Circular Economy in Selected EU Countries: Progress and Gaps

Gospodarka o obiegu zamkniętym w wybranych krajach UE: postępy i wyzwania

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This study evaluates the progress of Circular Economy (CE) implementation across selected European Union (EU) Member States Germany, France, Italy, Spain, Poland, the Netherlands, and Sweden using a multi-indicator analytical framework over ten-year period from 2013 to 2023. Four key indicators are applied to assess national circular performance: Circular Material Use Rate (CMUR), Material Footprint (MF), Water Savings Potential (WSP), and Energy Recovery Potential (ERP). Results reveal substantial disparities in circular transition levels. The Netherlands and Italy emerge as leaders, demonstrating high CMUR values, efficient material use, and advanced recovery systems. France, Germany, and Spain show moderate but uneven progress, while Poland and Sweden remain below EU averages, indicating persistent circularity and efficiency gaps. A composite index and tiered ranking structure confirm a pronounced asymmetry between Western-Southern and Central-Nordic regions. The outcomes of this paper indicate that, despite progress in implementing the EU's circular economy goals, the level of their implementation varies across the member states. Achieving the 2050 CE targets and sustaining progress beyond will require stronger coordination between national and EU strategies, greater industrial symbiosis, and sustained investment in circular infrastructure and innovation.
Key words: Circular economy indicators, resources intensive industries, water sustainability, waste management, energy recover

W niniejszym opracowaniu dokonano oceny postępów we wdrażaniu gospodarki o obiegu zamkniętym (GOZ) w wybranych państwach członkowskich Unii Europejskiej (UE): Niemczech, Francji, Włoszech, Hiszpanii, Polsce, Holandii i Szwecji, wykorzystując wielowskaźnikowe ramy analityczne w okresie dziesięciu lat od 2013 r. do 2023 r. Do oceny krajowych wyników w zakresie gospodarki o obiegu zamkniętym zastosowano cztery kluczowe wskaźniki: wskaźnik wykorzystania materiałów w obiegu zamkniętym (CMUR), ślad materiałowy (MF), potencjał oszczędności wody (WSP) i potencjał odzysku energii (ERP). Wyniki wskazują na znaczne różnice w poziomach przejścia na gospodarkę o obiegu zamkniętym. Holandia i Włochy wysuwają się na pozycję liderów, wykazując wysokie wartości CMUR, efektywne wykorzystanie materiałów i zaawansowane systemy odzysku. Francja, Niemcy i Hiszpania wykazują umiarkowany, ale nierównomierny postęp, podczas gdy Polska i Szwecja pozostają poniżej średniej UE, co wskazuje na utrzymujące się różnice w zakresie gospodarki o obiegu zamkniętym i efektywności. Złożony indeks i wielopoziomowa struktura rankingowa potwierdzają wyraźną asymetrię między regionami zachodnio-południowymi a środkowo-nordyckimi. Wyniki niniejszej analizy wskazują, że mimo postępów w realizacji celów UE dotyczących gospodarki o obiegu zamkniętym, poziom ich wdrażania jest zróżnicowany w poszczególnych państwach członkowskich. Osiągnięcie celów gospodarki o obiegu zamkniętym na rok 2050 będzie wymagać skoordynowanych strategii krajowych i unijnych, lepszej symbiozy przemysłowej oraz inwestycji w infrastrukturę i innowacje o obiegu zamkniętym.
Słowa kluczowe: wskaźniki gospodarki o obiegu zamkniętym, przemysły zasobochłonne, zrównoważenie wodne, gospodarka odpadami, odzysk energii

Research topic and purpose

Circular economy (CE) has assumed growing significance in recent years, reflecting the urgent need for sustainable resource management and environmental sustainability. In line with this, the European Green Deal calls for substantial emissions reductions, sustainable industrial sectors, food systems, and biodiversity protection, outlining the EU's goal to achieve climate neutrality by 2050 and beyond [3].

The EU directive and related recommendations highlight that many of the key challenges in the transition to a circular economy revolve around waste, its generation, reuse, and disposal. In fact, the European Commission considers waste management a strategic priority across all 28 EU Member States in facilitating the shift from a linear to a circular economy.

