

CIRCULAR ECONOMY IN A MULTI-SPEED EUROPE: CLUSTER EVIDENCE FROM EU MEMBER STATES

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The transition towards a circular economy is increasingly important for reducing resource dependency, waste generation and environmental pressures across the European Union. However, Member States differ substantially in their capacity to develop circular production and consumption systems. While some countries achieve high recycling rates, these improvements are not always accompanied by stronger resource productivity, lower material consumption or higher circular material use. The aim of this paper is to examine changes in circular economy performance across the EU-27 between 2014 and 2023. The analysis uses Eurostat data and nine indicators covering circular economy employment, investment and value added, material consumption, resource productivity, municipal waste generation, recycling performance and circular material use. Hierarchical cluster analysis based on Ward's method and squared Euclidean distance was applied separately for both years. The results identify four distinct country profiles in 2014 and 2023, confirming persistent differences in circular economy development across the European Union. The findings show that circular economy progress remains uneven and that improved recycling performance alone does not guarantee a comprehensive transition towards circularity. Stronger investment, resource efficiency and material recirculation are needed to support more balanced circular economy development.

Keywords: circular economy; European Union; cluster analysis; resource efficiency; waste management

Introduction

The transition from a linear "take–make–dispose" model towards a circular economy has become an important policy and research priority due to growing resource depletion, waste generation and environmental pressures (GHISELLINI et al., 2016). Linear production-consumption systems depend on continuous extraction of virgin resources and treat waste as an unavoidable outcome of economic activity (Merli et al., 2018). Such a model is environmentally unsustainable because it exceeds ecological limits and externalises a substantial share of environmental costs (Suárez-Eiroa et al., 2019). The circular economy represents an alternative approach aimed at retaining the value of products, components and materials within the economy for as long as possible (Kirchherr et al., 2017). Its core principles include reducing material inputs, extending product lifetimes, supporting reuse and repair, recycling materials and reducing waste generation at source (Velenturf and Purnell, 2021). Contemporary circular economy research increasingly emphasises that recycling alone does not represent a sufficient indicator of circularity because it addresses materials only after waste has already been generated (Zorpas, 2024). Higher-order strategies, such as refuse, rethink, reduce, repair and reuse, usually preserve more environmental and economic value than recycling or energy recovery (Uvarova et al., 2023). The assessment of circular economy performance remains challenging because the concept covers economic, environmental and material-flow dimensions simultaneously (Kirchherr et al., 2023). Countries may achieve high recycling rates while still reporting high levels of material consumption or municipal waste generation (Colasante et al., 2022). A strong waste-management system therefore does not necessarily indicate that an economy has reduced its dependency on primary resources or achieved effective waste prevention (D'Inverno et al., 2024). Circular economy performance should consequently be evaluated through a multidimensional set of indicators rather than through recycling outcomes alone (Voukkali et al., 2023). The European Union provides a relevant setting for examining these differences because its Member States follow a common policy direction while differing considerably in their economic structures, resource productivity, waste management

capacity and investment in circular sectors (European Commission, 2015). The Circular Economy Action Plan introduced in 2015 strengthened European ambitions in the areas of waste prevention, recycling, resource efficiency and secondary raw materials (European Commission, 2015). The subsequent Circular Economy Action Plan of 2020 further focused on sustainable product design, circular production processes, consumer empowerment and material-intensive sectors (European Commission, 2020). Despite the shared European policy framework, circular economy development remains uneven across Member States (Mazur-Wierzbicka, 2021). Western and Northern European countries generally demonstrate stronger resource productivity, higher recycling performance, more developed secondary material markets and greater investment capacity than many Central and Eastern European countries (Castillo-Díaz et al., 2024). However, the differences between countries cannot be interpreted only through a simple division between leaders and laggards because national profiles often combine strengths and weaknesses across different circular economy dimensions (Claudio-Quiroga and Poza, 2024). For example, a country may perform well in municipal waste recycling but remain weak in circular material use, private investment in circular sectors or raw material efficiency (Colasante et al., 2022). Existing research has increasingly used composite indicators, rankings and multivariate methods to assess circular economy performance across European countries (Mazur-Wierzbicka, 2021). Although composite indices simplify international comparison, they can mask substantial differences in the underlying combinations of economic and environmental characteristics (Castillo-Díaz et al., 2024). Cluster analysis offers a suitable alternative because it identifies groups of countries with similar profiles without reducing circular economy performance to a single score (Hair et al., 2019). This approach makes it possible to distinguish between countries that may reach similar overall results through different development pathways.

