the circular economy in the face of territorial inequality.

2.1 General theories on waste and management: from linearity to socio-environmental complexity

Understanding urban solid waste management requires an analysis that transcends the mere technical dimension, incorporating the complex social, economic and environmental interactions that shape it. Authors such as Ambrosi (2019), Bicalho and Pereira (2018), and Souza and França (2014) offer crucial perspectives for this understanding, discussing the social and environmental implications of waste and presenting different approaches to its management, highlighting the urgency of mitigating the impacts of the linear model of production and consumption.

Claudia Ambrosi's (2019) review of "The Power of Garbage: Anthropological Approaches to Solid Waste", organized by Carmen Rial, is an essential starting point for this discussion. The book, which brings together texts by Brazilian and Dutch authors, offers a critical and interdisciplinary analysis of the theme of solid waste, focusing on the contrasting realities of Brazil and the Netherlands, addressing everything from the symbolism of waste to public policies

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and social practices related to the disposal and reuse of materials. The discussion on the role of waste pickers, recycling and the impacts of new waste - such as electronic and nuclear - is particularly relevant. The comparison between the Brazilian reality, where much of the waste is disposed of inappropriately, and the Dutch reality, with very low landfill rates, highlights the disparity in management and the need for more effective public policies in the Brazilian context (Ambrosi, 2019).

In this sense, the challenges of waste management have increased, highlighting the need for a holistic and interdisciplinary perspective. The emergence of new wastes, such as *e- waste* and nuclear waste, demands not only social awareness, but also robust public policies for their proper management (Ambrosi, 2019). This is where the study by Bicalho and Pereira (2018) becomes complementary, by exploring the practical application of the National Solid Waste Policy (PNRS) in Lavras (MG). Social participation and shared responsibility among the various actors throughout the life cycle of waste, fundamental principles of the PNRS, are significant challenges, especially given the low effectiveness of public adherence and the failure to meet the targets set by law. These problems become even more critical in the case of electronic and nuclear waste, whose complexity demands integrated and technologically advanced solutions (Bicalho and Pereira, 2018).

Social participation in the management of urban solid waste (MSW) in the municipality of Lavras (MG) is a challenge for the implementation of the National Solid Waste Policy (PNRS), established by Law No. 12.305/2010. This policy establishes guidelines for the integrated management of solid waste, with an emphasis on social participation and shared responsibility between the different actors involved in the life cycle of waste. However, many Brazilian municipalities face difficulties in meeting these targets, especially with regard to the effective mobilization of the population and adequate environmental management (Bicalho and Pereira, 2018).

In Lavras, it was found that although measures such as the removal of waste pickers from the dump and the activation of a ditch with landfill characteristics have been implemented, social participation remains low and environmental management is not fully effective. This finding stems from a study that adopted a qualitative and quantitative approach, applying semi-structured questionnaires to the public administration and the Association of Waste Pickers of Lavras (Acamar), as well as structured questionnaires directed at the local population, with the aim of assessing the degree of social participation in MSW management and identifying gaps in compliance with the PNRS (Bicalho and Pereira, 2018).

The PNRS provides for shared responsibility between manufacturers, distributors, consumers and public authorities in the management of solid waste, with the aim of minimizing environmental impacts and promoting public health. In Lavras, however, the population is not sufficiently engaged in the process, which limits the effectiveness of the policies implemented. Only 5% of the solid waste produced in the municipality is sent for recycling, and selective collection does not yet cover the entire urban area. In addition, most citizens are unaware of social participation mechanisms, such as the Environment Council and non-governmental organizations working in the area (Bicalho and Pereira, 2018).

Social and environmental management is an essential tool for compliance with the PNRS, as it involves dialogic, participatory and emancipatory processes that guarantee

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transparency and co-responsibility. In Lavras, however, social management is still in its infancy, with low popular participation in decisions relating to MSW and little recognition of existing participation mechanisms and environmental education actions in the municipality (Bicalho and Pereira, 2018).

In turn, environmental management, which should integrate basic sanitation, environmental education and urban development policies, is still fragmented in Lavras. Despite investments, such as the contracting of Acamar for selective collection, the lack of awareness among the population and the absence of specific legislation on environmental education compromise the effectiveness of actions. Only 23% of respondents know the final destination of the materials collected by selective collection, and the majority are unaware of the voluntary drop-off points available (Bicalho and Pereira, 2018).

Social participation is a key element for successful MSW management, but it remains limited. Many residents consider that responsibility for public cleaning lies exclusively with the municipality, reflecting a lack of knowledge about the co-responsibility provided for in the PNRS. Only 3.5% of respondents actively participate in public policy-making processes, which highlights the need for more effective strategies to promote social engagement (Bicalho and Pereira, 2018).

Despite advances such as the social inclusion of waste pickers and the activation of a ditch with landfill characteristics, solid waste management in Lavras still faces significant challenges. Low social participation and low awareness of selective collection and recycling are key obstacles to the full implementation of the policy, and it is necessary to invest in environmental education campaigns and greater transparency of actions to foster co-responsibility (Bicalho and Pereira, 2018).

Strengthening social participation mechanisms, such as the Environment Council and non-governmental organizations, as well as integrating public policies aimed at MSW, are indispensable measures to advance management. University extension can contribute to this process through training courses in environmental education and awareness campaigns aimed at the local community. In addition, it is recommended that studies be carried out to assess the applicability of social and environmental management concepts in other Brazilian municipalities, considering their specificities and local challenges in implementing the PNRS (Bicalho and Pereira, 2018).

In summary, there is a need for an integrated and participatory approach to solid waste management, based on environmental education, transparency and co-responsibility. It should be noted that the implementation of the National Solid Waste Policy (PNRS) in Brazil requires social participation and the articulation of effective environmental management, essential elements for the success of public policies aimed at solid waste (Bicalho and Pereira, 2018). In this sense, the following reflection by Souza and França (2014) on the experience of waste as something unbearable in urban life expands the analysis by exploring how social practices and discourses on waste influence human conduct. The article proposes a more critical and philosophical approach, analyzing the different forms of waste management, from the perspective of social medicine to the transformations driven by ecological discourse, which redefines waste as waste, with direct implications for public policies and environmental practices.

