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Overview of Circular Economy Indicators in the City: Bratislava

Przegląd wskaźników gospodarki o obiegu zamkniętym w mieście na przykładzie Bratysławy

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Abstract

The transition from a linear to a circular economic model is a critical response to the environmental, social, and economic challenges facing urban areas. This study examines the role of cities, particularly Bratislava, in implementing circular economy principles. It highlights the need for appropriate indicators to assess circularity at the municipal level. Drawing upon a comprehensive review of academic literature, strategic municipal documents, and direct consultations with stakeholders, the study proposes a set of 27 indicators grouped into three core dimensions: environmental, economic-financial, and cultural-social. These indicators reflect key areas such as waste management, resource efficiency, public procurement, and citizen engagement. The indicators are further categorized into three priority levels (A–B–C) based on their relevance and data availability. The results reveal both promising trends—such as decreasing municipal waste landfilling rates—and persistent challenges, including insufficient recycling rates and data limitations in sectors such as energy and procurement. The absence of a unified methodological framework for monitoring circular economy progress at the city level remains a major obstacle. The study highlights the necessity of developing standardized and context-sensitive indicator systems that allow cities to systematically track, compare, and improve their circular strategies. The findings underscore the importance of continued interdisciplinary research and collaboration among public institutions, academia, and society in advancing the circular economy agenda.

Keywords

circular economy, sustainable city, city indicators, Bratislava, SDG 11: Sustainable Cities and Communities, SDG 12: Responsible Consumption and Production

Streszczenie

Przejście od liniowego do cyrkularnego modelu gospodarczego stanowi kluczową odpowiedź na wyzwania środowiskowe, społeczne i ekonomiczne, przed którymi stoją obszary miejskie. Niniejsze opracowanie analizuje rolę miast, w szczególności Bratysławy, we wdrażaniu zasad gospodarki o obiegu zamkniętym. Podkreśla ono konieczność stosowania odpowiednich wskaźników umożliwiających ocenę poziomu cyrkularności na poziomie miejskim. W oparciu o kompleksowy przegląd literatury naukowej, strategicznych dokumentów miejskich oraz bezpośrednich konsultacji z interesariuszami, badanie proponuje zestaw 27 wskaźników pogrupowanych w trzy kluczowe wymiary: środowiskowy, ekonomiczno-finansowy oraz kulturowo-społeczny. Wskaźniki te odzwierciedlają najważniejsze obszary, takie jak gospodarka odpadami, efektywne gospodarowanie zasobami, zamówienia publiczne oraz zaangażowanie mieszkańców. Dodatkowo, wskaźniki te podzielono na trzy poziomy priorytetów (A–B–C), uwzględniając ich znaczenie oraz dostępność danych. Wyniki ujawniają zarówno obiecujące tendencje—takie jak spadek udziału składowania odpadów komunalnych—jak i utrzymujące się wyzwania, w tym niewystarczające wskaźniki recyklingu oraz ograniczenia danych w sektorach takich jak energetyka i zamówienia publiczne. Istotnym problemem pozostaje brak ujednoliconych ram metodologicznych do monitorowania postępów gospodarki o obiegu zamkniętym na poziomie miejskim. Badanie podkreśla konieczność tworzenia zestandaryzowanych i jednocześnie uwzględniających kontekst systemów wskaźników, które umożliwią miastom systematyczne śledzenie, porównywanie i doskonalenie swoich strategii gospodarki cyrkularnej. Uzyskane wyniki podkreślają znaczenie dalszych interdyscyplinarnych badań oraz współpracy pomiędzy instytucjami publicznymi, środowiskiem akademickim i społeczeństwem w realizacji programu gospodarki o obiegu zamkniętym.

Słowa kluczowe

gospodarka o obiegu zamkniętym, zrównoważone miasto, wskaźniki miejskie, Bratysława, SDG 11: Zrównoważone Miasta i Społeczności, SDG 12: Odpowiedzialna Konsumpcja i Produkcja

1. Introduction

The term “circular economy” began to develop in the 1970s following the pioneering work of Boulding “The Economics of the Coming Spaceship Earth” on the observation of physical and thermodynamic limits placed on human societies (Boulding, 1966; Greer et al., 2021). The origin and foundations of the circular economy concept can be traced to the “cradle to cradle” principle (Winans et al. 2017). This principle was first introduced by German chemist Michael Braungart and American architect William McDonough in their book *Cradle to Cradle: Remaking the Way We Make Things*. It represents an approach inspired by nature, where, within biological processes, no waste is generated; rather, anything that could become waste is utilized as a nutrient for biological organisms (Braungart 2009). Another significant contribution to the discourse on adopting the circular economy concept and adhering to its principles according to Klimska (2022) was the book *Economics of Natural Resources and the*

Environment, published in 1990 by Pearce and Turner. This publication conceptualized the natural environment as a system that assimilates waste, functioning as a closed loop that directly absorbs the waste it produces. However, it emphasized that the environment cannot assimilate the waste generated by production and consumption processes, thus transforming into a repository for excess waste. This perspective highlighted the necessity of transitioning from a traditional economic model to a circular economy, which advocates for a balanced and sustainable interaction between the environment and economic activity.

