

Urban solid waste management in BRICS countries: a comparative analysis of indicators and efficiency

RESUMO

Christian Luiz da Silva

Universidade Tecnológica Federal
do Paraná (UTFR), Curitiba,
Paraná, Brasil

christianlsilva76@gmail.com

**Marta Chaves Vasconcelos de
Oliveira**

Universidade Tecnológica Federal
do Paraná (UTFR), Curitiba,
Paraná, Brasil

martacvasconcelos@hotmail.com

Este estudo teve como objetivo avaliar a eficiência na gestão de resíduos sólidos urbanos (RSU) nos países do BRICS, com foco comparativo entre cidades brasileiras e russas, utilizando a técnica de Análise Envoltória de Dados (DEA). Além da aplicação do modelo DEA, foi realizada uma análise descritiva dos indicadores sociais, econômicos, ambientais e institucionais dos países do BRICS, permitindo um panorama comparativo entre suas diferentes realidades. Os resultados indicaram diferenças expressivas de eficiência, destacando São Paulo, Saint Petersburg, Novosibirsk e Sochi como cidades mais eficientes. Observou-se que cidades com maior população e maiores investimentos financeiros nem sempre são as mais eficientes, ressaltando que a qualidade dos processos de coleta, separação e recuperação de materiais é mais determinante que o volume de recursos aplicados. A pesquisa apresentou limitações quanto à disponibilidade e atualização dos dados, restringindo a análise comparativa a Brasil e Rússia. Para estudos futuros, recomenda-se ampliar o levantamento de dados para os demais países do BRICS, incorporar novos indicadores e explorar modelos DEA dinâmicos que considerem variações temporais.

PALAVRAS-CHAVE: Gestão de resíduos sólidos urbanos. BRICS. Análise Envoltória de Dados (DEA). Eficiência operacional. Sustentabilidade urbana.

INTRODUCTION

The BRICS bloc stands out not only because of its economic significance but also because of its growing participation in international decisions. The consolidation of the BRICS countries, comprising Brazil, Russia, India, China, and South Africa, represents a significant milestone in global geopolitics, particularly due to their economic influence and the size of their populations. Together, they account for approximately 41% of the world's population, 24% of global Gross Domestic Product (GDP), and 16% of international trade (World Bank, 2022). Despite their distinct economic trajectories, these countries share common challenges, such as the rapid growth of cities, disorderly urbanization, and growing demands for infrastructure, public services, and efficient environmental management (UNEP, 2018).

In this context, urban solid waste (USW) management is one of the major environmental challenges facing the BRICS bloc. According to the World Bank's What a Waste 2.0 report (Kaza et al., 2018), these five countries are responsible for a significant portion of the world's solid waste generation. Together, they generate over 2 billion tons of waste annually, driven by population growth, urbanization, and consumption patterns. China leads the way, producing around 395 million tons per year, followed by India, with approximately 277 million, while Brazil, Russia, and South Africa also face significant challenges in terms of volume, recycling, and final disposal of waste (Kaza et al., 2018; UNEP, 2021). Furthermore, it is estimated that in most of these countries, over 40% of the waste is still disposed of inappropriately, either in landfills or in landfills with no environmental controls (UNEP, 2021). This demonstrates not only the environmental impact, but also the social and economic challenges related to solid waste management.

Given this scenario, the aim of the present study is to answer the following research question: how is urban solid waste management efficiency characterized in the BRICS countries? Therefore, the main goal is to assess how efficiently the BRICS countries manage their urban solid waste. This research is justified, in theoretical terms, by the need for more in-depth discussions on environmental management, sustainable development, and public solid waste policies in emerging economies (Dias, 2019; Wilson et al., 2006). In practical terms, the results can help public administrators, policymakers, and international organizations to develop more effective strategies to promote more sustainable and efficient waste management systems in line with the Sustainable Development Goals (SDGs), especially SDGs 11 and 12 (UN, 2015).

This article is organized into five sections, in addition to this introduction. In the second section, the theoretical framework is presented, addressing the concepts of solid waste management, sustainable development, and efficiency analysis, with an emphasis on the application of Data Envelopment Analysis (DEA) in environmental studies. The third section details the methodological procedures, including variable definition, DEA model selection, analysis period, and data sources. The fourth section then discusses the results obtained, with a comparative analysis of the BRICS countries. Finally, in the fifth section, the concluding remarks are presented, highlighting the main findings, research limitations, and suggestions for future studies.

THEORETICAL FRAMEWORK

The theoretical framework that underpins the development of this study is presented below, addressing the key concepts related to urban solid waste management, efficiency in public administration and the use of DEA as a comparative evaluation tool between decision-making units.

