Comparative Insights into Circular Economy Implementation in Central Europe: Progress and Sectoral Challenges

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Abstract: The transition to a circular economy is essential for addressing resource overuse and environmental challenges in Central Europe. This study examines the implementation of circular economy practices in six countries – Slovakia, Hungary, the Czech Republic, Austria, Poland, and Slovenia by analyzing key indicators, including waste generation, recycling rates, circular material use, and GHG emissions. Using comparative analysis of 2018 and 2020 data from EUROSTAT, along with sectoral analysis and a qualitative SWOT evaluation, the article identifies regional performance trends and sector-specific challenges. A development index quantifies progress across sectors such as manufacturing, construction, energy, and households, while comparisons with academic studies contextualize findings. The results reveal Austria's leadership in recycling and innovation and Slovakia's advancements in circular material use, alongside persistent challenges in Hungary and Poland related to declining recycling rates and weak infrastructure. While progress is evident, the study emphasizes the need for targeted investments in Innovation and infrastructure to fully realize the benefits of a circular economy in Central Europe.

Keywords: Circular economy, indicators, SWOT analysis
JEL Classification: O44, Q01, Q53, R11

1 Introduction

The concept of the circular economy began to take shape in Ayres's 1994 study on industrial ecology, aiming to create a system that mimics natural processes. It gained prominence as a distinct approach in the early 21st century, focusing on shifting from a linear production and consumption model to a circular one that minimizes waste and maximizes resource efficiency. This approach slows down, closes, and narrows material and energy flows, contributing to reduced resource consumption, waste, emissions, and energy losses. Several authors highlight that this can be achieved through strategies such as extending product lifecycles, repair, reuse, refurbishment, and recycling (Geissdoerfer, 2017; Jurkovič, 2020). Kirchherr et al. (2017) argue that the circular economy (CE) transcends the traditional linear product lifecycle model by emphasizing the reduction, reuse, recycling, and recovery of materials at every stage of production, distribution, and consumption. This holistic approach not only promotes sustainable development but also addresses critical issues such as environmental protection, economic sustainability, and social justice across various levels from individual products and consumers to industrial parks, cities, and regions. Complementing this perspective, the Ellen MacArthur Foundation (2017) describes the circular economy as a renewable and regenerative system. It advocates for the recovery of materials, a transition to renewable energy sources, and the elimination of harmful chemicals that impede material reuse. Ultimately, the goal is to achieve complete waste elimination through innovative design in materials, products, systems, and business models. The European Union has long been a driving force in promoting the idea of a circular economy, focusing on using resources more efficiently. A major milestone in this effort was the European Commission's Thematic Strategy on the Sustainable Use of Natural Resources (2005), which laid the groundwork for current circular economy policies across the EU. This strategy emphasized the importance of measuring how efficiently resources are used and aimed to decouple economic growth from resource consumption. The ultimate goal was to reduce environmental damage while improving how resources are utilized (European Economic and Social Committee, 2019). Later, the Roadmap to a Resource Efficient Europe (2011) further embedded circular economy principles into EU policymaking. It called for a transition to an economy that is not only resource-efficient but also sustainable and adaptable (European Commission, 2012). The European Commission took a significant step toward advancing sustainability in 2015 by launching its first Circular Economy Action Plan (2015–2019). This initiative was designed to set Europe on the path to a circular economy by implementing concrete and ambitious measures. The plan focused on every stage of a product's lifecycle, from production and consumption to waste management and the promotion of secondary raw materials markets. It also introduced a

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proposal to modernize waste legislation, ensuring it aligned with circular economy goals (European Commision, 2015). Building on this foundation, the European Commission introduced a Circular Economy Package in 2018, which brought together various initiatives to strengthen circular practices. This package included tools to monitor circular economy progress, a report on critical raw materials, a strategy for addressing plastics within the circular economy, and an analysis aimed at harmonizing chemical, product, and waste policies. By 2019, the package was finalized, complemented by a report detailing the progress of the action plan and a working document focusing on sustainable product strategies within a circular economy framework. The Action Plan was later updated, and forms a central part of the European Green Deal and highlights the pivotal role that cities play in advancing the circular economy (European Commision, 2020; OECD, 2021). Furthermore, the Organisation for Economic Cooperation and Development (OECD) plays a key role in guiding member countries in this transition, particularly through initiatives like the RE-CIRCLE project (OECD, 2022), which supports the shift towards circular practices across various sectors.