The European Commission in 2023 defined the circular economy (CE) as a production and consumption system that prioritizes the continual use of materials and products, thereby extending their life cycle. This shift is essential for the EU's transition toward sustainable development, with CE models playing a central

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role. The complexity of the (CE) requires the use of multidimensional indicators to measure and assess its impacts, particularly at the micro level, while simultaneously promoting innovative business models in the industrial sectors, agricultural, urban and to improve resource efficiency [1].

Circular economy indicators are essential tools for assessing progress toward sustainability goals. These indicators are managed by government institutions, international organizations, and non-profit entities involved in sustainability and environmental assessment.

To measure progress toward an economic framework that incorporates circularity concepts across different countries and sectors such as industry, agriculture and urban development a range of indicators is commonly used. The values of these indicators are regularly reported, providing relevant and up-to-date information.

EU countries strongly emphasize the need to assess progress in the circular economy (CE) transition through the use of CE indicators at various levels. Several proposed indicators can also be adopted by other countries to help policymakers shape national monitoring frameworks. However, to evaluate the transformation process at the European level and enable comparisons between countries, it is recommended to use European CE monitoring framework, as it offers a standardized set of indicators that ensure consistent data and provide a holistic view across all European countries [2]. Both EU and Polish sector specific laws drive circular economy implementation through binding regulations and national measures. These laws impose technical, process, and product requirements for water-intensive industries, packaging, electronics, plastics etc. [10].

However, there are still notable knowledge gaps in identifying circularity approaches, circular economy (CE) strategies, and their implementation across various sectors. As research on CE implementation continues to grow, the unresolved questions remain diverse. In this context, the literature emphasizes an increasing demand for more consistent circular practices among policymakers, businesses, industries, experts, citizens, scholars, and national governments. The transition to a circular economy in the EU represents a significant opportunity to advance sustainability by promoting resource efficiency, environmental protection, and innovation. However, more coherent policies and substantial investments are required to ensure progress across all EU Member States [4].

The current research focuses on evaluating the implementation of Circular Economy (CE) principles within the industrial sectors of selected EU countries, including Germany, France, Italy, Spain, Poland, the Netherlands, and Sweden. The primary objective is to analyze progress, performance gaps, and efficiency trends across four key indicators: Circular Material Use Rate (CMUR), Material Footprint (MF), Water Savings Potential (WSP), and Energy Recovery Potential (ERP) [7]. Together, these indicators encompass the core pillars of circularity resource efficiency, water management, and energy recovery highlighting their interconnections within Europe's industrial transition, which ultimately enhance environmental performance and reinforce sustainability objectives [8].

To realise the primary goal of this paper, five research questions were formulated, as follows: How much progress have EU Member States made in implementing CE practices during the assumed period 2013–2023?, What are the differences in material, water, and energy circularity performance across industrial systems?, Which structural, technological, or policy factors explain disparities between leading and lagging countries?, How can multi-dimensional CE indicators (CMUR, MF, WSP, ERP) provide a more integrated understanding of industrial circularity and guide future policy actions?

The answers aim to identify existing gaps, diagnose systemic strengths and weaknesses, monitor areas of limited advancement, and elucidate insufficiently explored dimensions of the circular economy across different disciplines.

Table 1. Description of the Analyzed Circular Economy Indicators

Indicator	Acronym	Indicators formula	Concept & Interpretation
Circular Material Use Rate	**CMUR** %	**CMUR = (Usec / Utotal) × 100**	Evaluates material circularity and virgin resource substitution through the ratio of recycled waste-derived inputs to total material consumption *High = Strong circularity in materials*
Material Footprint	**MF** *(tonnes per capita)*	**MF = DM + Raw Imports – Raw Exports**	Indicates how much material is consumed per person domestically, highlighting the intensity of resource use and dependence on natural materials *Lower = More resource efficiency*
Water Sustainability Performance	**WSP** %	**WSP = (Total water abstraction/ Available water resources) × 100**	Reflects water reuse, recycling, and treatment efficiency across sectors, indicating overall water saved and the capacity for circular water management *High = Strong circular water management*
Energy Recovery Proportion	**ERP** %	**ERP = Σ(Erecovered / Einput) × 100**	Measures energy recovery from non-recyclable waste, indicating circular energy efficiency and integrated waste-to-energy performance *High = Integrated waste to energy*

