საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 20(194), №2, 2026
BULLETIN OF THE NATIONAL ACADEMY OF SCIENCES OF GEORGIA, vol. 20(194), no. 2, 2026

Economics

Scale-Based Infrastructure Architecture of a Circular Economy

Solomon Pavliashvili

Academy Member, National Academy of Sciences of Georgia, Tbilisi, Georgia

Abstract. Based on a comparative analysis of circular economy infrastructure in Georgia and various small/medium and large EU countries, this paper identifies the key challenges that determine the efficiency of the transformation process. The Circular Economy Performance Index (CEPI) was calculated by integrating circular material use rates, recycling rates, and per capita waste generation. The index evaluates both a country's current circular maturity and the effectiveness of its related policy frameworks. The results indicate that the efficiency of Georgia's circular economy is limited by underdeveloped infrastructure, inadequate recycling systems, and the lack of economies of scale. © *2026 Bull. Natl. Acad. Sci. Georg.*

Keywords: circular economy, waste management, recycling, infrastructure, performance index

Introduction

Country scale has a significant impact on both the type of infrastructure and the ability to achieve economic efficiency. The analysis presented in this paper is based on a classification of countries according to population size. Specifically, large countries are defined as EU member states with populations exceeding 10 million that demonstrate best practices in waste management and circular economy development, including the Netherlands, Belgium, and Italy. In contrast, small countries are defined as EU member states with populations below 10 million, namely Malta, Estonia, and Slovakia. Small countries are characterized by limited domestic markets, which constrain the scale of waste processing, secondary resource recovery, and recycling. As a result, in many cases domestic waste treatment does not meet technological and economic requirements. Small markets are also less attractive to private investors, which increases the importance of flexible, multifunctional, and integrated infrastructural models.

Large countries benefit more from economies of scale, enabling the deployment of circular technologies and the formation of broad domestic markets for secondary raw materials. However, one of the main challenges in large countries is the geographical complexity of infrastructure, the high costs of waste collection and transportation across extensive territories, and the scale of system management, which often reduces the overall efficiency of resource collection and processing (Ndoka, 2023; van Eijk, 2015).

In small countries, the problem takes a different form: the primary barriers are the insufficient scale of recycling infrastructure and the economic non-viability of investments. In this context, market integration, particularly participation in cross-border recycling networks, represents a key mechanism that partially compensates for the lack of economies of scale and enables more efficient resource use. This constitutes an important opportunity for countries that can receive high-quality, separately collected waste not only from within their own borders but also from other states (EEA, 2021). Accordingly, the success of the circular economy largely depends on how effectively countries transform their spatial and scale-related constraints into institutional and infrastructural mechanisms.

Regional inequality constitutes a significant challenge for many countries, as investments, infrastructural capacity, and service provision are typically more developed in urban centers than in peripheral regions (OECD, 2023). High-income countries generally possess more advanced institutional structures and monitoring capacities, which facilitate the effective implementation of circular economy strategies and promote more efficient resource use across sectors.

In small countries, weaker enforcement capacity and institutional fragmentation are frequently observed, making the adoption of simple, integrated, and pragmatic regulatory frameworks particularly important. From a technological perspective, circular infrastructure in large countries tends to rely on capital-intensive solutions and substantial investment in research and development (R&D), whereas in small countries adapted or imported technologies prevail, with an emphasis on low-cost and easily deployable mechanisms (Pavliashvili and Tokmazishvili, 2025).

A further major barrier is the weakness of data infrastructure. The circular economy requires detailed accounting and continuous monitoring of resource flows and waste streams (OECD, 2019). In small countries, the absence of unified and publicly accessible datasets complicates evidence-based policy design, while in large countries data fragmentation across multiple administrative levels remains a persistent challenge.

The lack of systemic coordination represents a common constraint across country contexts. In large countries, this challenge is primarily associated with governance complexity and multi-regional administrative structures, whereas in small countries it is linked to limited market size and underdeveloped logistical networks. In addition, national models often exhibit conceptual limitations that impede the practical implementation of broadly defined policy objectives at the strategic level (Zavos and Pyyhtinen, 2024).