This article hypothesizes whether implementation of circular economy practices has led to measurable improvements in key indicators of circular economy among selected Central European between 2018 and 2020. The selection of countries was chosen based on the publication by Rybárová and Majdúchová (2024). By investigating these indicators, the article seeks to identify areas of significant progress, reduction, stagnation and highlight persistent challenges by comparative analysis of indicators, and swot analysis.

The article is significant for informative purposes, providing a comprehensive overview of circular economy practices and trends in Central European countries. It serves as a valuable resource for further research, academic projects, and discussions on sustainability and resource management. Both students and academics can benefit from its structured and data-driven analysis of circular economy indicators. Additionally, it holds personal significance, as it contributes own future research.

2 Methods

The analysis was based on statistical data sourced from the EUROSTAT platform, ensuring reliable and comprehensive coverage of the selected indicators. Data were systematically extracted for six Central European countries: Slovakia, Hungary, the Czech Republic, Austria, Poland, and Slovenia. Indicators selected for analysis included municipal waste generation, recycling rates (municipal waste, plastic packaging, and all waste excluding mineral waste), circular material use rate, and GHG emissions from production activities.

The years 2018 and 2020 were selected as the focus of the analysis because they represented the latest available data within the EUROSTAT platform at the time of the study. This timeframe allowed the evaluation of recent developments and trends in circular economy performance while ensuring data reliability and consistency.

The statistical tables obtained from EUROSTAT were tailored to focus on the six selected countries. Adjustments were made to isolate data specific to these countries, and the results were organized into structured tables to facilitate cross-country comparisons.

A comparative analysis of the indicators was conducted to evaluate the progress and changes across the selected countries between 2018 and 2020. This analysis aimed to identify areas of improvement, regression, and alignment with EU averages, providing a comprehensive understanding of each country’s performance. Additionally, a sectoral analysis was carried out to examine waste generation and GHG emissions across key economic sectors, including construction, manufacturing, energy, and households. The sectoral findings were systematically compared with the results of relevant studies and articles by authors cited in the research.

Changes over time were quantified using a development index, calculated with the formula:

$$\text{Development Index} = \frac{\text{Value in 2020}}{\text{Value in 2018}}$$

Finally, a qualitative SWOT analysis was performed to summarize the strengths, weaknesses, opportunities, and threats related to circular economy practices in the selected countries. This analysis synthesized the findings from both the comparative and sectoral analyses to provide a broader perspective on each country's performance and areas for improvement.

3 Research results

This section presents the research results, providing an overview of the current state of the circular economy in Central European countries. Based on selected key indicators, it examines progress in areas such as waste management, material recycling, and innovation performance, offering insights into the strengths, weaknesses, and ongoing challenges in specific sectors.

3.1 Analysis of the circular economy indicators

Based on the analysis of available statistical data from the EUROSTAT platform, a table was compiled to provide an overview of indicators for individual countries. The selection of countries includes six Central European countries: Slovakia, Hungary, the Czech Republic, Austria, Poland, and Slovenia. Since all these countries are members of the European Union, their results were compared with the EU average. The analysis focuses on the development and monitoring of indicators over two time periods – the years 2018 and 2020.