The article "Garbage, human conduct and the management of the unbearable", by Ricardo Abussafy de Souza and Sonia Aparecida Moreira França, addresses the problem of

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garbage as an unbearable experience of urban life, analyzing how social practices and discourses on garbage influence human conduct and forms of "governmentality". The genealogical method, inspired by the studies of Michel Foucault, allows us to trace the evolution of management practices of waste and their impacts on modern society, highlighting two main forms of management: the first, linked to social medicine, which treats waste as putrid and useless matter; and the second, related to ecological discourse, which transforms waste into residue, the object of public policies and practices of recycling and environmental preservation (Souza and França, 2014).

It is based on the hypothesis that the ways in which waste is managed, from the everyday act of disposing of it to the concept of recyclable waste, produce effects of truth that shape contemporary human conduct. Garbage, as an unbearable element, challenges the population's government strategies, as it represents everything that is not in line with modern urban projects, such as odors, remains and substances that interfere with the flow of the city, and is analyzed as revealing social practices and power relations (Souza and França, 2014).

Urban life is a central concept for the analysis of waste, divided into two dimensions: the urbs, which represents the materiality of the city, and the civitas, which symbolizes its social, cultural and political life. Modernity reanimates the inert, transforming waste into an object of intervention and governmentality, a Foucauldian concept that describes how waste management practices organize human conduct not only through direct control, but also through the relationship between individuals and the objects around them (Souza and França, 2014).

Genealogy makes it possible to map the formation of discourses and practices related to waste, highlighting their agglutination into regimes of truth that legitimize certain forms of management. Historical documents, such as records of hygiene congresses and municipal legislation, show how medico-social and ecological practices influenced waste management and the production of habits in modern society. This analysis is divided between the period of social medicine, which treats waste as a public health problem, and that of environmental discourse, which transforms it into waste (Souza and França, 2014).

In the context of social medicine, waste was seen as a threat to public health, especially in the growing cities of the early 20th century. Hygienist discourses, based on knowledge imported from Europe, promoted urban reorganization to prevent epidemics and ensure health. Hygienist doctors acted as architects of health, shaping both the physical structure of cities and the habits of citizens, considering waste a problem that required state intervention through laws and regulations on waste disposal and management (Souza and França, 2014).

Waste management became a central element in the organization of modern cities, especially in Brazil, where rapid urban growth demanded new hygiene and sanitation practices. Hygiene congresses in the early 20th century disseminated sanitary practices and educated the population about the risks of waste, which came to be seen as an indicator of urban development and civilization, with clean streets and proper waste management symbolizing progress and modernity (Souza and França, 2014).

From the second half of the 20th century, the discourse on waste changed with the emergence of ecology and sustainability, and it came to be understood as a potentially valuable resource for recycling and reuse. International conferences, such as the United Nations

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Conference on the Human Environment (1972) and ECO-92, drove this change by introducing concepts such as recycling, reverse logistics and integrated solid waste management (Souza and França, 2014).

The environmental discourse transformed waste into residue, the object of public policies and governmental practices, seen as a reusable element that reduces environmental impacts and promotes sustainability. This perspective has led to new individual behaviors and habits, stimulated by advertising campaigns and environmental education programs aimed at separating and recycling waste (Souza and França, 2014).

Waste management is not just a technical or administrative issue, but a biopolitical device that acts on human behavior. Governmentality, in this sense, is not restricted to direct control, but operates through the production of habits and norms that regulate citizens' behavior in relation to waste, highlighting the power relations and social practices that shape urban life (Souza and França, 2014).

The production of habits related to waste, such as throwing it in the appropriate container or separating it for recycling, involves not only the imposition of norms, but also the internalization of values and practices by individuals. From the end of the 19th century, hygienist practices shaped behavior through laws, regulations and health education campaigns, transforming cleanliness and waste management into a matter of individual and collective responsibility (Souza and França, 2014).

In the contemporary context, environmental education has replaced health education as the main tool of governmentality. Campaigns based on values such as sustainability and the preservation of natural resources promote the internalization of new behaviours, transforming separation, recycling and reducing consumption into moral acts that express individual responsibility towards the environment and society, being understood as ethical and political practices (Souza and França, 2014).

However, individual responsibility for waste can hide collective and structural responsibilities related to waste production and consumption. The emphasis on individual recycling practices can distract from systemic problems, such as the excessive production of waste and the lack of effective public policies. It is necessary to understand waste management as a complex issue that links public policies, social practices and structural changes in production and consumption models (Souza and França, 2014).

The conclusion is that waste, as an unbearable experience of urban life, has become an object of intervention and governmentality, shaping social practices and power relations in modern society. Its transformation into waste, driven by environmental discourse, reflects significant changes in forms of management, but also reveals challenges and contradictions in this perspective, requiring a broad and integrated approach that considers individual practices, social and political structures that support the production and disposal of waste (Souza and França, 2014).

The studies converge in highlighting the complexity of urban solid waste management in Brazil, which transcends the technical dimension and involves social, environmental and political aspects. Ambrosi offers a critical anthropological perspective by comparing the Brazilian and Dutch realities, highlighting disparities in waste management and warning of the emergence of new types of waste that require robust public policies. In addition, the analysis of the practical

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application of the National Solid Waste Policy (PNRS) at municipal level reveals significant challenges related to social participation and compliance with the established targets, especially in the management of electronic and nuclear waste, whose complexity reinforces the need for integrated solutions (Ambrosi, 2019; Bicalho and Pereira, 2018).

In this context, biopolitical reflection on waste management helps to broaden understanding of the issue by exploring how practices and discourses on waste shape human conduct and forms of governmentality. While it highlights gaps between legislation and practice and the need for greater social engagement, it warns against the risk that individual responsibility, although relevant, can obscure structural and systemic responsibilities related to the production and consumption of waste. The articulation of these reflections indicates that the transition to an effective and equitable waste management model requires not only technical and legal improvements, but also a profound reassessment of the social and political dynamics that structure the human relationship with the disposal and recovery of materials (Souza and França, 2014; Ambrosi, 2019; Bicalho and Pereira, 2018).

In this way, an analysis of general theories on waste and management reveals the complexity of the problem and the need for integrated approaches that consider the social, economic, environmental and political dimensions. The transition from a linear to a circular model, the implementation of the PNRS and overcoming the challenges of social participation and territorial inequality depend on an in-depth understanding of these interconnections and the implementation of public policies that promote co-responsibility and critical environmental education, as will be discussed below.