This study examines circular economy performance in the EU-27 in 2014 and 2023. The selected period captures changes occurring before and after the implementation of key European circular economy policies, particularly the first Circular Economy Action Plan adopted in 2015 (European Commission, 2015). The analysis uses nine Eurostat indicators representing

circular economy employment, investment and gross value added in circular sectors, raw material consumption, resource productivity, municipal waste generation, circular material use, municipal waste recycling and recycling of waste electrical and electronic equipment. The aim of this paper is to assess changes in circular economy performance across the EU-27 between 2014 and 2023. Using nine Eurostat indicators covering economic engagement in circular sectors, resource use, waste generation, recycling and material recirculation, the study identifies groups of Member States with similar circular economy profiles. Hierarchical cluster analysis is applied to examine whether EU countries have become more similar over time or whether differentiated circular economy pathways persist.

Material and Methods

Data and indicator framework

The analysis was based on country-level data for the 27 European Union (EU) Member States obtained from the Eurostat circular economy monitoring framework (Eurostat, 2026). Two cross-sectional datasets were analysed for the years 2014 and 2023. The year 2014 was selected as the earliest year with complete and comparable data for all indicators, whereas 2023 represented the most recent year available at the time of data extraction.

Nine indicators were selected and grouped into four dimensions: competitiveness and innovation, production and consumption, waste management, and secondary raw materials (Claudio-Quiroga and Poza, 2024). The selected indicators, their measurement units and their expected relationship with circular economy performance are presented in Table 1. The indicator framework reflects the systemic nature of the circular economy, in which economic performance, resource use, waste generation and material recovery are interconnected (Claudio-Quiroga and Poza, 2024).

Cluster analysis

Hierarchical cluster analysis was applied to identify groups of EU Member States with similar circular economy profiles (HAIR et al., 2019). Prior to clustering, all indicators were standardised separately for 2014 and 2023 using z-scores to eliminate differences in measurement units and scales (Everitt et al., 2011). The standardised value was calculated as:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j} \quad (1)$$

where: x_{ij} – the value of variable j for country i ; $\bar{x}_j$ – the mean of variable j ; s_j – the standard deviation of variable j

This step is essential to ensure that no single variable dominates the clustering results due to differences in scale (Everitt et al., 2011)

Hierarchical clustering was performed using Ward's minimum variance method (Ward, 1963). Dissimilarity between countries was measured using squared Euclidean distance:

$$d_{ij} = \sum_{k=1}^p (x_{ik} - x_{jk})^2 \quad (2)$$

where: d_{ij} – the distance between countries i and j ; p – the number of variables

This metric is particularly suitable for Ward's method, as it emphasises larger differences between observations (Hair et al., 2019). The analysis was conducted separately for 2014 and 2023. The optimal number of clusters was determined using dendrograms, agglomeration history and changes in semi-partial R^2 values. A four-cluster solution was retained for both years. Clusters were interpreted using the original indicator values, and changes between years were assessed through shifts in cluster composition and country membership. Because variables were standardised separately for each year, the results reflect relative changes in countries' positions within the EU rather than absolute convergence. All analyses were performed using SAS® software.

Results and Discussion

The hierarchical cluster analysis identified four distinct circular economy profiles in both 2014 and 2023. Figure 1 presents the dendrograms obtained using Ward's method and squared Euclidean distance. In both years, the four-cluster solution was retained because further merging would combine country groups with substantially different circular economy characteristics. Tables 2 and 3 report cluster membership and mean values for all nine indicators included in the analysis.