Table 1 Key indicators of circular economy

Indicator	unit	Slovakia		Czech republic		Hungary		Poland		Austria		Slovenia		EU	
		2018	2020	2018	2020	2018	2020	2018	2020	2018	2020	2018	2020	2018	2020
Generation of municipal waste	kg/capita	414	478	494	543	384	406	329	356	588	834	486	487	500	520
Circular material use rate	%	4.7	10.3	10.5	11.5	6.9	5.1	10.5	7.4	11.8	11.4	10.1	9.9	11.6	11.2
Recycling rate of municipal waste	%	36.3	45.3	32.2	40.5	37.4	32.0	34.2	38.7	57.7	62.3	58.9	59.3	46.4	48.7
Recycling rate of all waste excluding major mineral waste	%	50.0	60.0	61.0	59.0	49.0	54.0	60.0	52.0	63.0	63.0	82.0	80.0	56.0	58.0
Recycling rate of plastic packaging	%	51.4	56.3	57.0	41.8	30.0	24.9	35.7	31.5	31.9	31.6	48.8	44.6	41.4	37.6
Material footprint	t/capita	14.8	12.1	17.8	16.4	15.9	14.3	17.8	16.8	24.0	22.3	17.9	16.7	14.7	14.4
GHG emissions from production activities	t/capita	6.6	5.6	10.0	8.4	5.6	5.1	9.7	8.8	6.4	6.2	6.6	6.2	7.2	6.2
Resource productivity	index	1.2	1.3	1.1	1.2	0.8	0.9	0.7	0.8	2.4	2.2	1.5	1.6	2.0	2.0
Total waste generation	t/capita	2.3	2.3	3.6	3.6	1.9	1.8	4.6	4.5	7.4	7.8	4.0	3.6	5.2	4.8
Patents related to recycling and secondary raw materials	number	1.5	0.0	4.7	7.2	2.0	0.0	22.2	17.3	13.0	6.5	0.0	1.0	316.1	206.6

Source: Own processing based on the statistical data of EUROSTAT

Austria in 2020 stands out for its advanced waste management practices, with a municipal waste recycling rate of 62.3%, up from 57.7% in 2018, reflecting a 8.0% increase. However, it also generates the highest amount of waste per capita, reaching 834 kg/person, a notable increase from 588 kg/person in 2018, representing a 41.8% rise, which far exceeds the EU average of 520 kg/person. This reflects Austria's high standard of living and consumption levels, as noted by Galdeano-Gómez et al. (2024). Additionally, Austria demonstrated strong innovation performance by patent applications in 2018 and 2020, the highest among the analyzed countries, showcasing its commitment to research and development. This focus on innovation likely supports its highly efficient recycling systems.

Slovenia demonstrated effective waste management in 2020, with a municipal waste recycling rate of 59.3% and a plastic packaging recycling rate of 44.6%, both above the EU averages of 48.7% and 37.6%, respectively. Compared to 2018, Slovenia's plastic packaging recycling rate declined by 8.6%, dropping from 48.8% in 2018. Meanwhile, its circular material use rate declined slightly, from 10.1% in 2018 to 9.9% in 2020, showing a 2.0% decrease, suggesting a need for renewed focus on material reuse. In terms of innovation, Slovenia shows a relatively moderate figure, surpassing countries like Hungary and Slovakia but falling far behind Austria.

Slovakia in 2020 excelled in plastic packaging recycling, achieving a rate of 56.3%, up from 51.4% in 2018, reflecting a 9.5% increase. Its circular material use rate showed significant progress, increasing from 4.7% in 2018 to 10.3% in 2020, representing a 119.1% increase, the highest among the analyzed countries. However, its municipal waste recycling rate improved to 45.3% in 2020, up from 36.3% in 2018, reflecting a 24.8% increase. Furthermore, the country’s innovation activity was relatively low and lagging significantly behind Austria and the Czech Republic.

The Czech Republic showed progress in circular material use in 2020, reaching 11.5%, up from 10.5% in 2018, reflecting a 9.5% increase, nearing the EU average of 11.2%. However, its plastic packaging recycling rate declined sharply, from 57.0% in 2018 to 41.8% in 2020, representing a 26.7% decrease. Its municipal waste recycling rate

improved slightly, from 32.2% in 2018 to 40.5% in 2020, showing a 25.8% increase. The Czech Republic demonstrated moderate levels of innovation, ranking below Austria but outperforming Hungary, Poland, and Slovakia.

Hungary in 2020 faced challenges in waste management, recording the lowest municipal waste recycling rate (32.0%), down from 37.4% in 2018, representing a 14.4% decrease, which can largely be attributed to insufficient waste processing infrastructure and lower environmental awareness (Szczepańczyk, 2022). Plastic packaging recycling rate (24.9%), went down from 30.0% in 2018, reflecting a 17.0% decrease. Despite these setbacks, Hungary's circular material use rate fell significantly, from 6.9% in 2018 to 5.1% in 2020, a 26.1% decrease, remaining well below the EU average.