2.2 Environmental education and pedagogical practices: towards a critical and transformative approach

Environmental Education (EE) is a fundamental pillar in building a more sustainable society, acting to raise awareness and engage the population in adopting more conscious practices in relation to solid waste. The evolution of pedagogical approaches in environmental education, as well as the challenges and opportunities in their implementation, are crucial to the effectiveness of public policies. Studies such as those by Gomes *et al.* (2023), Guilherme *et al.* (2017), Moraes and Cremer (2018), and Silva, Maria and Honda (2013) offer valuable information on the trajectory and prospects of environmental education in Brazil.

Firstly, the study by Gomes *et al.* (2023) presents a systematic review of articles published in the Revista Brasileira de Estudos Pedagógicos between 2010 and 2020, with the aim of analyzing the predominant pedagogical conceptions and approaches in EE. To do this, the authors used the systematic review methodology, based on the operationalization of Minayo (1999), and categorized the articles based on the intersection of the teaching approaches proposed by Mizukami (1986), the educational paradigms described by Behrens (2013) and the currents of EE identified by Sauvé (2005).

The results showed a predominance of innovative conceptions of EE, especially in publications published after 2015. This finding suggests a paradigmatic transition in the way EE is conceived and implemented in the Brazilian educational context. The traditional approach, characterized by an emphasis on transmitting knowledge and reproducing content, was

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identified in fewer articles. On the other hand, the innovative approach, which emphasizes the active construction of knowledge and the critical participation of students, was more recurrent in the publications analyzed. This movement may be related to the influence of the National Curriculum Guidelines for Environmental Education (DCNEA), established in 2012, which emphasize the need for more dynamic and interactive teaching practices (Gomes *et al.*, 2023).

Among the approaches analyzed, the sociocultural approach, which is based on dialogue and the active participation of students, showed a strong relationship with the critical current of environmental education. This current seeks to promote education aimed at social transformation and the emancipation of subjects, based on the principles of problematizing education (Freire, 2019). On the other hand, the traditional approach was more in line with the naturalist and conservationist currents, which emphasize teaching content about nature and the need to conserve natural resources, but without necessarily promoting a critical questioning of environmental issues (Gomes *et al.*, 2023).

In addition to traditional and innovative approaches, the presence of pedagogical practices that mix elements from different currents of environmental education was also identified. This phenomenon, known as educational syncretism (Sauvé, 2005), highlights the complexity of teacher training and the influence of multiple theoretical references in the construction of educational practices. In particular, some pedagogical initiatives have sought to balance the transmission of scientific content about the environment with active learning methodologies, such as the use of interdisciplinary projects and field activities (Gomes *et al.*, 2023).

The humanist approach has also been gaining ground in the practice of environmental education, aligning itself with currents such as eco-education and praxis. These currents value the integral development of the subject and the connection between the emotional, cognitive and ethical dimensions in the educational process (Gomes *et al.*, 2023). This approach is especially relevant in early childhood education, as it favors children's direct contact with nature and encourages the construction of socio-environmental values from the earliest school years (Rodrigues and Saheb, 2018 *apud* Gomes *et al.*, 2023).

Another aspect considered is the influence of public policies on the consolidation of pedagogical approaches in EE. The National Environmental Education Policy (PNEA), established in 1999, and the National Curriculum Guidelines for Environmental Education (DCNEA) have been fundamental to the expansion of environmental education in the Brazilian education system (Gomes *et al.*, 2023). However, the implementation of these policies still faces challenges, such as the lack of specific training for teachers and resistance to adopting innovative methodologies (Farias Filho and Farias, 2020 *apud* Gomes *et al.*, 2023).

The relationship between environmental education and the teaching of different disciplines is also evident, such as the use of mathematics to address environmental problems, through mathematical modeling and the analysis of environmental data (Costa and Pontarolo, 2019 *apud* Gomes *et al.*, 2023); and the intersection between environmental education and geosciences, highlighting the use of participatory methodologies to promote sustainability and geoconservation (Santos and Jacobi (2017) *apud* Gomes *et al.*, 2023). These experiences reinforce the idea that environmental education should be worked on across the school curriculum, stimulating interdisciplinarity and students' critical thinking (Gomes *et al.*, 2023).

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Finally, the analysis of the selected articles showed that the sociocultural approach has been widely used in environmental education, especially in proposals aimed at the active participation of students and the collective construction of knowledge (Freire, 2019). This approach emphasizes the need to establish a horizontal dialogue between educators and students, allowing students to be the protagonists of their own learning and develop a critical understanding of environmental issues (Gomes *et al.*, 2023). The use of participatory methodologies, such as socio-environmental mapping and group debates, encourages student engagement and increases their capacity for critical reflection on local environmental problems (Santos and Jacobi, 2017 *apud* Gomes *et al.*, 2023).

Pedagogical practice reflects teachers' theoretical conceptions, highlighting the importance of ongoing training to cover different approaches to environmental education. Teacher training must go beyond the transmission of content, incorporating strategies that stimulate critical thinking and the practical application of the knowledge acquired, and the lack of specific training is a challenge for the consolidation of innovative approaches (Groenwald, Justo and Gelle, 2013 *apud* Gomes *et al.*, 2023). In this sense, the lack of specific training for educators still represents a challenge for the consolidation of innovative approaches in environmental education (Gomes *et al.*, 2023).

EE should not be restricted to the school environment, but integrated into different social contexts, as exemplified by projects involving socio-environmental research and intervention with the participation of high school students and postgraduate students, showing its continuous, interdisciplinary nature and aimed at solving contemporary environmental problems (Albuquerque, Vicentini and Pipitone, 2015 *apud* Gomes *et al.*, 2023). This experience reinforces the idea that environmental education should be a continuous and interdisciplinary process, promoting the development of concrete solutions to contemporary environmental challenges (Gomes *et al.*, 2023).

Finally, there is a trend towards valuing innovative conceptions of environmental education, especially after the implementation of the DCNEA in 2012, and the coexistence of different approaches and currents is fundamental to guaranteeing the diversity and effectiveness of pedagogical practices. Adopting strategies that promote critical, reflective and transformative environmental education broadens the debate on the theoretical foundations of the area and enhances its impact on citizen education (Gomes et al., 2023).