The 2014 cluster solution revealed a relatively polarised structure (Table 2). Belgium, France, Italy and the Netherlands formed a balanced circular economy profile. Although employment in circular economy sectors was not the highest in this group, these countries combined relatively strong investment and gross value added in circular sectors, high resource productivity, low raw material consumption and the highest circular material use rate among the multi-country clusters. Their municipal waste recycling rate was also relatively high. This combination suggests that circular economy performance was supported not only by waste treatment, but also by more efficient use of materials and stronger recirculation of secondary resources. The largest group in 2014 consisted of 16 countries and represented

Table 1 Description and classification of circular economy indicators used in the analysis

Code	Dimension	Indicator	Unit
x1	competitiveness and innovation	persons employed in circular economy sectors	per 1,000 inhabitants
x2	competitiveness and innovation	private investment and gross value added related to circular economy sectors	€ per capita
x3	competitiveness and innovation	private investment and gross value added related to circular economy sectors	% of GDP
x4	production and consumption	raw material consumption	tonnes per capita
x5	production and consumption	resource productivity	€ per kg
x6	production and consumption	municipal waste generation	kg per capita
x7	secondary raw materials	circular material use rate	%
x8	waste management	recycling rate of municipal waste	%
x9	waste management	recycling rate of waste electrical and electronic equipment separately collected	%

Source: Author's own processing based on Eurostat data

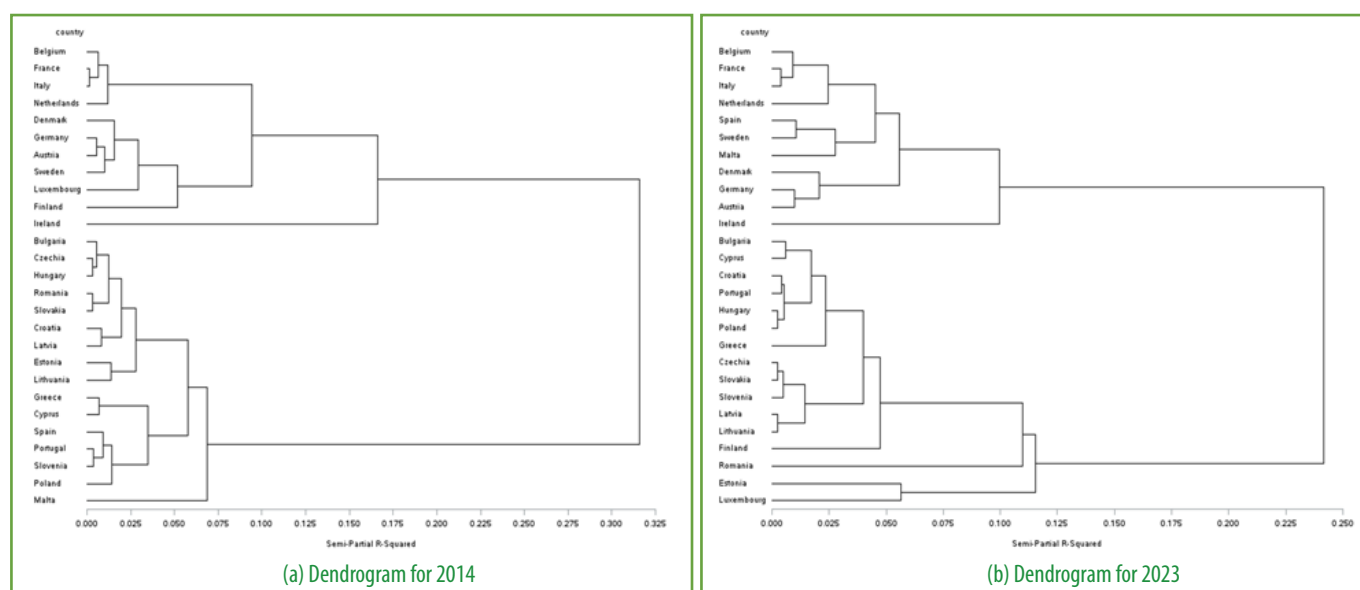


Figure 1 Dendrograms of hierarchical cluster analysis for EU Member States in 2014 (a) and 2023 (b)
Source: Authors' own calculations based on Eurostat data