Consequently, circular infrastructure strategies are fundamentally shaped by country scale. In large countries, such strategies are based on the principles of scale and specialization, which, under conditions of a broad domestic market, enable the efficient operation of capital-intensive and technologically advanced systems, while simultaneously increasing the risks of coordination failures and regional inequality. In small countries, comparatively limited volumes of resources and waste, narrow domestic markets, and constrained institutional capacities often create structural barriers to large-scale projects. In these contexts, infrastructure relies less on scale and more on flexibility and integration. As a result, small countries tend to adopt decentralized, multifunctional, and flexible models, in which international and regional cooperation becomes particularly important and is often facilitated by the active involvement of state institutions.

The infrastructural architecture of the circular economy is not universal and requires adaptation to a country's demographic, economic, and spatial characteristics. National economic scale therefore plays a decisive role in shaping appropriate infrastructural models.

Comparative Analysis: Georgia vs. European Countries

European countries exhibit two distinct patterns in circular economy development. Large countries are characterized by high circular material use, stable administrative support, and robust infrastructure, which together ensure an efficient system. In contrast, small and medium-sized countries rely on flexible, integrated infrastructure and regional cooperation to drive increases in the Circular Material Use Rate (CMUR) and maintain effective recycling systems.

In large EU countries such as the Netherlands, Belgium, and Italy, the circular economy is highly developed. CMUR ranges from 21.6% to 32.7% (Eurostat, 2025), recycling rates are 30-60%, and reuse programs are widely implemented. Infrastructure is robust, regionally differentiated, and supported by stable administrative frameworks.

Small and medium EU countries, including Malta, Estonia, and Slovakia, operate in smaller markets but show rapid progress. Over the past decade, CMUR increased by 7-14 percentage points, recycling rates range from 7% to 20%, and waste management relies on flexible, regionally integrated systems. Infrastructure is adapted to smaller markets, with growth-oriented and flexible policies.

In Georgia, CMUR is only 1.3-1.48%, well below the EU average of 11.5%, while per capita waste generation is lower than global and regional averages (World Bank, 2018). Despite low waste, recycling is limited – 4.6% overall and less than 5% for plastics (UNEP, 2023). Recycling and reuse remain largely small-scale private initiatives, and infrastructure is weak, heavily dependent on landfills, and underdeveloped. Existing frameworks, including the Waste Management Code and EPR, are poorly implemented, posing significant challenges to circular economy development (Praseki et al., 2022; Praseki et al., 2024).

Overall, large EU countries combine high CMUR with robust infrastructure and well-established reuse and recycling systems. Small and medium EU countries progress through flexible infrastructure and regional cooperation. Georgia, constrained by limited infrastructure and a small domestic market, lags behind, with its economy remaining predominantly linear.

Circular Economy Performance Index (CEPI)

To evaluate the efficiency of Georgia's circular economy, the Circular Economy Performance Index (CEPI) was employed. CEPI is a composite indicator designed to measure the performance of a country's or organization's circular economy across multiple dimensions.

Assessment of the circular economy increasingly relies on composite indices, which integrate indicators of resource use, waste management, economic value, and environmental impact within a unified analytical framework (Kakulia et al., 2025). This approach reflects the multidimensional

Table 1. Cross-country indicators (2010–2024)

Indicator	Georgia	Small/medium EU countries	Large EU countries
Circular Material Use Rate (CMUR)	1.3-1.48%	7-14%	21.6-32.7%
Recycling Rate	4.6%	7–20%	30-60%
Waste Generation per Capita (per day)	0.6 kg (below average)	Average	Average/High
Reuse Practices	✕ Limited private initiatives	✓ Flexible, integrated programs	✓ Well-developed systems
Infrastructure	✕ Weak, few specialized facilities	✓ Flexible, adaptable, regionally supported	✓ Well-developed market, regionally differentiated model
Strategy / Governance	Legislation, EPR, limited practical implementation	✓ Flexible policies, regional cooperation	✓ Stable administrative support, multi-tiered governance

Source: Eurostat (2024), EEA (2023), UNEP (2023), World Bank (2022), MEPA Georgia (2016), EU–UNDP (2024). World Bank. (2018).