Methodology and Data Framework

The study adopts a comparative, indicator-based analytical perspective, emphasizing the industrial sector as a driver of circular transformation. By integrating material, energy, and water indicators, it reveals how circular practices not only improve resource efficiency but also enhance decarbonization potential and industrial resilience. This dual perspective combining quantitative assessment with policy relevance provides both scientific evidence and practical guidance for Europe's transition toward a sustainable and competitive circular economy. in selected European Union (EU) Member States. The methodology focuses on evaluating the industrial circularity performance of seven countries Germany, France, Italy, Spain, Poland, the Netherlands, and Sweden using a multi-indicator framework that combines material, water, and energy dimensions of circularity. The research design integrates three analytical layers: indicator measurement, normalization and comparison, and ranking and interpretation to identify patterns, leaders, and laggards in CE implementation.

Circular Flow Indicators track the flow and circulation of resources within the economy, assessing how effectively materials and energy are reused, recycled, or recovered. Key examples include the Circular Material Use Rate (CMUR), which measures the share of recycled materials in total material use, and the Energy Recovery Potential (ERP), which represents the recoverable energy from waste and industrial by-products. High circular flow values indicate strong material recirculation and waste minimization [4].

Overview of the Analyzed Circular Economy Indicators

The indicators presented in Table 1. reflect the main areas of industrial circularity, focusing on materials, water, and energy consumption. Together, they provide a clear picture of the industry's contribution to the circular economy.

Glossary of terms used in formulas:

- ***Usec (Recycled materials used):*** *Quantity of materials obtained through recycling processes.*
- ***Utot (Total materials used):*** *Total quantity of materials consumed, including both virgin and recycled materials.*
- ***DM (Domestic extraction):*** *Total quantity of raw materials extracted domestically.*

- **Raw Imports, Exports:** *Total quantity of raw materials imported, exported.*
- **Erecovered:** *Total energy recovered from waste, typically measured in megajoules or gigajoules, generated by processes such as incineration with energy recovery.*
- **Einput (Waste input):** *Total quantity of waste treated or generated, depending on the reporting scope.*

The following tables 2, 3, 4, 5 present statistical data on CE indicators (CMUR, MF, WSP, and ERP) that were collected and analyzed for the purposes of this study for the period 2013-2023 [5][6].

Table 5. Material Footprint (MF, tonnes per capita)

Year	Germany	France	Italy	Spain	Poland	Netherlands	Sweden	EU-27 (avg)
2013	13.8	12.1	9.7	12.4	16.2	11.6	23.5	13.7
2014	13.5	12.0	9.6	12.2	16.0	11.4	23.2	13.5
2015	13.3	11.8	9.4	12.0	15.7	11.3	23.0	13.4
2016	13.0	11.7	9.2	11.8	15.4	11.1	22.8	13.2
2017	12.8	11.6	9.1	11.6	15.2	11.0	22.7	13.0
2018	12.6	11.5	9.0	11.5	15.0	10.9	22.5	12.9
2019	12.5	11.4	8.9	11.4	14.8	10.8	22.3	12.8
2020	12.3	11.3	8.8	11.3	14.6	10.7	22.0	12.7
2021	12.2	11.2	8.7	11.2	14.5	10.6	21.8	12.6
2022	12.1	11.1	8.6	11.1	14.4	10.5	21.6	12.5
2023	**12.0**	**11.0**	**8.5**	**11.0**	**14.3**	**10.4**	**21.5**	12.4

Interpretation: As material footprints (MF) gradually decline across all Member States, resource efficiency appears to be improving and becoming less tied to economic growth. Sweden and Poland, however, remain above the EU average due to their high material use and material-intensive industries.