We live in an era where more than 55% of the global population (75% in Europe) resides in cities, and this proportion continues to grow. It is projected that by 2050, the Earth's population will reach 9-10 billion, with 70% of them (85% in Europe) living in urban environments. Cities, and especially large metropolitan areas, are the driving force of the global economy – today, 85% of global GDP is generated in urban areas. At the same time, cities are responsible for producing up to 70% of global greenhouse gas emissions, 50% of global waste production, and represent two-thirds of global energy demand (EIB 2024). As noted in (Jastrzebska 2022), cities ought to assume a central role in implementing sustainable development in accordance with the principles of the circular economy.

It is often stated that "what cannot be measured cannot be improved," experts, policymakers, and researchers emphasize the need for the development of methodological frameworks to measure the circular economy. According to a study by the OECD (2020), measuring the current state, progress, and impacts of the circular economy serves four main purposes: raising awareness, providing arguments in favour of the circular economy, stimulating actions and initiatives, and monitoring performance to evaluate achieved results.

In the study of circular economy indicators (OECD 2020), more than 400 indicators related to the circular economy were collected between 2018 and 2020. The study classifies these indicators into five main categories, which are displayed in the following figure 1. The environmental sector has the highest share of indicators (39%).

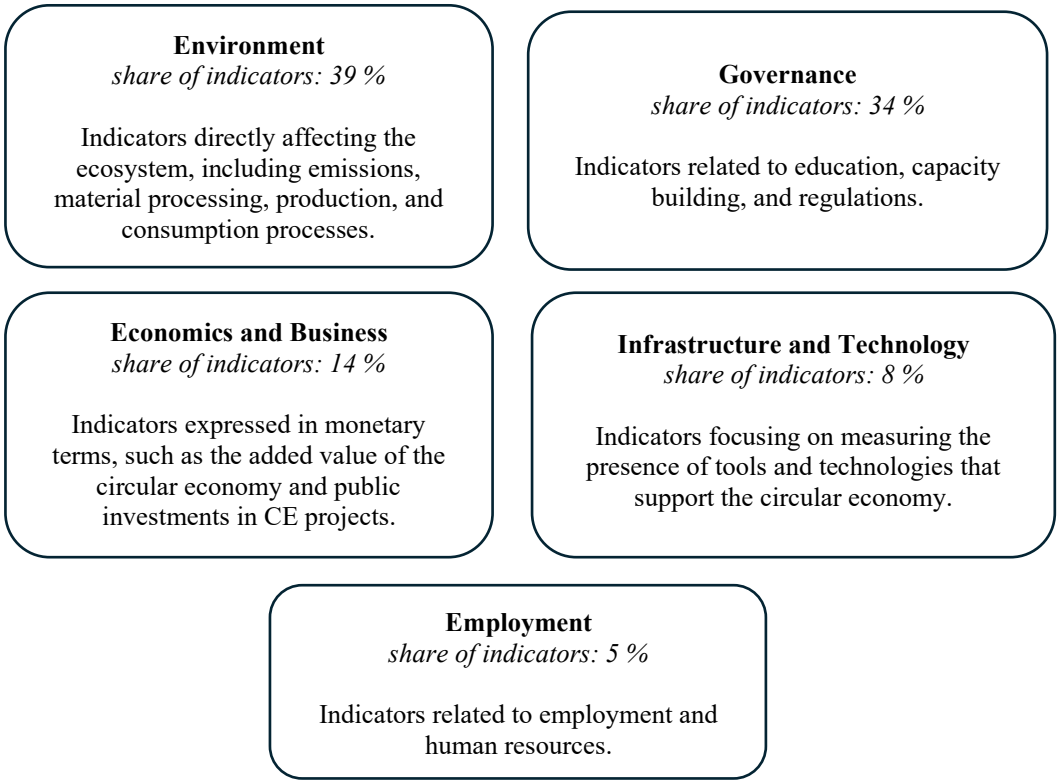

Figure 1: Circular economy indicators classified into 5 main categories. Source: Own elaboration based on data from (OECD 2020).

Given the focus of this study, it is not necessary to analyse all 400 circular economy indicators in detail, as these pertain to the broader monitoring of the circular economy at the national level. Our goal is to focus exclusively on the circular economy indicators that are applicable to the urban - city level.

2. Circular City Indicators

In recent years, there has been growing interest among European cities in the concept of the circular city, which builds upon the broader idea of the circular economy. Many studies (Girard and Nocca 2019; Gravagnuolo et al. 2019; Birgovan et al. 2022; Foster and Saleh 2021; Paoli and Pirlone 2022; Kopp et al. 2024; Cavaleiro de Ferreira et al. 2019; Paiho et al. 2020) confirm that cities, when assessing their progress in transitioning to a circular economy, typically adopt their own methodologies and indicators, resulting in discrepancies in the metrics used. There is no universally agreed-upon set of indicators that all cities apply in a standardized approach.