developing circular economy systems. This profile recorded relatively high employment in circular economy sectors, but lower investment and gross value added, low resource productivity and limited circular material use. Municipal waste recycling was also substantially weaker than in the more advanced clusters. At the same time, WEEE recycling was relatively high, showing that successful performance in one specific waste stream does not necessarily indicate a broader circular transition. This finding is consistent with the argument that circular economy performance should not be assessed through isolated recycling indicators alone (Colasante et al., 2022; D'Inverno et al., 2024). Denmark, Germany, Luxembourg, Austria, Finland and Sweden formed a high-performing profile in 2014. The group combined strong investment and value added in circular economy sectors with high municipal waste and WEEE recycling rates. However, it also recorded the highest raw material consumption and municipal waste generation among the multi-country clusters. This result is important because it demonstrates that

economically advanced circular economy systems may still be associated with high consumption levels and material throughput. High recycling performance therefore does not automatically imply lower environmental pressure or effective waste prevention (Zorpas, 2024). Ireland formed a separate high-investment outlier in 2014. Its private investment and gross value added in circular economy sectors substantially exceeded the values observed in all other Member States. However, circular material use remained low and municipal waste generation was relatively high. Ireland's distinctive position was therefore driven mainly by economic intensity in circular sectors rather than by consistently high performance across all circular economy dimensions.

The 2023 results showed a more differentiated cluster structure (Table 3). A broad developing profile remained the largest group, although its membership declined from 16 to 13 countries. These countries continued to show relatively high employment in circular economy sectors, but their

Table 2 Cluster profiles of EU Member States in 2014

Cluster profile	Member States	n	x1	x2	x3	x4	x5	x6	x7	x8	x9
Balanced circular economy performers	BE, FR, IT, NL	4	6.75	609.45	1.77	11.85	3.16	493	19.35	46.5	80.55
Developing circular economy systems	BG, CZ, EE, EL, ES, HR, CY, LV, LT, HU, MT, PL, PT, RO, SI, SK	16	12.15	225.52	1.56	14.9	1.1	405.56	5.53	23.32	85.73
High-performing circular economy leaders	DK, DE, LU, AT, FI, SE	6	8.63	791.43	1.67	27.16	2.31	595	8.87	49.47	84.45
High-investment outlier	IE	1	7.32	2,874.39	6.65	15.85	2.19	564	2.2	39.8	83.7

Source: Authors' own calculations based on Eurostat data

Table 3 Cluster profiles of EU Member States in 2023

Cluster profile	Member States	n	x1	x2	x3	x4	x5	x6	x7	x8	x9
Developing circular economy systems	BG, CZ, EL, HR, CY, LV, LT, HU, PL, PT, SI, SK, FI	13	13.29	334.33	1.28	18.27	1.19	488.69	6.62	36.72	86.72
Advanced circular economy performers	BE, DK, DE, IE, ES, FR, IT, MT, NL, AT, SE	11	8.16	972.19	1.77	14.37	3.24	583.36	15.43	47.6	77.35
High-intensity circular economy systems	EE, LU	2	36.21	1,042.84	1.57	25.6	2.58	545.5	15.3	47.2	85.15
Low-performing outlier	RO	1	10.41	138.91	0.82	29.08	0.4	305	1.5	12.4	38.4

Source: Authors' own calculations based on Eurostat data

investment intensity, resource productivity and circular material use remained below the values observed in the advanced profiles. The mean municipal waste recycling rate was higher than in the 2014 developing profile; however, because the two groups differed in country composition, this contrast should not be interpreted as a direct improvement of an identical cluster. Material recirculation nevertheless remained limited, indicating that progress in downstream waste treatment was not necessarily accompanied by stronger use of secondary materials in the economy. The advanced profile included 11 countries in 2023 and combined high investment and gross value added in circular sectors with the highest resource productivity among the multi-country clusters. It also achieved stronger circular material use and municipal waste recycling than the developing profile. These results suggest that more advanced circular economy systems are characterised by the simultaneous presence of economic capacity, efficient material use and greater secondary material recirculation. Nevertheless, municipal waste generation remained high, again confirming that circularity cannot be evaluated through waste indicators alone. Estonia and Luxembourg formed a separate high-intensity profile. These countries recorded exceptionally high employment and investment in circular economy sectors, relatively strong resource productivity, high circular material use and strong recycling performance. However, their raw material consumption and municipal waste generation also remained high. Their profile therefore illustrates that strong circular economy capacity can coexist with high material demand. Romania formed a separate low-performing outlier in 2023. Although municipal waste generation was comparatively low, this country recorded low investment and gross value added in circular sectors, very low resource productivity, high raw material consumption, limited circular material use and weak municipal waste and WEEE recycling. This confirms that lower waste generation alone should not be interpreted as evidence of stronger circular economy performance.