This search for diversified and innovative strategies in environmental education is also reflected in the importance of interdisciplinarity, which is an essential approach to strengthening environmental education. Knowledge and application of interdisciplinarity in environmental education (EE) reveal significant challenges in teaching practice, as demonstrated in a study carried out with teachers from two public schools in Catingueira, Paraíba. Although 72.2% of teachers claim to know the concept of interdisciplinarity in the environmental context and 61% develop practical activities with environmental themes, difficulties such as lack of personal training (72.2%) and lack of partnerships (61.1%) limit the effective implementation of interdisciplinary teaching (Guilherme et al., 2017).

Disciplinary fragmentation remains an obstacle to the effective application of environmental education, restricting integration between different areas of knowledge. Interdisciplinarity enables dynamic and efficient connections in the educational process,

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broadening understanding of the relationship between society and the environment. However, teachers' resistance to changing pedagogical practices, coupled with the lack of adequate infrastructure and materials, hinders this consolidation. Many teachers still associate environmental education only with environmental preservation, disregarding its systemic dimension involving human relations with nature (Costa and Loureiro, 2015 *apud* Guilherme et al., 2017).

In addition to structural and conceptual difficulties, there is a significant correlation between teachers' length of experience and their perception of the applicability of interdisciplinarity in environmental education. Teachers with more experience tend to have a more traditional view of teaching, which can make it difficult to adopt interdisciplinary approaches. This finding reinforces the need for continuing education programs that encourage more integrated and critical pedagogical practices (Guilherme et al., 2017). According to Morin (2000), knowledge should be built collectively and systemically, allowing for a broader understanding of socio-environmental issues.

Another relevant aspect is the discrepancy between teachers' intentions and practice in relation to interdisciplinarity. Although 66.7% of the teachers said that interdisciplinarity can cover different contents, 33.3% reported difficulties in applying it effectively in their classes. This may be related to the traditional teaching model adopted in many institutions, which still prioritizes the segmentation of knowledge into isolated disciplines (Guilherme et al., 2017). According to Sousa and Bastos (2016), the lack of experience in interdisciplinary methodologies and the absence of institutional support can compromise the adoption of this approach in the school environment.

EE, on the other hand, when worked on in an interdisciplinary way, can generate greater student engagement and promote a more critical view of environmental issues. However, 38.9% of teachers reported a lack of student interest, which suggests the need for more dynamic and contextualized teaching strategies (Guilherme et al., 2017). According to Boff (2003), environmental education should stimulate a new type of relationship between human beings and the environment, promoting awareness and transformative action. In this way, implementing interdisciplinary projects can be an effective alternative for strengthening the link between students and environmental content (Guilherme et al., 2017).

The challenges faced by teachers in implementing Environmental Education in an interdisciplinary way also include the lack of adequate teaching resources and the absence of institutional incentives. According to 55.6% of the teachers interviewed, the lack of materials and infrastructure limits the adoption of more active and participatory methodologies. In addition, 50% reported that school coordination does not offer sufficient support for the inclusion of interdisciplinarity in the curriculum. These factors reinforce the importance of public policies aimed at training teachers and improving the structural conditions of schools, ensuring that environmental education is approached in a more integrated and effective way (Guilherme et al., 2017).

Another point to note is the need to encourage teachers to develop interdisciplinary projects that involve the school community. Experiences such as outdoor activities, visits to natural areas and debates on local environmental issues can contribute to more meaningful and engaging teaching (Guilherme et al., 2017). Velloso *et al.* (2016) point out that interdisciplinarity

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should be encouraged in all classes, making learning more dynamic and contextualized. However, the study's data shows that only 61.1% of teachers have already taken part in interdisciplinary projects, highlighting the need for greater encouragement for this type of initiative (Guilherme et al., 2017).

Finally, despite the recognition of the importance of interdisciplinarity in Environmental Education, there are still challenges to be overcome if it is to be fully implemented in teaching practice. Continuous teacher training, support from educational institutions and the adoption of innovative methodologies are essential if environmental education is to fulfill its role of forming critical citizens who are aware of socio-environmental issues. This reinforces the need for an educational approach that integrates different areas of knowledge, favoring broader learning that is connected to the students' reality (Guilherme et al., 2017).

In this context of searching for innovative methodologies, chapter 18 of the book Ensino, Pesquisa e Realizações, entitled "Active methodologies for environmental education actions: a comparative of methodologies based on problematization", written by Ana Carolina de Moraes and Marta Jussara Cremer, addresses the importance of active learning methodologies in the context of environmental education. Environmental education should be based on a dialogical, contextualized, interdisciplinary and problem-solving approach, aimed at providing students with an integral education, including the development of both technical skills and critical and reflective attitudes towards the environment. In this context, three active learning methodologies can be applied: Problem-Based Learning (PBL), Problematization Methodology (PM) and Design Thinking (DT) (Moraes and Cremer, 2018).

Problem-Based Learning (PBL) is a methodology that focuses on solving contextualized problems, originally developed in the medical course at McMaster University in Canada. PBL involves seven main stages: identification of the problem, exploration of pre-existing knowledge, generation of hypotheses, identification of learning questions, self-study to acquire new knowledge, reassessment and application of the new knowledge to the problem, and evaluation and reflection on the learning achieved. This methodology encourages the active participation of students, promoting the development of skills such as critical thinking, collaboration and autonomy (Moraes and Cremer, 2018).

The Problematization Methodology (PM), proposed by Charles Maguerez, is based on critical and liberating pedagogy, with the aim of transforming social reality through education. PM consists of five stages: observing reality and defining a problem, identifying key points, theorizing, formulating hypotheses for a solution and applying it to reality. This methodology values students' direct contact with reality, encouraging critical reflection on environmental problems and the search for solutions that consider the social, political and cultural aspects involved (Moraes and Cremer, 2018).

Finally, Design Thinking (DT) is an approach that proposes a new way of thinking, based on three main values: empathy, collaboration and experimentation. DT is divided into three spaces: inspiration, ideation and implementation. During the process, students are encouraged to observe people's needs, generate creative ideas and prototype solutions that can be tested and refined. DT is a flexible methodology that can be adapted to different contexts and that values creativity and innovation in solving complex problems (Moraes and Cremer, 2018).