The following Table 1 presents a list of recommended indicators proposed within the framework of the “Urban Agenda for the EU” Partnership on Circular Economy. This initiative, coordinated and supported by the European Commission, aims to strengthen the urban

dimension of EU policy through multilevel governance and stakeholder collaboration. These indicators were developed based on mapping and feedback gathered during a workshop on circular economy indicators for cities held in Brussels in 2018. The indicators were evaluated according to three main criteria: relevance for measuring the circular economy in cities, availability and quality of data at the city level, and the influence of local governments on the respective indicator.

The Urban Agenda for the EU is embedded within the broader strategic context of the European Green Deal and the Circular Economy Action Plan, which outline the EU's commitment to transitioning towards a sustainable and resource-efficient economy. Eurostat plays a key role in this process by maintaining the EU monitoring framework on the circular economy, which includes a set of thematic indicators covering production and consumption, waste management, secondary raw materials, competitiveness and innovation, and global sustainability.

Table 1: List of recommended circular city indicators

This table presents the recommended circular city indicators in the field of municipal solid waste management, selected from the Urban Agenda for the EU (2019). The indicators are ordered according to the level of influence that local authorities can exert on them, which helps identify those areas where municipal policy can most effectively support the transition towards a circular economy.

Area	Category	Indicator
Production and consumption	Self-sufficiency for raw materials	Input of virgin materials per capita Water used for production processes and domestic water consumption
Production and consumption	Green Public procurement	Share of major procurement that includes environmental requirements
Waste management	Waste generation	Annual amount of solid waste (domestic and commercial) All waste for all industry sectors Waste Electrical & Electronic Equipment (WEEE) Generation Hazardous Waste Campaign and events on circular transformations and waste prevention Generation of food waste Recycling rate (% of the solid waste that is recycled)
Secondary raw materials	Contribution of recycled materials	Circular material use rate in economic processes Activities performed by cities to encourage of CE design measures
Competitiveness	Patents	Patents related to recycling and secondary raw materials
Investments and employment	Employment	Direct jobs in CE Number or circular economy businesses offered business support Budget amount allocated to calls for projects on CE Number of pilot project on CE Number of students trained in CE
Overarching indicators	Emissions	Greenhouse bases

Source: Selected from Urban Agenda for the (EU 2019).

The authors Girard and Nocca (2019) examined indicators, which they divided into two groups. The first group is based on theoretical works and represents potentially useful metrics for assessing a circular city; however, their practical applicability is often limited by a lack of data. The second group of indicators is derived from case studies and represents proven tools that have already been applied in practice. This research emphasizes the need for combining theoretical concepts with empirical experiences in developing measurement systems for circular cities. Several studies (Birgovan et al. 2022; Paoli and Pirlone 2022) suggest that indicators should be divided into three main dimensions:

1. **Environmental dimension:** tracks environmental aspects such as waste generation, energy consumption, greenhouse gas emissions, water usage. The key environmental indicators include: municipal waste per capita, the waste sorting rate, the share of renewable energy sources of urban buildings, the share of recycled materials in construction, the city's carbon footprint and waste consumption per capita.
2. **Economic and financial dimension:** considers economic indicators such as innovation, employment in green sectors, investments in research and development, and local economic value creation. The economic and financial indicators include: the number of circular start-ups, the share of employees in green and circular sectors, the volume of public procurement incorporating circular criteria, and investment in research and development of circular solutions.
3. **Cultural and social dimension:** reflects social and cultural aspects, such as citizen engagement, participation in community projects, education levels, and the preservation of cultural heritage. The cultural and social indicators include: the number of historical buildings undergoing adaptive reuse (as a proportion of total heritage sites), the level of citizen engagement in community activities, and the number of educational campaigns, volunteer events and workshops related to the circular economy.

This three-dimensional framework is crucial because it enables a comprehensive assessment of a city's progress in implementing the circular economy, taking into account not only technical and environmental factors but also social and economic aspects. In assessment of a city's progress in transforming into a circular city, it is important to monitor indicators that collectively cover environmental, economic-financial, and cultural-social aspects.

3. Methods

We conducted a thorough analysis of available scientific studies related to circular economy indicators in order to gain an overview of the methods for monitoring and assessing the implementation of this economic model in urban settings. Based on this analysis, we identified key indicators that enable effective tracking of progress and evaluate the success of circular economy implementation at the city level. However, it is important to emphasize that there is no single, universal set of indicators applicable to all cities, as each city has its specific

conditions. This means that there is no one-size-fits-all methodology for measuring the achieved level of circular economy.