Urban Solid Waste Management Policies in the BRICS Bloc

Urban solid waste (USW) management has attracted increasing attention in recent decades as one of the major challenges faced by public administration, especially in emerging countries. According to Medina (2007), solid waste is a direct consequence of rapid urban growth and disorderly consumption, and its mismanagement can compromise not only public health but also the environment and people's quality of life. In this context, several international studies have focused on analyzing efficient and sustainable management models, especially in the BRICS countries, which have distinct social and economic characteristics but share common structural challenges.

Wilson et al. (2006) and Hoornweg and Bhada-Tata (2012) pointed out that low- and middle-income countries face challenges related to collection coverage, adequate final disposal, and structured recycling systems. These studies reinforce the importance of integrated public policies that include legal instruments, stable funding, community involvement, and monitoring and evaluation mechanisms, as in the case of the BRICS. Integrated solid waste management is recognized as an ideal approach, ranging from minimizing generation to environmentally appropriate final disposal (ABRELPE, 2022).

In the Brazilian context, the National Solid Waste Policy (PNRS), enacted through Law No. 12,305/2010, stands out as a legal framework that guides waste management. The PNRS emphasizes shared responsibility between the government, the business sector, and civil society, in addition to encouraging reverse logistics and the inclusion of waste pickers.

In Russia, more recent research has revealed tentative progress in modernizing the sector, focusing on the privatization of collection and disposal services, as well as programs to encourage recycling and make less use of landfills (OECD, 2021). However, as Petrov and Kolomytsev (2020) pointed out, a lack of adequate infrastructure remains, combined with low levels of public awareness regarding waste separation and reuse.

In India, municipal solid waste management is one of the main challenges facing local governments, especially due to rapid urbanization and population growth. The country has sought to implement policies such as the Swachh Bharat (Clean India) Mission, which promotes door-to-door collection, composting, and the elimination of landfills. Furthermore, public-private partnerships and the role of NGOs in strengthening selective collection are highlighted. However, the effectiveness of these policies varies widely across Indian regions and cities, with significant disparities in infrastructure and funding (Kumar et al, 2022).

In China, urban solid waste management policies are integrated into a broader circular economy and sustainable development strategy. The Chinese government

has set ambitious goals to increase recycling rates, reduce waste generation, and promote incineration with energy recovery. The city of Shanghai, for example, implemented a mandatory waste separation system in 2019, serving as a model for other regions. However, despite progress, challenges remain regarding public awareness and the consistent implementation of policies throughout the territory (Knothe, 2024).

In South Africa, urban solid waste management is guided by the 2020 National Waste Management Strategy, which aims to minimize waste, increase recycling, and create green jobs. The country faces significant challenges, such as the informal sector, low collection rates in rural and peri-urban areas, and the need for greater technical training. On the other hand, there are promising initiatives for including waste pickers and encouraging cooperatives, in addition to a consolidating legal framework (Department of Forestry, Fisheries and Environment, 2022).

Use of the DEA Technique to Evaluate the Efficiency of Solid Waste Management

Data Envelopment Analysis (DEA) has been used to evaluate the technical efficiency of urban solid waste (USW) management. Zaman and Lehmann (2011) analyzed large Asian metropolises and noted that the use of advanced technologies, combined with reduced operating costs and the appropriate use of human resources, resulted in better indicators, such as higher recycling rates and less waste sent to landfills. This reinforces the strategic importance of technological innovation in sustainable waste management. Cordeiro et al. (2012) evaluated the technical efficiency of small and medium-sized enterprises in Wales regarding waste management, within the context of European Union environmental policies. The study compared the results of the DEA and Stochastic Frontier Analysis (SFA) techniques, finding a high correlation between the efficiency rankings. Furthermore, management practices such as environmental audits and joining local groups were associated with greater technical efficiency.

Rogge and Jaeger (2012) measured both overall efficiency and that of specific waste fractions in 293 municipalities in Flanders, Belgium considering that certain costs are shared among the processes involved. The study showed that the adapted DEA technique enables the identification of areas with potential for improvement. Chang, Liu, and Yeh (2013) investigated the impact of organizational learning on recycling efficiency in 23 local governments in Taiwan between 2001 and 2009. The authors observed variations in efficiency according to household income and advocated for recycling policies adapted to local economic realities.