The three methodologies presented in the chapter - PBL, PM and DT - share the

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characteristic of actively involving students in problem-solving, promoting the construction of knowledge through individual and collective activities. However, they differ in terms of the origin of the problem to be worked on. In PBL, the problem is developed by the teacher, while in PM, the starting point is the reality observed by the students, who identify the problems based on concrete facts. In DT, the problem is reconstructed by the students after a discovery phase, in which they observe and interpret the needs of the people involved in the context studied. This difference in the origin of the problem reflects the approach of each methodology: PBL is more structured and guided by the teacher; PM, centered on reality and critical reflection; and DT, more flexible and focused on empathy and innovation (Moraes and Cremer, 2018).

Another comparative aspect to be addressed is the organization of working groups. In all three methodologies, students are organized into teams, and it is recommended that each group has a leader and a writer. The leader has the task of ensuring that the discussion of the problem follows the steps of the chosen methodology, while the writer is responsible for recording the stages of the discussion. In DT, however, only the leader is needed, due to the more fluid dynamics of the process. In this case, the importance of developing leadership and teamwork skills is highlighted, pointing out that, in adult life, students will not always work with people from their circle of friends. For this reason, it is suggested that groups be formed by drawing lots or based on criteria predefined by the teacher (Moraes and Cremer, 2018).

The activities developed in each methodology are also compared. PBL and PM include specific stages for theoretical study, while in DT, study takes place in a way that is more integrated with the process of discovery and interpretation. In addition, observation of reality is a central element in PBL and DT, but it can be adapted to contexts in which students cannot leave school unsupervised. In these cases, the teacher can use resources such as images, videos or news to simulate the observation of reality. Prototyping, for its part, is an essential stage in DT, but it can also be incorporated into the other methodologies as a way of making ideas tangible and valid. That's why it's important to work with students on the issue of letting go and reusing materials during prototyping, promoting environmental awareness right from the learning process (Moraes and Cremer, 2018).

The role of the teacher in all three methodologies is highlighted as fundamental, but with a significant change from the traditional teaching model. In active methodologies, the teacher takes on the role of facilitator, mentor and mediator, rather than being the exclusive holder of knowledge. They must help students avoid superficial diagnoses, stimulate critical thinking and promote autonomy in the learning process. The teacher must also monitor the process of each group, ensuring that the learning objectives are achieved (Moraes and Cremer, 2018). This paradigm shift requires teachers to rethink their pedagogical practice, assuming a reflective stance and constant self-training (Alarcão, 2011; Perrenoud, 2002).

Finally, assessment in active methodologies must be formative and take place throughout the learning process. The teacher must monitor the students' development, observing whether the planned objectives are being achieved. It is also important for students to carry out self-assessments and peer assessments, reflecting on their contributions and how the group is functioning. There is also the risk of the teacher getting carried away by the quality of the final product, such as a prototype or presentation, without considering the learning process that led to that result. A well-designed end product does not always reflect a well-

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executed process, and vice versa. Therefore, the teacher must be careful when evaluating both the product and the process (Moraes and Cremer, 2018).

Finally, the three methodologies - ABP, MP and DT - value problematization as a central teaching and learning strategy, involving students in a dialogical process aimed at transforming reality. However, the application of these methodologies in environmental education actions requires careful planning, taking into account the socio-environmental context in which the school is located. Dialogue with students throughout the process is essential, as is mediation by the teacher, who must help them reflect on the social, economic, political, cultural and ethical aspects related to environmental problems.

It can be concluded that the use of active methodologies in environmental education can contribute to the formation of more critical citizens who are aware of their role in building a sustainable society. However, the success of these methodologies depends on the teacher's ability to adapt them to the specific context of their pedagogical practice, promoting environmental education that is truly transformative and emancipatory (Moraes and Cremer, 2018).

This is shown by a practical case study that illustrates the application of environmental education to urban solid waste. In Anhumas-SP, public environmental education actions, both formal and informal, have been promoted to strengthen urban solid waste management and ensure compliance with legislation, such as the National Solid Waste Policy (PNRS). These actions aim to enlighten the population about the proper management of waste and their role in shared responsibility, ranging from training teachers and health workers, lectures in schools and educational competitions, to informal initiatives such as the distribution of folders, joint efforts to collect electronic waste and cooking oil, as well as the engagement of shopkeepers and churches in promoting environmental awareness (Silva, Maria and Honda, 2013).

The results in Anhumas, with the population's great commitment to selective collection, especially families with school-age children, demonstrate the potential of well- applied environmental education. However, the lower participation of families from lower income brackets suggests the need for environmental education strategies that take into account socio-economic and territorial inequalities in order to ensure more equitable and effective participation. Finally, the experience reinforces the idea that solid waste management requires the effective participation of the community in all its stages, and that environmental education is an Indispensable sensitizing tool for this purpose.

In summary, Environmental Education, especially when adopted from a critical and transformative perspective, with active and interdisciplinary methodologies, and adapted to local realities, is a powerful tool for promoting awareness and changing behavior in relation to solid waste. However, for its potential to be fully realized, it is imperative to overcome challenges related to teacher training, institutional support and taking into account socio-economic inequalities that can limit the participation of certain social groups. This emphasis on the need for educational practices adapted to the context ties in directly with the broader challenges of waste management and sustainability, themes addressed in the study by Custódio, Junqueira and Manrique (2024), the first to be analyzed in the following topic.

2.3 Practical models and public policies: challenges and opportunities in the transition to the

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circular economy

The transition from a linear to a circular economic model is crucial for reducing waste and promoting more efficient use of natural resources. In this context, public policies play a central role, especially at the municipal level, where solid waste management manifests itself most directly. Studies by Custódio, Junqueira and Manrique (2024), Silva and Sauka (2023), and Dias, Marques and Dias (2013) provide a solid basis for analyzing the challenges and opportunities of this transition, as well as the tensions between management models and the effectiveness of public policies in Brazil.