In our approach, we did not conduct a formal systematic literature review such as frequency analysis of indicators across studies. Instead, the selection of indicators was primarily guided by the availability and quality of data specific to the city of Bratislava. This pragmatic approach allowed us to tailor the indicator set to the local context, ensuring feasibility and relevance for municipal-level monitoring. However, we acknowledge that this method may limit the generalizability of the indicator set to other cities with different data infrastructures. This limitation is important to consider when interpreting the results and comparing them across urban contexts.

3.1. Research Object

Bratislava is the capital city of the Slovak Republic and also the largest city in the country. The population of the capital city is approaching half a million inhabitants, while on working days, the city is visited by approximately another two hundred thousand people from the surrounding areas. The city of Bratislava is organized into five districts, which are further subdivided into seventeen city parts. According to data from the Statistical Office, by the end of 2023, Bratislava had a recorded population of 477,481 residents, 250,083 residential units, and 40,108 family houses. The total area of the city is 367.6 km² (Štatistický úrad SR 2023).

Figure 2: Bratislava – city districts overview. *Source: (Magistrát Hlavného Mesta Bratislava 2022).*

3.2. Data Sources

The selection of relevant data sources is crucial for our research. Therefore, we have decided to obtain information to analyze indicators from the following sources:

1. **Statistical Office of the Slovak Republic**: A source of data focused on waste management in the city of Bratislava.
2. **Annual Reports**: A source of quantitative and qualitative data from companies active in the city of Bratislava, primarily DPBA, OLO, and BVS.
3. **Strategic Documents**: A source of data from municipal, regional, and national documents that contain strategies and plans related to waste and circular economy management, as well as future directions (e.g., Bratislava 2030, Action Plan, SECAP, Bratislava Zero Waste, European Investment Bank, OECD).
4. **Scientific Studies**: A source of information from relevant literature, including scientific articles, case studies, conference proceedings, and books, addressing circular economy and its application at the city level.
5. **Interviews and Electronic Communication**: This form of data source was utilized through collaboration with representatives from the Bratislava City Hall and the INCIEN Institute.

Based on scientific articles, as well as available city-level information, we have formulated a set of indicators for evaluating and monitoring progress in the implementation of circular economy principles. These indicators have been selected in three main areas: environmental, economic-financial, and socio-cultural, with a focus on waste management, transportation, the private sector, construction, public procurement, and emissions. For each of these areas, we proposed relevant indicators, for which we aimed to obtain data for at least the past two years.

The final indicator set was shaped by the availability of reliable and consistent data in Bratislava. While this ensured practical applicability, it also means that the selected indicators may reflect local data constraints rather than a universally applicable framework. This context-specific adaptation should be considered when comparing results with other cities or applying the methodology elsewhere.

These indicators were subsequently organized into a single list and divided into three levels (A-B-C), which represent different priorities and significance for the process of

implementing the circular economy in the city. The indicators within each level are arranged according to their contribution to monitoring progress and the effectiveness of circular economy implementation.

4. Results

Table A1 (Appendix 1) presents the indicators that, based on our research findings, are considered beneficial for implementation and monitoring within the city context. In total, 27 indicators related to the adoption of the circular economy in urban environments were identified.

The prioritization of these indicators was guided by a combination of factors, including the availability of reliable data in Bratislava, their alignment with the city's strategic objectives, and their potential for international comparability. This multi-criteria approach ensured that the selected indicators are both locally applicable and relevant within broader European policy frameworks. However, it should be noted that the prioritization reflects the specific data infrastructure and strategic context of Bratislava and may not be directly transferable to other urban settings without appropriate adaptation.

4.1. "A" Level Indicators

This level includes five key indicators that we have identified as the most significant in terms of evaluating the transition to a circular economy. These environmental indicators are supported by available data and strategic objectives set by the city, which enables their effective comparison and objective evaluation. Based on this analysis, it is possible to accurately assess the effectiveness of implementing circular economy principles in waste management within the capital city.

The selection of "A" level indicators was particularly influenced by their strong alignment with Bratislava's municipal priorities and the availability of consistent time-series data. Additionally, these indicators were assessed for their relevance to EU-level monitoring frameworks, such as those maintained by Eurostat, to enhance their comparability across cities.

4.1.1. Municipal Waste per capita (kg/year)

One of the fundamental indicators for evaluating the transition to a circular economy is the amount of municipal waste generated per inhabitant per year. The expected and desired trend for this indicator is a gradual decrease, which aligns with the principles of a circular

economy. Reducing waste generation and overall consumption is a key factor for achieving environmental sustainability and effective waste management within the city.

In 2023, the amount of municipal waste generated per capita in the capital was 411 kg, which represents a slight decrease of 2 kg compared to the previous year. In comparison with the European average, which reached 511 kg per capita in the same period, the amount of municipal waste generated in Bratislava was one-fifth lower, or 100 kg less per capita, compared to the EU average for 2023. This substantial gap between Bratislava and the EU average suggests a relatively strong performance in municipal waste management, however, further reductions in waste generation will require the introduction of systematic measures supporting waste prevention (such as the KOLO reuse centre) and more efficient sorting and recycling mechanisms.