Simões, Carvalho and Marques (2012) studied the economic benefits of jointly providing waste, water, and sewage services. Although they did not identify economies of scope, they observed economies of scale in small municipalities, suggesting that intermunicipal cooperation can reduce operating costs. Yeh, Chang, and Liu (2016) used a dynamic DEA model to analyze how accumulated organizational learning affected the performance of recycling systems in Taiwan between 2002 and 2011. The results showed that this kind of learning has a positive and lasting effect on efficiency, offering important insights for improving

public policies and demonstrating the relevance of dynamic DEA models in the waste sector.

METHODOLOGY

The BRICS countries were chosen for the purposes of this study. Secondary data were initially collected on socioeconomic, environmental and institutional indicators. The data were gathered from the databases of the World Bank (<https://data.worldbank.org/?locations=1W-ZA>) and the Statista platform (<https://www.statista.com/search/?q=municipal+waste&Search=&p=1>), which provide up-to-date and systematized information on a range of global indicators. The data were analyzed using descriptive statistics, which enabled a preliminary understanding of the patterns of and disparities between countries. Subsequently, data were sought for the application of the data envelopment analysis technique. It is noteworthy that data were not available for all the BRICS countries that would allow for the full application of the DEA technique. Complete data were obtained only for Brazil and Russia, making it impossible to include India, China, and South Africa in the efficiency analysis due to the lack of the necessary variables for modeling. To measure the efficiency of urban solid waste management in these countries, Data Envelopment Analysis (DEA) was used. This technique allows an assessment of the relative efficiency of units responsible for performing similar functions, known as Decision Making Units (DMUs). This method generates an index ranging from 0 to 1, with values closer to 1 indicating higher operational efficiency, while a value of 1 indicates that the unit in question has reached the efficiency frontier. In this study, each DMU corresponds to a BRICS member country. It was decided to use the output-oriented DEA model under variable returns to scale (VRS), which allows an assessment of the performance of units by considering their efforts to maximize results (outputs) relative to the available inputs.

DEVELOPMENT (RESULTS AND DISCUSSIONS)

The main findings of this research are discussed below. First, a comparative description of the social, economic, environmental, and institutional conditions of the BRICS countries is presented, based on the collected and systematized data, followed by a specific overview of their urban solid waste management. Finally, the results of the evaluation of urban solid waste management efficiency are presented and analyzed, considering only Brazil and Russia, the only countries for which the necessary database for applying the DEA technique was available.

Comparative Panorama of the Indicators of the BRICS Countries

Table 1 contains a wide-ranging set of social, economic, environmental and institutional indicators of the BRICS countries. These data show a comparative panorama that is necessary to understand the different realities of each country.

Table 1 – Economic, social, environmental and institutional indicators of the BRICS countries.

Social Indicator	Brazil	Russia	India	China	South Africa
Poverty rate (less than US\$3/day, PPP 2021, %)	3.8 (2023)	0.2 (2023)	5.3 (2023)	0.0 (2023)	31.2 (2023)
Life expectancy at birth (years)	76 (2023)	73 (2023)	72 (2023)	78 (2023)	66 (2023)
Total Population	211,998,573 (2024)	143,533,851 (2024)	1.45 billion (2024)	1.41 billion (2024)	64,007,187 (2024)
Annual population growth (%)	0.4 (2024)	-0.2 (2024)	0.9 (2024)	-0.1 (2024)	1.2 (2024)
Net migration	-225,510 (2024)	-178,042 (2024)	-630,830 (2024)	- 318,992 (2024)	166,972 (2024)
Human Capital Index (0-1)	0.6 (2020)	0.7 (2020)	0.5 (2020)	0.7 (2020)	0.4 (2020)
Economic Indicator	Brazil	Russia	India	China	South Africa
GDP (current US\$)	2.18 trillion (2024)	2.17 trillion (2024)	3.91 trillion (2024)	18.74 trillion (2024)	400.26 billion (2024)
GDP per capita (current US\$)	10,280.3 (2024)	14,889.0 (2024)	2,696.7 (2024)	13,303.1 (2024)	6,253.4 (2024)
Annual GDP growth (%)	3.4 (2024)	4.3 (2024)	6.5 (2024)	5.0 (2024)	0.6 (2024)
Unemployment (% of labor force)	7.6 (2024)	2.5 (2024)	4.2 (2024)	4.6 (2024)	33.2 (2024)
Annual consumer price inflation (%)	4.4 (2024)	6.7 (2024)	5.0 (2024)	0.2 (2024)	4.4 (2024)
Personal remittances received (% of GDP)	0.2 (2024)	0.1 (2024)	3.5 (2024)	0.2 (2024)	0.2 (2024)
Environmental Indicator	Brazil	Russia	India	China	South Africa
Forest area (% of land area)	59.1 (2022)	49.8 (2022)	24.4 (2022)	23.8 (2022)	14.0 (2022)
CO2 emissions per capita (t CO2e/capita)	2.3 (2023)	14.4 (2023)	2.1 (2023)	9.4 (2023)	6.3 (2023)
Access to electricity (% population)	99.8 (2023)	100.0 (2023)	99.5 (2023)	100.0 (2023)	87.7 (2023)
Annual withdrawals of fresh water (% internal resources)	1 (2021)	2 (2021)	45 (2021)	20 (2021)	47 (2021)