Table 2. Circular Material Use Rate (CMUR, %)

Year	Germany	France	Italy	Spain	Poland	Netherlands	Sweden	EU-27
2013	11.2	18.1	18.7	7.5	8.1	25.4	9.3	10.7
2014	11.5	18.2	19.0	7.8	8.3	26.1	9.4	10.9
2015	11.8	18.3	19.5	8.0	8.4	26.7	9.6	11.0
2016	12.0	18.6	19.7	8.2	8.5	27.0	9.8	11.2
2017	12.2	18.8	20.0	8.5	8.7	27.5	10.0	11.3
2018	12.4	19.0	20.2	8.7	8.8	28.0	10.1	11.4
2019	12.6	19.1	20.4	8.8	8.9	28.4	10.2	11.6
2020	12.8	19.2	20.5	9.0	9.0	29.0	10.4	11.7
2021	13.0	19.3	20.6	9.2	9.1	29.4	10.5	11.7
2022	13.1	19.3	20.7	9.3	9.1	29.9	10.6	11.7
2023	13.3	19.4	20.8	9.5	9.2	30.6	10.8	11.8

Table 3. Energy Recovery Proportion (ERP, % of total waste treated)

Year	Germany	France	Italy	Spain	Poland	Netherlands	Sweden	EU-27 (avg)
2013	19.5	10.2	8.6	6.4	5.5	17.3	25.8	11.0
2014	19.8	10.4	8.7	6.5	5.6	17.6	26.1	11.2
2015	20.1	10.6	8.9	6.7	5.8	17.9	26.5	11.3
2016	20.4	10.9	9.1	6.8	6.0	18.3	27.0	11.5
2017	20.7	11.1	9.3	6.9	6.2	18.8	27.5	11.7
2018	21.0	11.4	9.4	7.0	6.3	19.2	28.0	11.9
2019	21.3	11.6	9.5	7.1	6.4	19.5	28.4	12.0
2020	21.6	11.8	9.6	7.2	6.5	19.9	28.7	12.1
2021	21.8	12.0	9.7	7.3	6.6	20.1	29.0	12.2
2022	22.0	12.2	9.8	7.4	6.7	20.4	29.3	12.3
2023	**22.2**	**12.4**	**9.9**	**7.5**	**6.8**	**20.7**	**29.6**	**12.4**

Interpretation: ERP trends show that waste-to-energy systems are becoming increasingly important, especially in Northern Europe. Sweden, Germany, and the Netherlands have the highest recovery rates, while Poland and Spain are still developing their infrastructure.

Table 4. Water Sustainability Performance (WSP, %)

Year	Germany	France	Italy	Spain	Poland	Netherlands	Sweden	EU-27 (avg)
2013	7.5	5.2	9.8	14.0	3.5	10.2	5.0	7.9
2014	7.8	5.4	10.0	14.3	3.6	10.5	5.1	8.1
2015	8.0	5.6	10.2	14.5	3.7	10.8	5.2	8.3
2016	8.3	5.8	10.4	14.8	3.8	11.0	5.3	8.5
2017	8.6	6.0	10.6	15.0	4.0	11.3	5.4	8.7
2018	8.8	6.2	10.8	15.2	4.1	11.5	5.5	8.9
2019	9.0	6.4	11.0	15.5	4.2	11.8	5.6	9.1
2020	9.3	6.6	11.3	15.7	4.4	12.0	5.7	9.3
2021	9.5	6.8	11.5	15.9	4.5	12.3	5.8	9.5
2022	9.7	7.0	11.8	16.0	4.6	12.5	5.9	9.7
2023	**10.0**	**7.2**	**12.0**	**16.2**	4.8	12.8	6.0	9.9

Interpretation: Efforts to improve water reuse and efficiency are underway in Southern Europe (especially Spain and Italy), where managing scarce water resources remains a major challenge. Northern countries, though less water-stressed, are also making significant efforts to enhance water efficiency.

Water Sustainability Performance (WSP) and Water Exploitation Index Plus (WEI⁺)

In this paper, the Water Sustainability Performance (WSP) indicator was applied to assess water use efficiency and overall sustainability. However, this indicator is closely related to the Water Exploitation Index Plus (WEI^+), which is defined and interpreted as follows: The WEI^+ quantifies the pressure exerted on renewable freshwater resources by comparing the total freshwater abstraction to the total renewable freshwater availability within a given region. It reflects how intensively water resources are being used, a high WEI^+ value indicates greater stress and weaker circular water management, while a low WEI^+ value represents efficient and sustainable use, the Formula of WEI^+ can be written**:** $WEI^+=100-WSP$.