Because the clustering procedures were estimated independently for 2014 and 2023, the comparison refers to changes in countries' relative cluster allocation rather than literal transitions between identical cluster categories. Belgium, France, Italy and the Netherlands, which formed the balanced profile in 2014, were assigned to the advanced profile in 2023. Spain and Malta were allocated from the 2014 developing profile to the 2023 advanced profile, whereas Estonia and Luxembourg formed a distinct high-intensity profile in 2023. Romania was assigned to a separate low-performing outlier profile, while Finland was included in the developing profile in 2023. Ireland, an individual high-investment outlier in 2014, was included in the advanced profile in 2023. These patterns support the concept of a multi-speed Europe, in which countries do not progress towards circularity at the same pace or through identical development pathways (Mazur-Wierzbicka, 2021; Castillo-Díaz et al., 2024). They also support the multidimensional approach proposed by Claudio-Quiroga and Poza (2024), because the distinction between profiles was explained by the combined pattern of investment, value added, resource productivity, material consumption, waste generation, circular material use and recycling outcomes. Across both years, private investment and gross value added in circular economy sectors, resource productivity and circular material use were more consistently associated with advanced profiles than employment in circular sectors or WEEE recycling. Employment alone did not distinguish advanced profiles, while WEEE recycling remained relatively high even in the developing groups. This confirms that individual indicators may provide a partial or potentially misleading picture when interpreted in isolation. The findings underline that circular economy policy should extend beyond recycling infrastructure. A more balanced transition requires stronger markets for secondary materials, investment in circular business models, eco-design, repair and reuse systems, and measures aimed at reducing primary

material dependency and total waste generation (Kirchherr et al., 2023; ZORPAS, 2024).

Conclusion

The transition towards a circular economy remains an important objective for reducing resource dependency, waste generation and environmental pressures in the European Union. However, the results show that Member States do not follow a uniform pathway towards circularity. The comparison of circular economy profiles in 2014 and 2023 confirmed substantial differences in economic engagement in circular sectors, resource productivity, material recirculation and waste-management performance. By examining these dimensions jointly, this study shows that circular economy performance cannot be adequately captured by a single recycling indicator. Four country profiles were identified in both analysed years. The more advanced profiles combined higher investment and gross value added in circular sectors with stronger resource productivity, higher circular material use and better municipal waste recycling performance. Nevertheless, these profiles also reported relatively high municipal waste generation and, in some cases, high raw material consumption. This confirms that progress in recycling does not necessarily lead to lower material throughput or a fully circular economic system. The findings indicate that policy approaches should move beyond recycling targets and support broader structural changes. Stronger markets for secondary materials, investment in circular business models, eco-design, repair, reuse, waste prevention and resource-efficient production and consumption are needed to achieve a more balanced transition. Such policies should be coordinated across waste, industrial, innovation and consumer policy domains to prevent fragmented and short-term interventions. At the same time, the differences between country profiles suggest that uniform policy measures may not be equally effective across all Member States. The study is limited by the use of two cross-sectional time points and by the relative nature of cluster analysis. The results therefore show relative changes in the position of countries within the EU-27, rather than proving absolute convergence or direct policy effects. Future research should use longer time series, include social, institutional and behavioural indicators, and examine the policy conditions that enable countries to develop more advanced circular economy profiles.

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References

- Castillo-Díaz, F. J. – Belmonte-Ureña, L. J. – Diáñez-Martínez, F. – Camacho-Ferre, F. 2024. Challenges and perspectives of the circular economy in the European Union: A comparative analysis of the member states. In *Ecological Economics*, vol. 224, 2024. <https://doi.org/10.1016/j.ecolecon.2024.108294>
- Claudio-Quiroga, G. – Poza, C. 2024. Measuring the circular economy in Europe: Big differences among countries, great opportunities to converge. In *Sustainable Development*, vol. 32, 2024, no. 5, pp. 4707–4725. <https://doi.org/10.1002/sd.2925>
- Colasante, A. – D'Adamo, I. – Morone, P. – Rosa, P. 2022. Assessing the circularity performance in a European cross-country comparison. In *Environmental Impact Assessment Review*, vol. 93, 2022. <https://doi.org/10.1016/j.eiar.2021.106730>
- D'Inverno, G. – Carosi, L. – Romano, G. 2024. Meeting the challenges of the waste hierarchy: A performance evaluation of EU countries. In *Ecological Indicators*, vol. 160, 2024. <https://doi.org/10.1016/j.ecolind.2024.111641>