Renewable electricity except hydro (% total)	22.1 (2021)	0.5 (2021)	9.2 (2021)	12.9 (2021)	3.7 (2021)
Use of safe sanitation (% population)	50 (2022)	61 (2022)	52 (2022)	67 (2022)	72 (2022)
Institutional Indicator	Brazil	Russia	India	China	South Africa
Intentional homicides (per 100,000 population)	22 (2020)	7 (2020)	3 (2020)	1 (2020)	42 (2020)
Central government debt (% of GDP)	83.0 (2023)	18.5 (2023)	46.5 (2018)	-	76.2 (2022)
General statistical performance (0-100)	80.6 (2023)	82.9 (2023)	73.6 (2023)	59.5 (2023)	82.4 (2023)
Individuals using the internet (% population)	84 (2024)	92 (2024)	56 (2024)	78 (2024)	76 (2024)
Share of parliamentary seats held by women (%)	18 (2024)	16 (2024)	14 (2024)	27 (2024)	45 (2024)
Foreign direct investment (% of GDP)	3.3 (2024)	-0.4 (2024)	0.7 (2024)	0.1 (2024)	0.6 (2024)

Source: Research data (2025).

Table 1 shows that South Africa faces serious public safety challenges, with the highest homicide rate of the BRICS. Brazil also has a high rate, indicating problems in public safety governance. Russia has relatively low public debt, while Brazil and South Africa's are a cause for concern, indicating fiscal pressures. Regarding female participation in parliament, South Africa leads, demonstrating greater progress in political inclusion, while India and Russia have low female representation. China has the lowest homicide rate, a reflection of effective public safety governance.

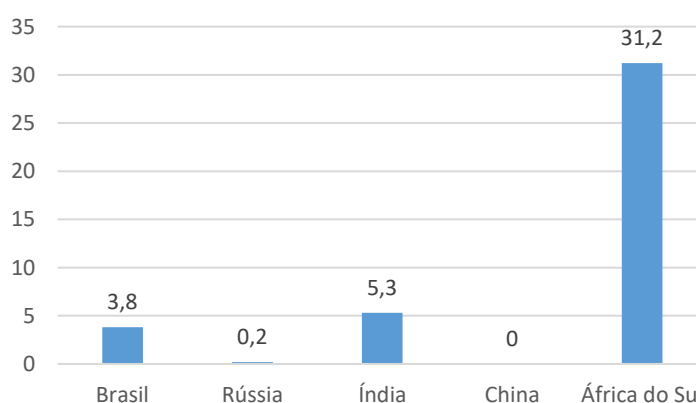
In addition to these aspects, female participation in parliament is a critical indicator of political inclusion, highlighting South Africa's positive performance, with nearly half of its parliamentary seats held by women. This is in contrast with low female representation in Russia, India, and Brazil, highlighting the urgent need for affirmative action policies in these countries. Another relevant issue is human capital. Russia and China have better rates, indicating a direct relationship with life expectancy and investment in education and health. India and South Africa face significant challenges in this respect, which could jeopardize long-term sustainable economic growth due to structural limitations in human capital development.

Regarding the environment, Brazil and Russia have large forest areas, especially Brazil, (59.1%), indicating great potential for sustainable conservation strategies. India and South Africa face serious water management challenges, with

high levels of freshwater withdrawal, posing a substantial risk to future sustainability. China is the largest per capita emitter of CO₂, but has made considerable progress in the use of renewable energy. Brazil has relatively low per capita emissions, suggesting positive potential for expanding low-carbon policies.

In terms of social issues, South Africa has the highest poverty rate, highlighting considerable social challenges that contrast with the near-total eradication of extreme poverty in China and Russia. While Brazil and India have middling poverty levels, Brazil has better life expectancy and human capital than India, indicating differences in access to health and education. South Africa faces a particularly alarming situation, with more than 30% of the population living on less than US\$3 a day, while Brazil and Russia have significantly lower rates, reflecting better access to basic social services (Figure 1).