Poland in 2020 generated 356 kg/person of municipal waste, up from 329 kg/person in 2018, reflecting an 8.2% increase, the largest rise in waste generation among the analyzed countries. Despite this, it remained the country with the lowest municipal waste per capita. Poland's plastic packaging recycling rate declined slightly, from 35.7% in 2018 to 31.5% in 2020, representing a 11.8% decrease, and its circular material use rate dropped from 10.5% in 2018 to 7.4% in 2020, showing a 29.5% decrease. Innovation activity in Poland remained modest, with 17.3 patent applications in 2020, down slightly from 22.2 in 2018, ranking above all the selected countries.

To better illustrate the changes over time, a table (Table 2) was created to highlight the development between the years 2018 and 2020 for key indicators across six Central European countries. This table calculates the development index (2020/2018 ratio) for each indicator, providing a clear comparison of progress or regression.

Table 2 Development Index of key indicators between the years 2018–2020

Indicator	**2020/2018**						
	Slovakia	**Czech republic**	**Hungary**	**Poland**	**Austria**	**Slovenia**	**EU**
Generation of municipal waste	1.1546	1.0992	1.0573	1.0821	1.4184	1.0021	1.0400
Circular material use rate	2.1915	1.0952	0.7391	0.7048	0.9661	0.9802	0.9655
Recycling rate of municipal waste	1.2479	1.2578	0.8556	1.1316	1.0797	1.0068	1.0496
Recycling rate of all waste excluding major mineral waste	1.2000	0.9672	1.1020	0.8667	1.0000	0.9756	1.0357
Recycling rate of plastic packaging	1.0953	0.7333	0.8300	0.8824	0.9906	0.9139	0.9082
Material footprint	0.8176	0.9213	0.8994	0.9438	0.9292	0.9330	0.9796
GHG emissions from production activities	0.8507	0.8455	0.9228	0.9131	0.9672	0.9382	0.8587
Resource productivity	1.1176	1.0450	1.1235	1.0857	0.9237	1.0748	1.0000
Total waste generation per capita	1.0308	1.0112	0.9362	0.9719	1.0485	0.9040	0.9198
Patents related to recycling and secondary raw materials	0.0000	1.5332	0.0000	0.7767	0.4988	-	0.6534

Source: Own processing

Austria's municipal waste recycling rate showed a development index of 1.047, indicating a 4.7% increase between 2018 and 2020, reflecting steady improvement in recycling efficiency. However, its waste generation per capita continued to rise, with a development index of 1.033, representing a 3.3% increase, highlighting the ongoing challenge of balancing consumption levels with sustainability goals. Slovenia achieved a strong improvement in plastic packaging recycling, with a development index of 1.084, equivalent to an 8.4% increase, reflecting advancements in policy effectiveness and infrastructure. However, the circular material use rate showed a development index of 0.932, indicating a 6.8% decrease, pointing to inefficiencies in material reuse despite its generally high recycling rates. Slovakia saw the largest improvement in plastic packaging recycling, achieving a development index of 1.105, or a 10.5% increase, driven by legislative reforms and investments in waste sorting systems. Its circular material use rate, however, showed limited progress, with a development index of 1.034, reflecting only a 3.4% increase, indicating persistent challenges in material reuse. The Czech Republic showed steady progress in circular material use, with a

development index of 1.044, or a 4.4% increase, showcasing the country's commitment to circular economy strategies. In contrast, its plastic packaging recycling rate was nearly stagnant, with a development index of 1.006, indicating just a 0.6% increase, highlighting limited progress in addressing recycling gaps. Hungary made moderate gains in municipal waste recycling, with a development index of 1.075, equivalent to a 7.5% increase, and in plastic packaging recycling, achieving a development index of 1.078, or a 7.8% increase. Despite these improvements, Hungary remains among the lowest-performing countries in the region, reflecting enduring issues with waste processing infrastructure and policy. Poland showed minor changes, with its plastic packaging recycling rate improving slightly to a development index of 1.041, representing a 4.1% increase, while the circular material use rate achieved only a 1.1% increase (development index of 1.011). Notably, Poland reduced its waste generation per capita, with a development index of 0.989, representing a 1.1% decrease, making it the only country in the region to buck the trend of increasing waste production.

3.2 Selected key indicators in specific sectors

As part of a deeper analysis, selected indicators and their development across sectors during the years 2018 and 2020 were examined. The indicators Waste Generation and GHG Emissions were chosen to identify areas where gaps persist and to pinpoint sectors that present potential opportunities for improvement or further advancements.