The article entitled "Zero waste for the circular economy: the importance of municipalities and their circular economy public policies", by Maraluce Maria Custódio, José Claudio Junqueira and Jorge Isaac Torres Manrique, addresses the need to transition from a linear economic model to a circular model, with a focus on waste reduction and environmental sustainability. The increase in the production of solid urban waste (MSW) in Brazil, driven by urbanization, industrialization and technological advances, has led to pressure on natural resources and significant environmental problems, such as soil, water and air pollution. Given this scenario, the circular economy has emerged as a viable alternative for minimizing waste and maximizing the reuse and recycling of materials, promoting more sustainable economic development (Custódio, Junqueira and Manrique, 2024).

The research, which is qualitative and descriptive in nature, uses the deductive method and the bibliographic technique, with Valdemir Pires' theory of municipalism as its theoretical framework, which advocates a more active role for municipalities in implementing efficient public policies for economic and environmental development. The central objective is to analyze the possibility of establishing a circular economy in Brazil, based on the 2010 National Solid Waste Policy (PNRS), and to discuss the role of municipalities as key agents in this process. In order to achieve the circular economy, it is necessary not only to assign competencies to municipalities, but also to provide adequate financial resources for the implementation of public policies that encourage the reduction, reuse and recycling of waste (Custódio, Junqueira and Manrique, 2024).

The linear economy, the predominant model since the Industrial Revolution, is based on the extraction of natural resources, production, consumption and disposal of waste. This model, which considers natural resources to be infinite, has led to environmental degradation, loss of biodiversity and scarcity of materials, as well as contributing to climate change. The linear economy is contrasted with the circular economy, which proposes a system in which waste from one process becomes raw material for another, following the "cradle to cradle" principle. The circular economy aims to reduce dependence on virgin natural resources, promote the reuse and recycling of materials and minimize the environmental impact of waste disposal (Custódio, Junqueira and Manrique, 2024).

The transition to the circular economy is seen as a solution to the environmental and economic problems arising from the linear model. However, this change requires a systemic approach, involving not only industry and consumers, but also the state, through effective public policies. In this context, municipalities are considered the actors closest to society and therefore the most suitable for implementing circular economy policies. The PNRS, established by Law No.

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12.305/2010, is an important milestone in this regard, as it establishes guidelines for integrated solid waste management, including selective collection, reverse logistics and shared responsibility between the public and private sectors (Custódio, Junqueira and Manrique, 2024). The PNRS provides for the preparation of municipal solid waste management plans,

which must include strategies for the reduction, reuse and recycling of materials. However, despite legislative advances, the implementation of these policies still faces significant challenges, such as the lack of financial resources and the need to raise public awareness of the importance of selective collection and reverse logistics. In addition, many Brazilian municipalities still dispose of their waste improperly, in open dumps , which exacerbates environmental and public health problems (Custódio, Junqueira and Manrique, 2024).

Reverse logistics, one of the PNRS instruments, is also fundamental and aims to guarantee the return of post-consumer products to the production cycle. It is essential for the circular economy, as it allows for the reuse and recycling of materials, reducing the need to extract natural resources and minimizing the environmental impact of waste disposal. However, the implementation of reverse logistics in Brazil is still in its infancy, with only 3% of potential recyclable materials actually being collected and recycled (Custódio, Junqueira and Manrique, 2024).

Another point to be discussed is the need for public policies that encourage innovation and scientific research to develop new materials and processes that facilitate the transition to the circular economy. Technological innovation is crucial to making the circular economy more viable and attractive for companies, reducing costs and increasing efficiency in the use of resources. In addition, it is necessary to promote environmental education and raise public awareness of the benefits of the circular economy, both in environmental and economic terms (Custódio, Junqueira and Manrique, 2024).

Therefore, the implementation of the circular economy in Brazil depends to a large extent on the actions of municipalities, which are the federal entities closest to social reality and therefore the most able to promote practical changes in solid waste management. However, for municipalities to be able to play this role effectively, they need to receive adequate financial resources and technical support to draw up and implement public policies that encourage waste reduction, reuse and recycling. Although the PNRS is an important step forward, it is still not enough to guarantee the transition to the circular economy, as it lacks funding mechanisms and greater integration between the different levels of government (Custódio, Junqueira and Manrique, 2024).

The participation of all actors involved in the life cycle of products, including manufacturers, distributors, retailers and consumers, is also important in building a circular economy. Shared responsibility, provided for in the PNRS, is a key concept to ensure that all sectors of society contribute to reducing waste and promoting sustainability. However, without clear and effective public policies, the implementation of the circular economy will continue to be a challenge in Brazil (Custódio, Junqueira and Manrique, 2024).

Finally, the circular economy must be seen as an opportunity for economic and social development, capable of generating new jobs, reducing costs and increasing the competitiveness of companies. The transition to a circular model requires a change in mentality on the part of both governments and society, and must be accompanied by investment in

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education, innovation and infrastructure. The municipality, as the federal entity closest to the population, has a central role in this process, but it needs to be supported by national and international policies that promote sustainability and waste reduction (Custódio, Junqueira and Manrique, 2024).

In short, the circular economy is a viable and necessary alternative for tackling the environmental and economic challenges of the 21st century, but its implementation in Brazil depends on the coordinated action of municipalities, the federal government and society as a whole. The PNRS is an important step in this direction, but there is still much to be done to ensure that the principles of the circular economy are effectively incorporated into public policies and the everyday practices of the population (Custódio, Junqueira and Manrique, 2024). This need for coordinated action to promote the circular economy takes on a practical perspective in the study by Silva and Sauka (2023), which examines the possibilities for local development based on waste picker cooperatives. The research was based on a qualitative approach, using methods such as non-participant observation, structured and semi-structured interviews, as well as a literature review that included the construction of a bibliometric portfolio on the circular economy and waste pickers (Silva and Sauka, 2023).

In the context of a Brazil that ranks fourth in the world in the generation of solid urban waste, the work of these cooperatives not only contributes to efficient waste management, but also plays a key role in strengthening local circular economy models. Cooperatives can also be agents of change, promoting social inclusion and the generation of work and income, while contributing to environmental sustainability (Silva and Sauka, 2023).

The current model of linear consumption, prevalent in modern societies, generates significant socio-environmental problems, such as the increase in the production of municipal solid waste (MSW). Brazil, considered the fourth largest generator of solid waste in the world, faces challenges related to the management and recovery of this waste, which makes it essential for waste picker cooperatives to act as agents of sustainable practices (Silva and Sauka, 2023).