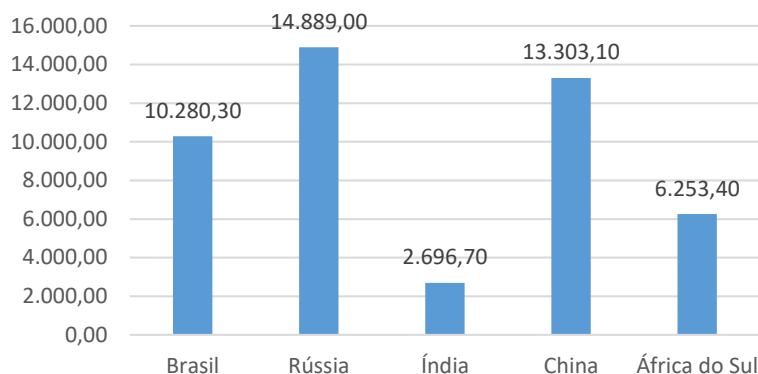
Figure 1 – Poverty index (% of the population on less than US\$3 per day)



Source: Research data (2025).

Economically, China stands out with the highest GDP and significant economic growth, followed by India with an even higher growth rate. Brazil and Russia have similar GDPs, but Russia has a higher GDP per capita and a lower unemployment rate. South Africa faces significant economic challenges, with high unemployment and limited economic growth, indicating significant structural vulnerability. Russia, has higher GDP and the lowest unemployment rate of the group, reflecting comparatively favorable economic stability (Figure 2).

Figure 2 – GDP per capita (current levels in US\$)



Source: Research data (2025).

Panorama of Urban Solid Waste Management in the BRICS countries

Despite their cultural, economic, and social differences, the BRICS share similar challenges in environmental management, especially in the production and treatment of urban solid waste. According to the World Bank (2022), these countries together generate over 1 billion tons of urban solid waste annually, approximately 30% of the global total, highlighting the importance of this issue for sustainable public policies in the bloc (World Bank, 2022).

Brazil produces around 79 million tons of solid waste per year, much of which is sent to landfills, although there are gaps in terms of adequate infrastructure (ABRELPE, 2022). The National Solid Waste Policy (Law No. 12,305/2010) seeks to regulate this management, encouraging sustainable practices and shared responsibility between the public and private sectors. However, challenges related to selective collection and recycling remain significant (IPEA, 2021). Management is predominantly the responsibility of private companies contracted by city governments, although some regions still rely on municipal public services. The public has shown growing awareness of the importance of separation and recycling, although practical initiatives continue to face limitations owing to the lack of infrastructure and insufficient government investment.

In Russia, around 70 million tons of urban solid waste are generated annually. Most of this waste is disposed of in landfills, many of which have low environmental standards (OECD, 2021). Recently, the government has turned its attention to increasing the recycling rate, which remains low, through programs and initiatives focused on sustainable management and incentives for the private sector to invest in treatment technologies (Russian Ecological Operator, 2022). The system is primarily managed by private companies contracted by the government. However, state investment has increased, especially in educational campaigns to raise public awareness of sustainable practices, although uptake is still moderate and hindered by limited awareness of the environmental impacts of waste.

India faces significant challenges, producing approximately 62 million tons of waste annually, little of which is recycled (MoHUA, 2022). Much of the waste is disposed of in open-air dumps, with worrying environmental and public health impacts. The Indian government has intensified efforts to implement the National Clean Cities Mission, targeting segregated collection and the expansion of recycling

and composting facilities (Kumar et al, 2022). Management services are generally provided by private companies under municipal contracts, and there is a growing effort in public-private partnerships to improve infrastructure. Public awareness is slowly increasing but remains low in many urban and rural areas due to a lack of ongoing environmental education.

China, the largest producer of urban solid waste in the BRICS, at around 235 million tons per year, has invested heavily in incineration with energy recovery, alongside the intensive use of modern landfills (National Bureau of Statistics of China, 2022). Recent policies such as the Circular Economy Promotion Law have encouraged recycling and source reduction practices, driven by clear government targets and the active participation of private companies (Knothe, 2024). Waste management is predominantly handled by large state-owned and private companies, with heavy government investment in advanced treatment and recycling technologies. The Chinese population has shown growing support for environmental initiatives, especially in urban areas, reflecting a significant cultural shift regarding the importance of sustainability.