For example, if a region uses 35 % of its renewable water each year, it experiences moderate water stress ($WEI^+ = 35$), while the corresponding WSP = 65 % indicates that 65 % of water use remains within sustainable limits. These two indicators together, provide complementary views of the same phenomenon: WEI^+ captures resource pressure, while WSP represents management sustainability. Because WSP and WEI^+ are mathematically complementary, they describe the same hydrological relationship from opposite perspectives, offering a more complete understanding of water use and circular water management [9].

Graphical representation of the results

The statistical values presented in the previous tables have been further elaborated and visualised in Figures 1, 2, 3, and 4.

The radar map in Figure 3 illustrates the relative performance of each country across the circular economy indicators,

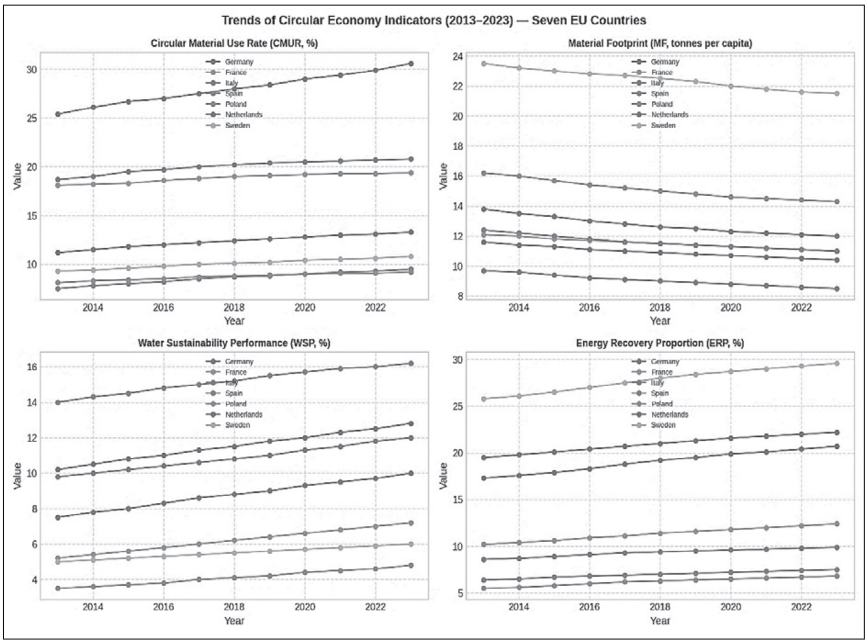

Figure 1.
Trends in (CE) Indicators across the analyzed EU countries, 2013–2023

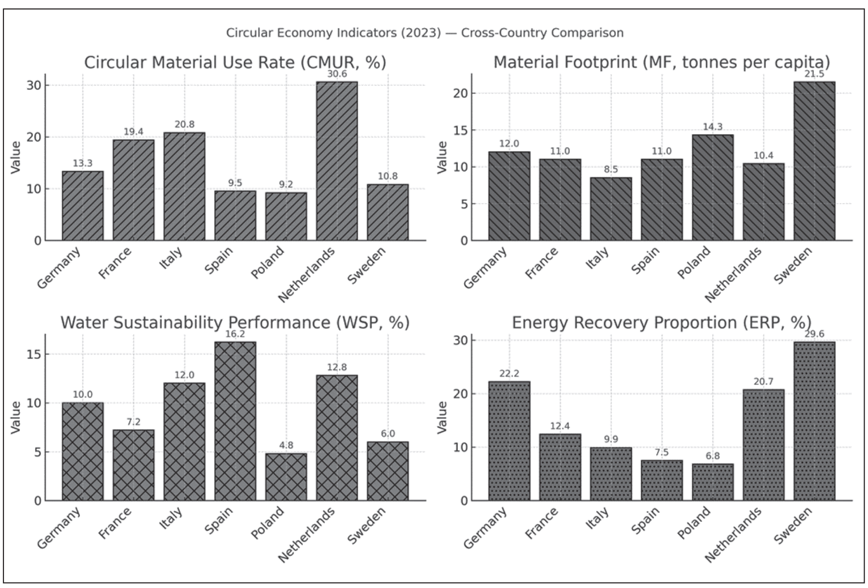

Figure 2.
Comparison of (CE) indicators among the analyzed EU countries, 2013–2023