4.1.2. Municipal Waste Sorting Rate (%)

The rate of municipal waste sorting is another key indicator of the effectiveness of implementing circular economy principles. In 2023, this rate in the capital city was 39.66%, representing a year-on-year increase of 1.52%. Despite the positive trend, Bratislava lags behind the average of the 30 largest cities in Slovakia, the average is 46.93% for the same period. This difference indicates significant room for improvement in waste sorting and optimization of waste management processes.

In the context of its long-term strategy for transitioning to a circular economy, the city has set ambitious goals—to increase the municipal waste sorting rate to at least 45% by 2026 and to reach 65% by 2035. To meet the near-term goal, the sorting rate must increase by another 5.36% by 2026. This will require systematic measures, such as improving the infrastructure for sorted collection and enhancing environmental awareness among residents.

Successful implementation of these measures will have a significant impact on reducing the volume of mixed waste, contributing not only to achieving the set goals but also to the long-term sustainability of waste management in the capital.

4.1.3. Municipal Waste Recycling Rate (%)

The recycling rate of municipal waste is one of the most important indicators of the effectiveness of transitioning to a circular economy. In 2023, this indicator in the capital city reached 26.1%, reflecting a year-on-year decrease of 2.7% compared to 2022. This unfavourable trend contradicts the goal of gradually increasing the recycling rate and highlights the need for substantial measures to support recycling processes and infrastructure.

The insufficient level of recycling could result from a combination of factors, including limited capacity of recycling facilities, low motivation among the population to separate waste, and inefficient waste collection and processing mechanisms.

As part of its environmental strategy, the city has set a target to achieve at least 40% recycling rate for municipal waste by 2026. To achieve this goal, extensive investments in modernizing recycling facilities and strengthening informational campaigns to raise public awareness about the importance of recycling will be necessary.

4.1.4. Recycling and Material Recovery Rate of Municipal Waste (%)

The combined recycling and material recovery rate of municipal waste is another important indicator of the effectiveness of transitioning to a circular economy. In 2023, this rate reached 41.69%, representing a year-on-year increase of 0.59%. Although this is a positive trend, the rate of growth remains relatively slow and indicates the need for more intensive measures to support recycling and waste recovery processes.

In the context of this study, "recycling" refers specifically to the reprocessing of municipal waste into new materials and products, excluding energy recovery and other forms of treatment. "Material recovery," on the other hand, encompasses a broader set of processes, including recycling, composting of biodegradable waste, and other non-energy recovery methods that result in the diversion of waste from landfills. Energy recovery (e.g., incineration with energy capture) is not included under either term in this analysis. The distinction between the two indicators—Municipal Waste Recycling Rate (%) and Recycling and Material Recovery Rate (%)—is important for understanding the depth and scope of circular economy practices. Tracking both indicators allows for a more nuanced assessment: the recycling rate provides insight into the effectiveness of material reuse, while the broader recovery rate reflects the overall efficiency of waste diversion strategies.

To achieve the long-term goal set by the city—reaching at least 65% recycling and material recovery by 2035—systemic solutions aimed at optimizing waste processing processes will be necessary. Long-term increases in this indicator will require not only technical and logistical improvements but also systematic efforts with the population in the areas of environmental education and motivation for proper waste sorting. Successful implementation of these measures will have a crucial impact on fulfilling the goals of the circular economy and reducing the environmental burden of the municipal waste.

4.1.5. Municipal Waste Landfilling Rate (%)

The landfilling rate of municipal waste is a critical indicator of a successful transition to a circular economy, as landfilling is the least sustainable method of waste management from both an environmental and economic perspective. In 2023, the landfilling rate in the capital city was 6.7%, representing a year-on-year decrease of 2.23%. This trend is extremely positive, as the city's goal for 2026—to landfill less than 10%—has been achieved for the third consecutive year.

In the long-term vision for transitioning to a circular economy, the city has set an even more ambitious goal—to reduce the landfilling rate of municipal waste to below 5% by 2035. The current decrease suggests that this goal is achievable in a relatively short time frame, however achieving it will require continued development of alternative waste management methods.

Key measures for further reducing landfilling will include investments in modern facilities for energy and material recovery, expanding recycling capacities, and intensifying public participation in waste sorting. Legislative regulation and economic mechanisms that encourage more efficient use of secondary raw materials and the minimization of waste going to landfills will also play an important role.