In South Africa, approximately 13 million tons of urban solid waste are produced annually, and the country relies heavily on landfills, many of which are close to exhaustion (Department of Forestry, Fisheries and Environment, 2022). Despite robust legislation, such as the Waste Act (2008), practical implementation remains hindered by challenges involving infrastructure and funding. Greater public-private collaboration is required to facilitate sustainable alternatives such as recycling and composting (Godfrey et al., 2021). Waste management is often handled by a combination of public municipal services and private contracts, with significant variations in the quality of services provided from one region to another. The South African population has become increasingly aware of environmental issues, although discrepancies persist between more developed regions, with greater access to adequate services, and poorer regions, where inadequate practices such as irregular disposal in improvised dumps prevail.

Analysis of the Efficiency of Urban Solid Waste Management in Brazil and Russia

Regarding financial investment, a great contrast was observed between cities. The capital city with the highest annual investment in urban cleaning was São Paulo, with around R\$ 3.5 billion, while Sochi had the lowest investments, only R\$ 39.3 million per year. The average annual expenditure for all cities was approximately R\$635 million, with a median of R\$249 million, indicating strong asymmetry among larger Brazilian cities, especially São Paulo and Rio de Janeiro.

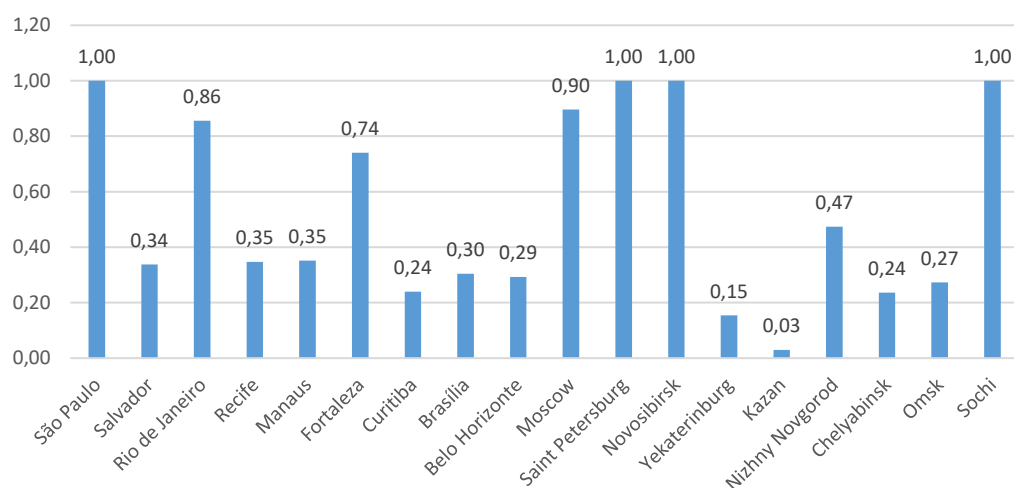
Concerning the total amount of waste collected, this scenario also varies significantly. The highest volume recorded was again in São Paulo, with approximately 3.9 million tons annually, while the lowest volume was in the city of Kazan, with only 63,800 tons. The average for all cities was approximately 1 million tons per year, with a median of 884,000 tons, demonstrating that population size and the level of urban activity directly impact waste generation.

As for recovered materials, excluding organic material and waste, Novosibirsk stood out, with 700,000 tons recovered annually, while Recife had the lowest volume, with only 1,146 tons. The average was approximately 83,000 tons.

Although larger cities, especially São Paulo, have the highest investments and waste volumes, this does not ensure the highest material recovery rates. The case of Novosibirsk, with relatively low annual investments and high recovery rates, shows that efficiency in solid waste management depends more on the structuring of processes and adopted policies than solely on the amount of funding.

Figure 3 shows significant differences between the Brazilian and Russian capitals that were evaluated. Among the Brazilian cities, São Paulo stood out as the most efficient, achieving a maximum index of 1, setting the benchmark within the group. Other Brazilian capitals with relatively high performance were Rio de Janeiro (0.8558) and Fortaleza (0.7407), indicating that, despite high costs, these cities are capable of structuring their solid waste management more efficiently. On the other hand, cities such as Curitiba (0.2401), Belo Horizonte (0.2933), and Salvador (0.3379) presented low levels of efficiency.

Figure 3 – Efficiency of Urban Solid Waste Management: Brazilian and Russian Capital Cities



Source: Research data (2025).

In the Russian context, significant contrasts can also be seen. The most efficient cities were Saint Petersburg, Novosibirsk, and Sochi, all with efficiency scores of 1. These results indicate that, even with budgets lower than those of Brazilian cities, these cities achieved proportional or superior results in terms of collection and, especially, material recovery. A striking example is Novosibirsk, which recovers approximately 700,000 tons of materials per year, with expenses of only R\$249,000, demonstrating a highly streamlined management model. In contrast, Kazan (0.0297) and Yekaterinburg (0.1543) were the least efficient in the Russian group, with low recovery rates and a greater imbalance between resources used and results achieved (Figure 3).