The circular economy is presented as an alternative to the linear model of production and consumption, which is based on the extraction of natural resources, production, consumption and disposal of waste. This linear model has led to environmental degradation, resource scarcity and increased waste generation, especially in large urban centers. The circular economy, on the other hand, proposes a system in which waste from one process becomes raw material for another, following the "cradle to cradle" principle. This approach aims to minimize environmental impact, reduce dependence on virgin natural resources and promote the reuse and recycling of materials (Silva and Sauka, 2023).

The National Solid Waste Policy (PNRS), established by Law No. 12.305/2010, is an important milestone for waste management in Brazil, as it establishes guidelines for selective collection, reverse logistics and shared responsibility between the public and private sectors. The PNRS also recognizes the role of waste picker cooperatives as key players in the recycling chain, encouraging social inclusion and income generation through the recovery of solid waste. However, the implementation of the PNRS faces challenges, such as a lack of financial resources and the need to raise public awareness of the importance of selective collection and recycling (Silva and Sauka, 2023).

The research was carried out at the Cooperative of Waste Pickers of Curitiba and the

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Metropolitan Region (CATAMARE), located in the Boqueirão neighborhood of Curitiba. The cooperative has 17 members and sorts recyclable materials from three main sources: (1) specialized selective collection carried out by Curitiba City Hall; (2) the public sector, through partnerships with government departments; and (3) the business and residential sector, with the participation of commercial companies and condominiums. CATAMARE uses technologies such as sorting conveyors, scales and forklifts, acquired through funding from institutions such as the National Health Foundation (FUNASA) and the National Bank for Economic and Social Development (BNDES) (Silva and Sauka, 2023).

The collaborative relationships between CATAMARE and other organizations can be highlighted as fundamental to strengthening the cooperative. CATAMARE maintains partnerships with other cooperatives, such as CataCuritiba and CataParaná, as well as establishing relationships with business sectors and educational institutions, such as the Federal Technological University of Paraná (UTFPR) and the Federal University of Paraná (UFPR). These partnerships allow the cooperative to receive recyclable materials from various sources, contributing to local sustainability and generating income for the waste pickers. In addition, CATAMARE participates in an institutional collaboration network that includes public and private bodies, strengthening its role in the recycling chain (Silva and Sauka, 2023).

Waste logistics at CATAMARE involves sorting recyclable materials, which are then sold to processing industries. The cooperative maintains commercial relations with two industries in São Paulo, which process plastic waste, and an industry in Curitiba, which works with paper, scrap metal, aluminum cans and glass. In addition, CATAMARE also negotiates with aparistas (intermediaries) who buy the sorted materials and forward them to processing industries. These commercial relationships are essential for ensuring the circularity of materials, transforming waste into new raw materials for industry (Silva and Sauka, 2023).

There is also potential for sustainable local development in the region where CATAMARE is located. The Boqueirão neighborhood has a significant commercial and industrial hub, with more than 25,000 active commercial permits, which represents 11% of Curitiba's total. The region concentrates industrial, commercial and service activities, generating a large amount of waste that could be sent to the cooperative. The research suggests that the creation of a collaborative network between CATAMARE and local companies could strengthen the circular economy in the region, promoting sustainable local development. This network would allow the waste generated by the companies to be sorted and recycled by the cooperative, generating income for the waste pickers and reducing the environmental impact of improper waste disposal (Silva and Sauka, 2023).

It can therefore be concluded that CATAMARE plays a key role in promoting the circular economy and sustainable local development. The collaborative relationships established by the cooperative with other organizations, both public and private, are essential for strengthening its activities and generating income for waste pickers. By recognizing the social and economic value of recyclable waste, the PNRS reinforces the importance of waste picker cooperatives in the recycling chain. However, the effective implementation of the circular economy still faces challenges, such as the need to raise public awareness of the importance of selective collection and recycling, as well as the lack of financial resources for the proper management of solid waste (Silva and Sauka, 2023).

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Finally, it is suggested that the creation of collaborative networks between CATAMARE and local companies could contribute to the development of a more efficient circular economy model in the Boqueirão region. These networks would allow the waste generated by companies to be sorted and recycled by the cooperative, promoting the circularity of materials and reducing the environmental impact of improper disposal (Silva and Sauka, 2023).

Sustainable local development depends on the participation of all the social and institutional actors involved in the recycling chain. Maintaining collaborative networks and ensuring efficient waste management planning are essential for promoting the circularity of materials and the preservation of natural resources. In addition, public policies that encourage the circular economy and support waste picker cooperatives are essential, guaranteeing social inclusion and income generation for recycling workers (Silva and Sauka, 2023).

In summary, CATAMARE's work is an example of how waste picker cooperatives can contribute to the implementation of the circular economy and sustainable local development. The collaborative relationships established by the cooperative with other local organizations and companies show that it is possible to promote the circularity of materials and reduce the environmental impact of waste disposal, while generating income and social inclusion for waste pickers. However, for these practices to be expanded and consolidated, they need the support of effective public policies and society's awareness of the importance of recycling and the circular economy (Silva and Sauka, 2023).

However, the effectiveness of these policies and practical models is often strained by the persistence of inadequate waste disposal practices, such as dumps, which represent a serious socio-environmental and public health problem in Brazil. The article "Lixão: tem solução?", by Dias, Marques and Dias (2013), discusses the influence of the dumps in Tupã and Presidente Prudente on the health of the surrounding population, highlighting the risks associated with these environments.

The inadequate final disposal of solid waste can cause risks to the environment and public health, encouraging the proliferation of insects and other disease vectors. The presence of biotic factors (cockroaches, flies and rats) and abiotic factors (smoke and odors) in areas near dumps revealed a significant number of residents who identified the presence of these unhealthy factors. The comparison between Tupã, which closed its dump and implemented a sanitary landfill and selective waste collection, and Presidente Prudente, which still had an active dump, shows that the solution to dumps lies in political will and the allocation of resources for the implementation of technically appropriate systems for the final disposal of waste, as well as environmental education (Dias, Marques and Dias, 2013).