Note: ✓ indicates a positive or well-developed feature; ✕ indicates a limitation or underdeveloped feature.

nature of the circular economy, which cannot be fully captured by a single indicator.

Although various indices have been developed in academic research, scholars highlight the subjectivity inherent in selecting and weighting indicators (Kirchherr et al., 2017).

Based on the combination of quantitative indicators presented in Table 1, we constructed the Circular Economy Performance Index (CEPI), incorporating only those measures for which statistical data are available for cross-country comparison. For each indicator (circular material use, recycling rate, and waste generation per capita) the percentage difference was calculated using the following formula:

$$\text{Diff}\,(\%) = \frac{\text{ValueEU} - \text{ValueGE}}{\text{ValueEU}} \text{x100}$$

The quantitative indicators were normalized to a 0–1 scale using the min–max normalization method, where 0 indicates the lowest performance and 1 indicates the highest performance for a given indicator. The min–max normalization is calculated using the following formula:

$$Normalized\ Score = \frac{\text{ValueGE} - \text{Valuemin}}{\text{aluemax} - \text{Valuemin}}$$

where ValueGE is the actual value of the indicator for Georgia, Valuemin is the minimum value of the same indicator within the comparison group (Georgia, small/medium EU countries, large EU countries), and Valuemax is the maximum value of the same indicator within the comparison group.

For the waste generation indicator, where a lower value represents better performance, an inverted normalization was applied:

$$Normalized\ Score = 1 - \frac{\text{ValueGE} - \text{Valuemin}}{\text{aluemax} - \text{Valuemin}}$$

This index was used to quantify the differences between Georgia's circular economy indicators and those of the European Union and to assess their relative significance. The normalized quantitative indicators were aggregated into a single Composite Circular Economy Performance Index (CEPI). This approach ensures equal weighting of all indicators and prevents any single measure from dominating the overall score, with higher values indicating better circular economy performance.

$$CEPI = \frac{\text{Normalized CMUR} + \text{Normalized RRate}}{3} + \\ + \frac{\text{Normalized WG per Capita}}{3}$$

Thus, Circular Material Use Rate (CMUR) highlights structural differences between Georgia and the European Union. CEPI is lowest in Georgia (0.333), as both the recycling rate and CMUR remain low despite relatively modest waste generation. In small and medium-sized EU countries, CEPI is slightly higher (0.391), reflecting more effective recycling practices (RR) and greater circular material use (CMUR). This suggests that Georgia's circular economy is gradually approaching the level of small and medium European countries.

Large EU countries have the highest CEPI (0.572), driven by advanced practices in circular material use and recycling, despite generating the highest per capita waste.

Conclusion

Large European countries achieve high circular economy performance due to sufficient waste volumes, capital, and market size, which support investment in specialized recycling technologies and enable full economies of scale. Small and

Table 2. Circular economy performance index (CEPI)

Circular material use rate (CMUR, normalized)	Recycling rate (RR, normalized)	Waste generation per capita (WG, normalized)	CEPI
Georgia	0	0	1
Small/Medium EU Countries	0.35	0.157	0.667
Large EU Countries	1	0.717	0

medium European countries offset scale limitations through flexible infrastructure and international or regional cooperation, successfully implementing circular systems even in small markets.

In Georgia, the small size of the domestic market limits economies of scale, weakening incentives for investment in high-tech recycling facilities and maintaining a predominantly linear economic model. In order to develop a circular economy in the context of a ver small economic scale, enhanced international cooperation, cross-border recycling, regional partnerships, and partially export-oriented strategies are essential. This transitional approach enables gradual infrastructure development, reduces technological gaps, and supports the emergence of integrated circular systems.