4.2. "B" Level Indicators

The indicators at this level predominantly consist of environmental metrics, with two exceptions that fall under the economic-financial category, relating to public procurement with elements of the circular economy. Most of the indicators at this level are currently recorded and monitored by the city, which we view as a positive step toward improving the sustainability and efficiency monitoring of urban policies. However, more ambitious goals are lacking—goals which would clearly define the city's direction in transitioning to a circular economy. While there are strategic efforts, such as increasing the share of public, pedestrian, and cycling transportation to 70%, supporting the smooth operation of public transport, and reducing energy consumption in residential, municipal, and private buildings through the use of renewable energy sources, some key indicators are still not monitored systematically. We have identified a number of indicators for which data is currently unavailable:

Water Loss Indicator: No current data on water leaks within the distribution system in the city.

Greenhouse Gas Emissions from Buildings, Waste, and Transport: Available data only covers the year 2022, and for a systematic evaluation of trends and the effectiveness of measures, continuous monitoring would be appropriate.

Share of Renewable Energy: Relevant and reliable data on the share of renewable energy in the city's consumption is missing.

Indicators Related to Public Green Procurement: Data is not yet publicly available or evaluated. For the purposes of our research, we obtained data directly from the public procurement department. While the share of green public procurement has increased year-on-year, the financial volume has decreased by nearly 11 million euros.

As part of the action plan for 2024, the city has declared its intention to introduce systematic monitoring, data collection, and subsequent evaluation of these indicators. This process is to be carried out by the Climate Office; however, the document does not specify the timeframe within which these indicators will be fully implemented.

4.3. "C" Level Indicators

The indicators in this group represent the lowest priority in terms of implementation, monitoring, and evaluation within the transition to a circular economy. Based on our findings, their introduction would yield a lower benefit compared to the indicators classified in groups A and B.

Given the current state of implementing the principles of the circular economy in the city, we view these indicators as prospective areas for monitoring that may become relevant in the long term. They offer potential inspiration for future strategies, but their introduction is not currently essential.

The city currently does not possess any data that would enable evaluation of these indicators, and in the near future, there are no plans to introduce systematic monitoring of these areas. However, this does not imply that they should be entirely disregarded—gradually incorporating them into analytical and strategic documents could, in the future, contribute to a more comprehensive assessment of sustainability and the effectiveness of the transition to a circular economy.

5. Discussion

The lack of a unified methodology and the limited availability of sustainability data for cities are also reflected in the international context. An example is the analysis *European Green*

City Index published in 2009 by the Economist Intelligence Unit. In the ranking of 30 European capitals, the city of Bratislava placed 20th. The study focused on indicators related to air quality, emissions, energy consumption, transport infrastructure, as well as waste and water resource management (EIU 2009). It is important to note that over the past 16 years, the city has not been included in any similar international comparative analysis, once again highlighting the challenge of data availability and the lack of systematic evaluation. Regular implementation of such assessments could contribute to better tracking of progress and greater comparability of results between cities.

One of the most recent research studies identified challenges related to indicators for the circular economy that align with our findings. Key issues include inadequacy and low relevance of current indicators, which hinder cities' ability to effectively monitor and evaluate progress. These indicators are often not sufficiently tailored to the specific goals and needs of local circular economy strategies, limiting their ability to provide reliable data on goal achievement. Furthermore, these problems with indicators complicate the objective assessment of progress in relation to sustainable development goals, thereby restricting cities' ability to make informed decisions and effectively evaluate the efficiency of implemented circular economy strategies (Kopp et al. 2024).

To address these challenges, we propose a practical decision-making framework for selecting and prioritizing circular economy indicators at the city level. This framework is based on four key criteria: (1) measurability – the indicator must be supported by reliable and consistent data; (2) data availability – the indicator should be feasible to track using the existing municipal or national data sources; (3) alignment with strategic objectives – the indicator must reflect the city's policy goals and sustainability targets; and (4) environmental impact – the indicator should capture meaningful outcomes related to resource efficiency, waste reduction, or emissions mitigation.

5.1. Recommendations

For effective monitoring of progress in the field of circular economy, it is essential to extend data tracking and collection to areas beyond waste management. A comprehensive analysis of a broad spectrum of factors influencing the transition to a circular economy will enable a more accurate assessment of the impacts of individual measures. At the same time, it is crucial to work on developing a unified methodology for monitoring and evaluating the circular economy at the municipal level.

5.2. Limitations of the study

We are aware of certain limitations of this research, as we were constrained by the availability of data accessible to us. The fact that some data is currently unavailable does not imply that it does not exist; it may be internal and restricted from disclosure for administrative reasons, despite our repeated requests for access. Until the relevant data is verified and made available, we consider it non-existent for the purposes of this study. Another limiting factor is the available relevant literature and scientific studies we had access to. Due to the language barrier, we focused exclusively on literature in English, Slovak, and Czech. Despite these limitations, we have strived to provide as objective a description and analysis as possible regarding the implementation of the circular economy at the municipal level and the associated evaluation of indicators.

6. Conclusion

Society faces the inevitable challenge of transformation, with a key step being the transition to a sustainable operating model that will replace the current linear economic approach with a circular one. This transition is essential not only for mitigating the negative impacts of climate change but also for ensuring the long-term resilience and competitiveness of cities.