Law 12.305/2010 (PNRS) established deadlines for the elimination of dumps, but the Brazilian reality still shows a large number of dumps in activity, which highlights the gap between the normative framework and the effectiveness of public policies. The persistence of dumps, despite legislation, underlines the limits of the circular economy in the face of territorial inequality and the lack of infrastructure and investment in many regions of the country. The problem of garbage dumps is not only a public health and environmental issue, but also a reflection of social inequality, where vulnerable populations are the most affected by their proximity to these waste dumps. In this context, environmental education plays a crucial role in raising awareness and training people to practice recycling and reuse, but the systemic solution requires overcoming the political and economic barriers that perpetuate the existence of dumps

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(Dias, Marques and Dias, 2013).

In short, the implementation of practical models and effective public policies for waste management and the transition to the circular economy in Brazil is a complex challenge that requires overcoming structural obstacles and coordination between different spheres of government and social actors. The PNRS represents a significant step forward, but its effectiveness is compromised by the persistence of inadequate practices, such as dumps, and by the lack of investment and awareness. Integrating environmental education, strengthening waste picker cooperatives and guaranteeing resources and infrastructure are essential elements if the circular economy is to make a real contribution to more sustainable and equitable development in the country (Dias, Marques and Dias, 2013).

In general, theories on waste and management, and environmental education, reveal a fundamental gap in the transition to sustainability. While authors such as Ambrosi (2019), Bicalho and Pereira (2018), and Souza and França (2014) unveil the socio-environmental complexity of waste, the insufficiency of public policies and the biopolitics of waste, environmental education (EE) emerges as a pillar for the paradigm shift. However, the effectiveness of environmental education, as discussed by Gomes *et al.* (2023), Guilherme *et al.* (2017), Moraes and Cremer (2018), and Silva, Maria and Honda (2013), depends on a critical and transformative approach that goes beyond mere individual awareness. The critique lies in the need for EE not only to inform about the problem of waste, but also to enable citizens to question the structures of production and consumption that generate the problem, as pointed out by Souza and França (2014) when warning about the risk of individual accountability obscuring systemic responsibilities.

This tension between the theoretical understanding of the challenges and the practical application of solutions is deepened by integrating practical models and public policies. Custódio, Junqueira and Manrique (2024) and Silva and Sauka (2023) defend the circular economy and the crucial role of municipalities and waste picker cooperatives, respectively, as paths to more sustainable development. However, the persistence of garbage dumps, as evidenced by Dias, Marques and Dias (2013), underlines the limits of the effectiveness of these policies and models. The criticism here lies in the fact that, despite theoretical advances and proposals for EE and the circular economy, the Brazilian reality is still faced with the ineffectiveness of the PNRS in eradicating predatory practices, revealing that political will and the allocation of resources, as argued by Dias, Marques and Dias (2013), are as crucial as awareness and innovation.

Ultimately, the critical articulation between the three conceptual axes - waste management theories, environmental education and practical models/public policies - points to the need for a holistic and integrated approach. The theoretical density (Ambrosi, 2019; Bicalho and Pereira, 2018; Souza and França, 2014) allows us to understand the depth of the problem; environmental education (Gomes *et al.*, 2023; Guilherme *et al.*, 2017; Moraes and Cremer, 2018; Silva, Maria and Honda, 2013) offers the tools to change mentality and behavior; and practical models and public policies (Custódio, Junqueira and Manrique, 2024; Silva and Sauka, 2023; Dias, Marques and Dias, 2013) provide the framework for action. The final criticism is that overcoming the challenges of urban solid waste management in Brazil will not be achieved through the isolated application of each of these pillars, but rather through their organic interconnection and the ability to tackle the structural inequalities that prevent the full realization of a more

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sustainable and equitable future.

3 CONCLUSION

The theoretical framework highlights the fact that the management of solid urban waste cannot be viewed in isolation, but rather requires an integrated approach involving technical, social, economic and environmental aspects. The paradigm shift in the treatment of waste, from the concept of waste to the notion of waste as a resource, reflects a growing awareness of the socio-environmental impacts of the linear consumption model prevalent in modern societies. This transformation, however, requires the strengthening of public policies that encourage shared responsibility and the active engagement of society, including the participation of different sectors, such as government, companies and citizens.

Environmental education plays a key role in this process, not only to raise awareness among the population about the importance of proper waste management, but also to empower individuals to adopt more sustainable practices in their daily lives. The pedagogical approaches that have been adopted in this field highlight the importance of interdisciplinarity and the adoption of active methodologies, which encourage critical reflection and the problematization of environmental issues. Although there has been significant progress in this direction, the challenges to the effective implementation of these practices include the needfor greater training for educators, support from educational institutions and overcoming structural limitations, such as the lack of resources and infrastructure.

Another relevant finding is the centrality of the circular economy as a concrete proposal for waste management, with a focus on reducing, reusing and recycling materials. The transition to this model, which aims to replace the linear "production-consumption-disposal" model, implies a transformation in economic and social practices. Waste picker cooperatives, as key agents of this change, have demonstrated their ability to contribute to sustainable waste management and local development. However, their effectiveness depends on the implementation of appropriate public policies that guarantee access to resources and the integration of these initiatives into the formal waste management network.

Ultimately, the studies reviewed indicate that building a sustainable society requires a holistic approach that combines environmental education, social participation, innovation in pedagogical methodologies and the promotion of more circular and sustainable economic models. The interconnection of these elements can result in more effective and inclusive solutions that promote a change in mentality and practices in relation to waste and consumption, thus contributing to environmental preservation and the well-being of present and future generations.

Acknowledgements

This article was carried out with the support of the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - Funding Code 001 - 88881.083131/2024-01". Post-doctoral scholarship - (PIPD).

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GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 13, n. 88, 2025

STATEMENTS

CONTRIBUTION OF EACH AUTHOR

When describing each author's participation in the manuscript, use the following criteria:

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DECLARATION OF CONFLICTS OF INTEREST

We, [**Uilmer Rodrigues Xavier da Cruz, Ricardo Alexandrino Garcia and Martín Andrés Díaz**], declare that the manuscript entitled "[**Urban solid waste management in Brazil: Challenges, public policies and social inclusion**]":

1. **Financial ties**: We have no financial ties that could influence the results or interpretation of the work.
2. **Professional Relationships**: We have no professional relationships that could impact on the analysis, interpretation or presentation of the results.
3. **Personal Conflicts**: We have no personal conflicts of interest related to the content of the manuscript.