ეკონომიკა

მასშტაბზე დაფუძნებული ცირკულარული ეკონომიკის ინფრასტრუქტურული არქიტექტურა

ს. პავლიაშვილი

აკადემიის წევრი, საქართველოს მეცნიერებათა ეროვნული აკადემია, თბილისი, საქართველო

სტატიაში საქართველოს, ევროკავშირის მცირე/საშუალო და დიდი ქვეყნების ცირკულარული ეკონომიკის ინფრასტრუქტურული თავისებურებების შედარებითი ანალიზის საფუძველზე იდენტიფიცირებულია ძირითადი გამოწვევები, რომლებიც განსაზღვრავენ ტრანსფორმაციის ეფექტიანობას. გაანგარიშებულია ცირკულარული ეკონომიკის ეფექტიანობის ინდექსი (CEPI), რომელიც აერთიანებს ცირკულარული მასალის გამოყენებას, რეციკლირების კოეფიციენტს და ნარჩენების წარმოქმნას ერთ სულ მოსახლეზე. ინდექსი გამოხატავს ქვეყნის ცირკულარული ეკონომიკის მდგომარეობას და პოლიტიკის ეფექტიანობას. შედეგები აჩვენებს, თუ რამდენად არის საქართველოში ცირკულარული ეკონომიკის ეფექტიანობა შეზღუდული ინფრასტრუქტურის, რეციკლირების სისტემებისა და მასშტაბის ეკონომიის გამო.

REFERENCES

EEA (2021). *Linking cross-border shipments of waste in the EU with the circular economy* (EEA Briefing No. 14/2021). European Environment Agency. https://www.eea.europa.eu/publications/linking-cross-border-shipments-of-waste-in-the-eu-with-the-circular-economy

Eurostat (2025, November 19). *Over 12% of materials in the EU come from recycling* [News release]. European Commission. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20251119-1

Kakulia, N., Chikobava, M., Arghutashvili, V., & Amashukeli, D. (2025). *Tsirkularuli ekonomikis ganvitarebis istoriuli mimokhilva da misi sinergia industrializatsiis fenomentan* [Historical review of the development of the circular economy and its synergy with the phenomenon of industrialization]. *Ekonomisti*, (4), 35-42.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221-232; https://doi.org/10.1016/j.resconrec.2017.09.005

Ndoka, E. (2023). *Barriers and enablers of circular economy: A systematic literature review*, https://www.researchgate.net/publication/381479462_Barriers_and_enablers_of_circular_economy_A_systematic_Literature_Review.

OECD (2019), *Global Material Resources Outlook to 2060: Economic drivers and environmental consequences*, OECD Publishing, Paris, https://doi.org/10.1787/9789264307452-en.

OECD (2020). *The circular economy in cities and regions: Synthesis Report*, OECD Urban Studies, OECD Publishing, Paris, https://doi.org/10.1787/10ac6ae4-en.

OECD. (2023), *OECD Regional Outlook 2023: The longstanding geography of inequalities*, OECD Publishing, Paris, https://doi.org/10.1787/92cd40a0-en.

Pavliashvili, S. & Tokmazishvili, M. (2025). Technological challenges of the circular economy. *Sciences of Europe*, 173, 79-82. https://zenodo.org/records/17237862.

Praseki, D., Pavliashvili, S., Kimeridze, M., & Chelidze, M. (2022). *Sakartvelos ekonomikis tsirkularobis donis shephaseba* [Assessment of the circularity level of the Georgian economy]. Tbilisi, Georgia.

Praseki, D., Pavliashvili, S., Kimeridze, M., & Chelidze, M. (2024). *Tsirkularobis gzamakvlevi sakartvelostvis* [Circularity guide for Georgia]. Tbilisi, Georgia.

UNEP. (2023). *Waste management outlook for Georgia*. United Nations Environment Programme. https://www.unep.org/resources/report/waste-management-outlook-georgia

Van Eijk F. (2015). *Barriers and drivers towards a circular economy*. Acceleratio, Netherlands, European Circular Economy Stakeholder Platform.

World Bank. (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050*. World Bank Publications. https://openknowledge.worldbank.org/handle/10986/30317

Zavos, A., & Pyyhtinen, O. (2024). The limits of waste as a resource: A critique of circular economy scaling. *Cambridge Journal of Regions, Economy and Society, 17*(3), 683-700. Cambridge Political Economy Society. https://doi.org/10.1093/cjres/rsae013

Received February, 2026