A key finding of this study is the absence of a unified framework of indicators and methodologies for the regular monitoring of progress in the implementation of the circular economy. This lack of consistent monitoring and evaluation represents a significant limiting factor in achieving the established goals. At the same time, it is necessary to emphasize that not all proposed indicators are equally relevant or necessary at the current stage of implementing the circular economy in Bratislava. The city is primarily focusing on evaluating and monitoring environmental impacts, which is fully understandable given the limited budget and the need to concentrate on key areas. We commend the initiative of the capital city in collaboration with the EIB in the development of indicators and monitoring of the circular economy in the construction sector, which is planned to be realized within the next three years.

For these reasons, the discussion and examination of the implementation of the concept of a circular city – particularly the methods of its implementation and subsequent monitoring – represent a promising area of research. The growing number of circular cities and the increasing interest in this topic will stimulate further research and enable the realization and gradual improvement of the indicators presented in this study.

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References

Bîrgovan, Andreea Loredana, Elena Simina Lakatos, Andrea Szilagyi, Lucian Ionel Cioca, Roxana Lavinia Pacurariu, George Ciobanu, and Elena Cristina Rada. 2022. "How Should We Measure? A Review of Circular Cities Indicators." *International Journal of Environmental Research and Public Health* 19 (9): 5177. https://doi.org/10.3390/ijerph19095177.

Boulding, Kenneth Ewart. 1966. "The Economics of the Coming Spaceship Earth." *Environmental Quality in a Growing Economy*, edited by Henry Jarrett, 3–14. Baltimore: Johns Hopkins University Press.

McDonough, William, and Michael Braungart. 2009. *Cradle to cradle: Remaking the way we make things*. London: Vintage.

Cavaleiro de Ferreira, António, and Francesco Fuso-Nerini. 2019. "A Framework for Implementing and Tracking Circular Economy in Cities: The Case of Porto." *Sustainability* 11 (6): 1813. https://doi.org/10.3390/su11061813.

Economist Intelligence Unit. 2009. *European Green City Index*. https://assets.new.siemens.com/siemens/assets/api/uuid:fddc99e7-5907-49aa-92c4-610c0801659e/european-green-city-index.pdf.

European Investment Bank. 2024. *The 15 Circular Steps for Cities*. https://advisory.eib.org/_tools/resources/documents/the-15-circular-steps-for-cities.pdf.

Foster, Gillian, and Ruba Saleh. 2021. "The Adaptive Reuse of Cultural Heritage in European Circular City Plans: A Systematic Review." *Sustainability* 13 (5): 2889. https://doi.org/10.3390/su13052889.

Girard, Luigi Fusco, and Francesca Nocca. 2019. "Moving Towards the Circular Economy/City Model: Which Tools for Operationalizing This Model?" *Sustainability* 11 (22): 6253. https://doi.org/10.3390/su11226253.

Gravagnuolo, Antonia, Mariarosaria Angrisano, and Luigi Fusco Girard. 2019. "Circular Economy Strategies in Eight Historic Port Cities: Criteria and Indicators Towards a Circular City Assessment Framework." *Sustainability* 11 (13): 3512. https://doi.org/10.3390/su11133512.

Greer, Rachel, Timo von Wirth, and Derk Loorbach. 2021. "The Waste-Resource Paradox: Practical Dilemmas and Societal Implications in the Transition to a Circular Economy." *Journal of Cleaner Production* 303. https://doi.org/10.1016/j.jclepro.2021.127012.

Jastrzębska, Ewa. 2022. "Implementation of Sustainable Development Goal 12 in Cities: Best Practices." *Studia Ecologiae et Bioethicae* 20 (3):13-24. https://doi.org/10.21697/seb.2022.17.

Klimska, Agnieszka. 2022. "Circular Economy Education – Challenges for Poland in the Context of Good Practices." *Studia Ecologiae et Bioethicae* 20 (2): 53-65. https://doi.org/10.21697/seb.2022.13.

Kopp, Mira, Anna Petit-Boix, and Sina Leipold. 2024. "Municipal Circular Economy Indicators: Do They Measure the Cities' Environmental Ambitions?" *Sustainable Production and Consumption* 50: 431–44. https://doi.org/10.1016/j.spc.2024.03.009.

Magistrát Hlavného Mesta Bratislava. 2022. *Bratislava 2030: Program rozvoja mesta 2022–2030*. https://bratislava2030.sk/wp-content/uploads/2023/03/B-Analyticka-cast-Bratislava-2030_032023.pdf.

OECD. 2020. *The Circular Economy in Cities and Regions*. https://www.oecd.org/regional/cities/circular-economy-cities.htm.

Paiho, Satu, Elina Mäki, Nina Wessberg, Martta Paavola, Pekka Tuominen, Maria Antikainen, Jouko Heikkilä, Carmen Antuña Rozado, and Nusrat Jung. 2020. "Towards Circular Cities—Conceptualizing Core Aspects." *Sustainable Cities and Society* 59. https://doi.org/10.1016/j.scs.2020.102089.