- European Commission. 2015. Closing the loop – An EU action plan for the circular economy (COM(2015) 614 final).
<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614>
- European Commission. (2020). A new circular economy action plan: For a cleaner and more competitive Europe (COM(2020) 98 final).
<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0098>
- Eurostat. 2026. Circular economy database. European Commission. Retrieved February 21, 2026, from <https://ec.europa.eu/eurostat/web/circular-economy/database>
- Everitt, B. S. – Landau, S. – Leese, M. – Stahl, D. 2011. Cluster analysis. 5th ed., Wiley, 2011.
<https://doi.org/10.1002/9780470977811>
- Ghisellini, P. – Cialani, C. – Ulgiati, S. 2016. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. In *Journal of Cleaner Production*, vol. 114, 2016, pp. 11–32.
<https://doi.org/10.1016/j.jclepro.2015.09.007>
- Hair, J. F. – Black, W. C. – Babin, B. J. – Anderson, R. E. 2019. *Multivariate data analysis*. 8th ed., 2019. Cengage Learning.
- Kirchherr, J. – Yang, N.-H. N. – Schulze-Spüntrup, F. – Heerink, M. J. – Hartley, K. 2023. Conceptualizing the circular economy (revisited): An analysis of 221 definitions. In *Resources, Conservation and Recycling*, vol. 194, 2023.
<https://doi.org/10.1016/j.resconrec.2023.107001>
- Mazur-Wierzbicka, E. 2021. Circular economy: Advancement of European Union countries. In *Environmental Sciences Europe*, vol. 33, 2021.
<https://doi.org/10.1186/s12302-021-00549-0>
- Merli, R. – Preziosi, M. – Acampora, A. 2018. How do scholars approach the circular economy? A systematic literature review. In *Journal of Cleaner Production*, vol. 178, 2018, pp. 703–722. <https://doi.org/10.1016/j.jclepro.2017.12.112>
- Suárez-Eiroa, B. – Fernández, E. – Méndez-Martínez, G. – Soto-Oñate, D. 2019. Operational principles of circular economy for sustainable development: Linking theory and practice. In *Journal of Cleaner Production*, vol. 214, 2019, pp. 952–961.
<https://doi.org/10.1016/j.jclepro.2018.12.271>
- Uvarova, I. – Atstaja, D. – Volkova, T. – Grasis, J. – Ozolina-Ozola, I. 2023. The typology of 60R circular economy principles and strategic orientation of their application in business. In *Journal of Cleaner Production*, vol. 409, 2023.
<https://doi.org/10.1016/j.jclepro.2023.137189>
- Velenturf, A. P. M. – Purnell, P. 2021. Principles for a sustainable circular economy. In *Sustainable Production and Consumption*, vol. 27, 2021, pp. 1437–1457.
<https://doi.org/10.1016/j.spc.2021.02.018>
- Voukkali, I. – Papamichael, I. – Loizia, P. – Lekkas, D. F. – Rodríguez-Espinosa, T. – Navarro-Pedreño, J. – Zorpas, A. A. 2023. Waste metrics in the framework of circular economy. In *Waste Management – Research*, vol. 41, 2023, no. 12, pp. 1741–1753.
<https://doi.org/10.1177/0734242X231190794>
- Ward, J. H. Jr. 1963. Hierarchical grouping to optimize an objective function. In *Journal of the American Statistical Association*, vol. 58, 1963, no. 301, pp. 236–244.
<https://doi.org/10.1080/01621459.1963.10500845>
- Zorpas, A. A. 2024. The hidden concept and the beauty of multiple “R” in the framework of waste strategies development reflecting to circular economy principles. In *Science of the Total Environment*, vol. 952, 2024.
<https://doi.org/10.1016/j.scitotenv.2024.175508>

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