Brazilian capital cities tend to have significantly higher expenditure than their Russian counterparts. Nevertheless, this does not necessarily mean greater efficiency. While São Paulo and Rio de Janeiro achieved good results, other capitals

with high expenditure did not show proportional efficiency. In the Russian case, even with lower investment, material recovery rates are generally higher. Thus, the analysis indicates that efficiency in urban solid waste management depends less on the absolute volume of resources invested and more on how these resources are applied. Cities that focus on structuring processes and material recovery, even with lower budgets, tend to achieve better results.

FINAL CONSIDERATIONS

This study showed the context of some of the environmental challenges facing the BRICS countries, especially urban solid waste management. Given the importance of the bloc's economies and population, evidenced by its significant contribution to global waste generation, the aim was to understand the practices and results of its USW management. The research was conducted comparatively, using the data available only on Brazil and Russia, as data on the other countries were limited.

The main goal of this study was to evaluate the efficiency of urban solid waste management in the BRICS countries, with an emphasis on comparing Brazilian and Russian cities. Data Envelopment Analysis (DEA) was used to assess variables such as annual urban cleaning expenses, total waste collection, and volume of materials recovered. The results showed that São Paulo had the best performance of the Brazilian cities. Meanwhile, in Russia, Saint Petersburg, Novosibirsk, and Sochi stood out, with efficiency indices of 1, demonstrating more streamlined and effective practices, despite lower financial investment.

It should be highlighted that cities with larger populations and larger volumes of waste are not always the most efficient. There tend to be better outcomes when there is an adequate public structure and enforced policies. The Russian cities, despite much lower budgets, were more efficient than the Brazilian cities in terms of recovery. This stresses the importance of quality processes rather than only focusing on the resources available.

On the other hand, it is important to mention the limitations of this study. The main concern is the availability and updating of data. It was not possible to include every BRICS city or even country in the DEA model application due to the lack of standardized and updated variables in public databases. Furthermore, some of the data analyzed referred to different years, which may preclude accurate comparisons of the analyzed units. Another limitation was the choice of variables used as inputs and outputs in the DEA model, which, while appropriate, did not address all the relevant dimensions for a more comprehensive assessment of waste management.

Therefore, future research should employ a wider range of data, seeking to include the other BRICS countries and new variables, such as social, environmental and institutional factors associated with waste management. Another suggestion is to conduct longitudinal studies that monitor the evolution of efficiency over time, considering possible impacts of implemented public policies. Finally, it would be interesting to apply dynamic DEA models and hybrid evaluation techniques, combining qualitative and quantitative analyses, to conduct even more robust diagnoses to aid the formulation of public policies and sustainable development strategies in urban and environmental contexts.

FUNDING

This research was funded by the National Council for Scientific and Technological Development (CNPq), grant numbers 304937/2022-3 and 407021/2023-0.

REFERENCES

ABRELPE. (2022). Panorama dos resíduos sólidos no Brasil 2022. Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais. Link: https://abespb.com.br/wp-content/uploads/2023/12/Panorama_Abrelpe_2022.pdf

Banco Mundial. (2022). World Development Indicators. Link: World Bank. <https://databank.worldbank.org/source/world-development-indicators>

Chang, D. S., Liu, W. & Yeh, L. T. (2013). Incorporating the learning effect into data envelopment analysis to measure MSW recycling performance. *European Journal of Operational Research*, 229(2), 496–504. DOI: 10.1016/j.ejor.2013.01.026

Cordeiro, J., Sarkis, J., Vazquez-Brust, D. et al (2012). An evaluation of technical efficiency and managerial correlates of solid waste management by Welsh SMEs using parametric and non-parametric techniques. *J Oper Res Soc* 63, 653–664 (2012). <https://doi.org/10.1057/jors.2011.22>

Department of Forestry, Fisheries and Environment. (2022). National Waste Management Strategy 2022. Government of South Africa.

Dias, S. M. (2019). Waste pickers and cities. *Environment and Urbanization*, 31(1), 241–256. Disponível em: <https://doi.org/10.1177/0956247816657302>

Godfrey, L., Ahmed, M. T., Gebremedhin, K. G., & Katima, J. H. (2021). Waste management in Africa: an overview. *Environmental Development*, 37, 100590. Disponível em: <https://www.wasterecyclingmag.com/news/waste-management/waste-management-in-africa-an-overview>

Kumar, P., Kumar, P., Sonowal, K., Gulia, S., Dwivedi, N., Raj, B., & Nath, P. (2022). Sustainable municipal solid waste management in india: Feasibility and challenges. *Journal of Environment and Bio-science*.

Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: A global review of solid waste management. World Bank. <https://openknowledge.worldbank.org/handle/10986/17388>

IPEA. (2021). Diagnóstico dos resíduos sólidos urbanos no Brasil. Instituto de Pesquisa Econômica Aplicada.

Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F. (2018). What a waste 2.0: A global snapshot of solid waste management to 2050. World Bank. <https://openknowledge.worldbank.org/handle/10986/30317>

Knothe, R. (2024). Circular Economy Policies in China and the EU A Comparative Analysis with the Extended Policy Mix Concept. Disponível em: <http://hdl.handle.net/20.500.12380/308394>

Medina, M. (2007). The world's scavengers: Salvaging for sustainable consumption and production. AltaMira Press.

Ministry of Housing and Urban Affairs (MoHUA). (2022). Annual Report 2022. Government of India.

National Bureau of Statistics of China. (2022). China Statistical Yearbook 2022. China Statistics Press.

OECD. (2021). Environmental performance reviews: Russian Federation 2021. OECD Publishing.

OECD. (2021). Waste management and circular economy in the Russian Federation. Disponível em: <https://www.oecd.org/environment/waste/>

ONU – Organização das Nações Unidas. (2015). Transformando nosso mundo: a Agenda 2030 para o Desenvolvimento Sustentável. <https://brasil.un.org/sites/default/files/2020-09/agenda2030-pt-br.pdf>

Petrov, K., & Kolomytsev, D. (2020). Waste management reforms in Russia: Policy instruments and environmental effectiveness. *Ecological Indicators*, 115, 106438. <https://doi.org/10.1016/j.ecolind.2020.106438>

Rogge, N. & De Jaeger, S. (2012). Evaluating the efficiency of municipalities in collecting and processing municipal solid waste: A shared input DEA-model. *Waste Management*, 32(10), 1968–1978. DOI: <https://doi.org/10.1016/j.wasman.2012.05.021>

Russian Ecological Operator. (2022). Annual report on solid waste management in Russia 2022. Government of Russia.

Simões, P., Carvalho, P., & Marques, R. C. (2012). Market structure of urban solid waste. Different models, different results. Càtedra Pasqual Maragall d'Economia i Territori–Documents de treball, WP 2X/2012. Disponible em: https://diposit.ub.edu/dspace/bitstream/2445/67763/1/PMM12-02_Simoes.pdf

Stuenkel, O. (2015). The BRICS and the future of global order. Lexington Books.

UNEP – United Nations Environment Programme. (2018). Africa waste management outlook. Nairobi: UNEP. <https://www.sidalc.net/search/Record/oai:wedocs.unep.org:20.500.11822-25514>

UNEP – United Nations Environment Programme. (2021). Global waste management outlook 2021. Nairobi: UNEP.

Wilson, D. C., Velis, C., & Cheeseman, C. (2006). Role of informal sector recycling in waste management in developing countries. *Habitat International*, 30(4), 797–808. <https://doi.org/10.1016/j.habitatint.2005.09.005>

World Bank. (2022). What a waste 2.0: A global snapshot of solid waste management to 2050. World Bank Group.

Yeh, L. T., Chang, D. S. & Liu, W. (2016). The effect of organizational learning on the dynamic recycling performance of Taiwan's municipal solid waste (MSW) system. *Clean Technologies and Environmental Policy*, 18, 1535–1550. DOI: 10.1007/s10098-016-1135-x

Zaman, A. U. & Lehmann, S. (2011). What is the zero waste concept? Disponible em: <https://www.nswai.org/docs/What%20is%20the%20Zero%20Waste%20City%20Concept.pdf>

Recebido: 05/08/2025

Aprovado: 09/09/2025

DOI: 10.3895/rts.v21n66.20678

Como citar:

SILVA, Christian Luiz da; OLIVEIRA, Marta Chaves Vasconcelos de. Urban solid waste management in BRICS countries: a comparative analysis of indicators and efficiency. **Revista Tecnologia e Sociedade**, Curitiba, v. 21, n. 66, p. 91-106, seção temática, 2025. Disponível em:

<https://periodicos.utfpr.edu.br/rts/article/view/20678>

Acesso em: XXX.

Correspondência:

Direito autoral: Este artigo está licenciado sob os termos da Licença Creative Commons-Atribuição 4.0 Internacional.