Paoli, Federica, Francesca Pirlone, and Ilenia Spadaro. 2022. "Indicators for the Circular City: A Review and a Proposal." *Sustainability* 14 (19): 11848. https://doi.org/10.3390/su141911848.

Štatistický úrad Slovenskej republiky. 2023. *Štatistická ročenka hlavného mesta Slovenskej republiky Bratislavy [Statistical yearbook of the capital of the Slovak Republic, Bratislava]*. https://slovak.statistics.sk/PortalTraffic/fileServlet?Dokument=66ec70f7-ed02-442b-95f4-53a07af47e87.

Urban Agenda for the EU. 2019. *Indicators for Circular Economy (CE) Transition in Cities – Issues and Mapping Paper*. https://ec.europa.eu/futurium/en/system/files/ged/urban_agenda_partnership_on_circular_economy_-_indicators_for_ce_transition_-_issupaper_0.pdf.

Winans, K., A. Kendall, and H. Deng. 2017. "The History and Current Applications of the Circular Economy Concept." *Renewable and Sustainable Energy Reviews* 68: 825–33. https://doi.org/10.1016/j.rser.2016.09.123.

Appendix 1: Recommended circular economy indicators for the city of Bratislava

Table A1: Recommended circular indicators for the city of Bratislava

This table summarizes selected circular economy indicators for the city of Bratislava, grouped into categories (A – key, B – additional) and assigned to specific dimensions and sub-dimensions, such as water use or municipal solid waste management. For each indicator, values for 2022 and 2023 are provided, together with the difference between these years and a simple trend symbol (upward or downward arrow), allowing readers to quickly assess whether the results in each area have improved or deteriorated.

Level	Category	Area	Indicator	2023	2022	Year-to-Year Change	Desired Direction
A	Environment	Waste	Municipal waste per capita (kg)	**411**	**413**	**2**	↓
A	Environment	Waste	Municipal waste sorting rate (%)	**40**	**38**	**2**	↑
A	Environment	Waste	Municipal waste recycling rate (%)	**26**	**29**	**3**	↑
A	Environment	Waste	Municipal waste rate of recycling and material recovery (%)	**42**	**40**	**2**	↑
A	Environment	Waste	Municipal waste landfilling rate (%)	**7**	**9**	**2**	↓
B	Environment	Waste	Water consumption per capita (l/day)	**248**	**220**	**28**	↓
B	Environment	Waste	Water loss (%)	-	-	-	↓
B	Environment	Waste	CO_2 equivalent emissions from municipal waste (t/year)	-	**73 330**	-	↓
B	Environment	Transportation	CO_2 equivalent emissions from transportation (t/year)	-	**436 037**	-	↓
B	Environment	Transportation	Number of registered passenger cars per 1 000 inhabitants	**748**	**715**	**33**	↓
B	Environment	Transportation	Number of passengers transported by public transportation annually (millions)	**265**	**224**	**42**	↑
B	Environment	Transportation	Length of main urban bike paths (km)	**147**	**141**	**6**	↑
B	Environment	Transportation	Number of registered electric and hybrid vehicles per 1 000 inhabitants	**68**	**44**	**24**	↑
B	Environment	Private sector	Share of recycled materials in construction (%)	-	-	-	↑
B	Environment	Private sector	Share of renewable energy sources in buildings energy consumption (%)	-	-	-	↑
B	Environment	Emissions	Carbon footprint of the city (t CO_2 eqv./inhabitant)	-	**3,5**	-	↓
B	Environment	Energy	Share of renewable energy sources in the energy consumption of buildings owned by the city (%)	-	-	-	↑
B	Environment	Energy	Energy consumption of buildings owned and managed by the city (MWh)	**168 773**	**179 335**	**10 562**	↓

Level	Category	Area	Indicator	2023	2022	Year-to-Year Change	Desired Direction
B	Economic & Finance	Public procurement	Value of public procurement in the circular economy (million €)	27	38	11	↑
B	Economic & Finance	Public procurement	Share of public procurement in the circular economy (%)	16	15	1	↑
C	Economic & Finance	Private sector	Share of employees in the circular economy (%)	-	-	-	↑
C	Economic & Finance	Private sector	Number of start-ups in the circular economy	-	-	-	↑
C	Economic & Finance	Private sector	Investments in research and development in the circular economy (€)	-	-	-	↑
C	Cultural & Social	Culture	Number of educational campaigns on the circular economy	-	-	-	↑
C	Cultural & Social	Culture	Number of Zero Waste events organized by the city	-	-	-	↑
C	Cultural & Social	Culture	Number of Zero Waste events organized by the private sector	-	-	-	↑
C	Cultural & Social	Culture	Number of historical buildings with adaptive reuse	-	-	-	↑

Source: Own elaboration.