emphasizing variations in efficiency, resource use patterns, and multidimensional relationships that enable comparative assessment across countries and indicators.

The heatmap in Figure 4 illustrates the magnitude and intensity of indicator values across the dataset, highlighting variations in performance across countries and analyzed indicators. This visualization allows for an immediate and clear comparison of indicator values, intensity levels, and trends for 2023.

Figure 5 shows the categorization of EU countries into leaders, moderate and lagging performers, based on the comparative analysis of the circular economy indicators discussed above.

Discussion of analysed indicators of the CE (2013–2023):

The analyzed indicators in this article are based on the available and most reliable Eurostat and other national data for the analyzed EU countries. Differences in reporting methodologies and data collection periods between member states could also influence the robustness of the results. Despite these limitations, the data were considered the most comprehensive and up-to-date source available at the European level.

A. Trends in Circular Material Use Rate (CMUR): Have risen across the EU but remain uneven. The Netherlands and Italy lead with advanced recovery systems, Germany and France show moderate progress, while Spain and Poland trail behind. Sweden's emphasis on energy recovery over material reuse highlights ongoing disparities in circular economy maturity across member states.
B. Material Footprint (MF): The trends of this indicator provide evidence of

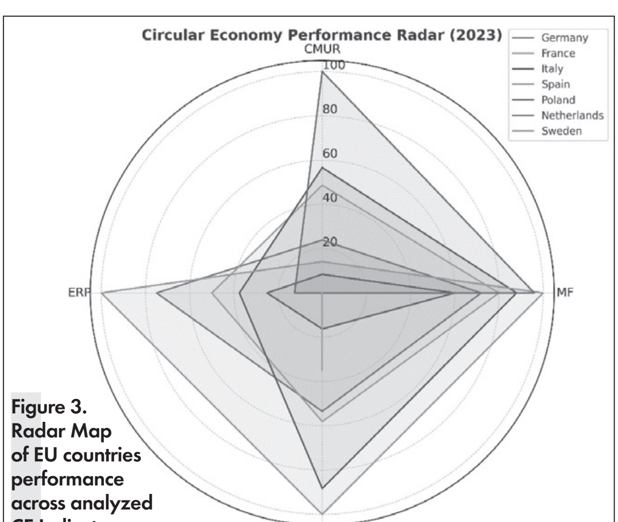

Figure 3.
Radar Map of EU countries performance across analyzed CE Indicators

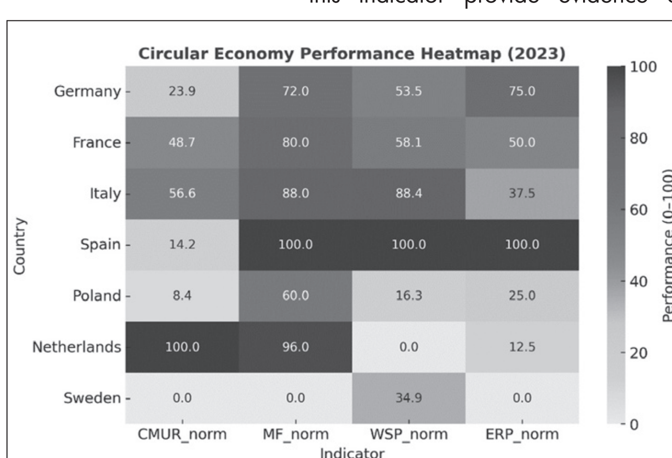

Figure 4.
Heatmap Illustrating the Performance of EU Countries across the Analyzed (CE) Indicators

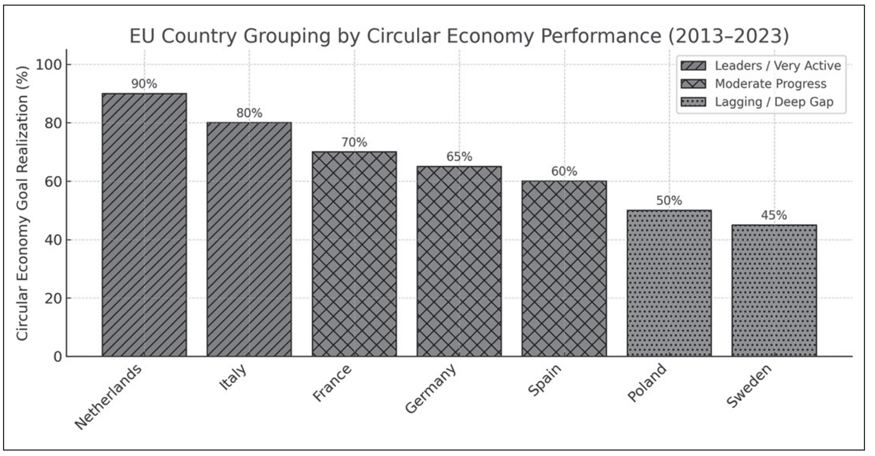

Figure 5.
Categorization of EU Countries by (CE) performance level

a gradual decoupling of resource use from economic growth, reflecting improved efficiency and lifecycle management. The Netherlands, France, and Italy maintain relatively low footprints, whereas Germany, Poland, and Sweden remain more resource-intensive. Sustained progress will require deeper industrial transformation and innovation in material substitution and recycling.

C. Water Sustainability Performance (WSP): Varies widely across the EU, influenced by climate and policy effectiveness. Spain, Italy, and the Netherlands lead in water reuse and efficiency, while Germany, France, and Sweden show steady gains, and Poland trails due to outdated infrastructure. Overall, rising WSP levels highlight the positive impact of EU water policies and the integration of resource efficiency into circular economy.

D. Energy Recovery Proportion (ERP): Has risen steadily across the EU, reflecting the expansion of waste-to-energy systems. Sweden, Germany, and the Netherlands lead with advanced infrastructures, while France and Italy show moderate gains and Spain and Poland lag due to limited investment. Although high ERP values support renewable energy goals, they also reveal a trade-off, as increased energy recovery can impede progress in material recycling.

Conclusion:

The integration of multi-dimensional Circular Economy (CE) indicators (CMUR, MF, WSP, and ERP), assessed in this study enables a more holistic understanding of industrial circularity. By capturing the interconnections among material, water, and energy flows, these indicators highlight systemic efficiencies, performance gaps, and cross-sectoral linkages, providing insight into trends that illustrate how the circular transition has advanced during the period from 2013 to 2023.

- All seven Member States have advanced in implementing the Circular Economy (CE), although progress remains uneven. While the CE framework has fostered EU-wide convergence, it also exposes persistent disparities in national performance.
- CMUR growth with MF reduction signals real material decoupling.
- Rising WSP and ERP values indicate improved resource efficiency and energy recovery.
- The EU's circular transition is advancing; however, achieving full circularity by 2050 will require sustained cross-sectoral integration, stronger policy coherence, and deeper collaboration among Member States.
- Sweden's case shows that single indicators can misrepresent circular performance, as its low material circularity contrasts with strong energy recovery and water management

The categorization of countries into Leaders, Moderate, and Lagging performers should therefore be interpreted as a relative and dynamic construct. These classifications are inherently temporal, reflecting year-to-year fluctuations in indicator performance and structural shifts driven by national contexts and innovations within industrial sectors. As circular economy indicators are context-sensitive and evolve alongside technological, policy, and economic transformations, continuous and comparative reassessment is essential to accurately trace the trajectory and progress of circular transitions.

The final conclusion was expanded to include a discussion of the importance of research findings for national circular economy policies (e.g., in Poland). It emphasized the need for data harmonization, the development of circular economy indicators, and their use in planning and monitoring national actions in relation to EU targets.

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