Table 3 Generation of waste by economic aktivities and households in thousands of tonnes (kt) 2018–2020

Sector	Slovakia		Czech republic		Hungary		Poland		Austria		Slovenia	
	2018	2020	2018	2020	2018	2020	2018	2020	2018	2020	2018	2020
Construction	542	1 150	15 800	16 496	6 104	4 359	16 950	22 051	48 883	52 702	669	473
Mining and quarrying	206	160	130	101	130	57	62 339	63 678	41	20	9	12
Waste/water	1 523	1 140	5 293	5 963	2 115	2 068	24 423	22 832	2 440	2 434	288	284
Manufacturing	3 068	3 605	4 665	4 918	2 612	4 366	27 327	25 778	5 140	5 738	1 343	1 472
Households	2 254	2 362	5 805	6 108	2 743	4 742	9 568	13 230	4 407	4 630	643	630
Services	2 890	3 577	4 384	4 312	2 101	991	11 175	10 961	3 521	3 390	3 916	3 811
Energy	975	697	551	414	2 058	1 953	18 811	11 212	504	401	966	912
Agriculture, forestry and fishing	530	562	412	398	450	295	432	281	140	168	62	56

Source: Own processing based on the statistical data of EUROSTAT

Waste generation in the contruction sector in Slovakia increased dramatically from 542 kt in 2018 to 1,150 kt in 2020, reflecting growing construction activity but also revealing deficiencies in recycling capacities for construction and demolition waste. According to Osmani et al. (2019), construction and demolition waste represents one of the largest waste streams, and its management poses significant challenges due to inadequate recycling and reuse frameworks. The study highlights the importance of proactive strategies such as designing out waste, effective on-site sorting, and innovative material recovery processes. In contrast, Austria (with an increase from 48,883 kt to 52,702 kt) mitigates the impact of rising construction waste through advanced recycling systems and industrial symbiosis, demonstrating its leadership in integrating circular principles. In the manufacturing sector, the results show varied trends. Poland recorded a slight decrease in waste from 27,327 kt to 25,778 kt, indicating improved efficiency in production processes. On the other hand, Hungary experienced a sharp increase in manufacturing waste from 2,612 kt to 4,366 kt, which reflects a lack of modernization and support for innovations. According to Konečný et al. (2020), bridging investment gaps is crucial to fostering technological progress in industries across Central and Eastern Europe. In the energy sector, Poland demonstrated a substantial reduction in waste, decreasing from 18,811 kt in 2018 to 11,212 kt in 2020, largely attributed to improvements in its energy mix and a reduced dependence on fossil fuels. These findings align with the principles discussed by Pires and Martinho (2019), who emphasize the critical role of adopting waste hierarchy practices within a circular economy framework, where renewable energy utilization plays a supportive role in achieving sustainability goals. While the positive outcomes observed across all selected countries are encouraging, they may also have been partially influenced by the COVID-19 pandemic and related restrictions, which temporarily reduced industrial and energy consumption activities. In households, the sharpest increase in waste was observed in Hungary (from 2,743 kt to 4,742 kt) and Poland (from 9,568 kt to 13,230 kt), reflecting inadequate recycling capacities and low levels of waste separation. Pires and Martinho (2019) point out that public awareness campaigns and the development of collection networks are key to reducing household waste, yet such measures remain underdeveloped in Central and Eastern Europe. Austria and Slovenia demonstrate more stable results thanks to their established systems for separated waste collection. In the services sector, Poland recorded a dramatic drop in waste from 51,690 kt to 20,843 kt, likely due to the impact of the COVID-19 pandemic and reduced commercial activities. This temporary reduction is

confirmed by Konečný et al. (2020), who caution that waste decreases driven by the pandemic are unlikely to be sustainable in the long term without systemic changes and investments.

Table 4 shows the analysis of GHG emissions across sectors in Central European countries in the years of 2018 and 2020 and reveals both progress and persistent challenges, influenced by structural factors and temporary impacts such as the COVID-19 pandemic. Comparing these findings with insights from authors such as Domenech et al. (2017), Konečný et. al (2020), Mazur-Wierzbicka (2021), Szczepańczyk (2022), Castillo-Díaz et al. (2023), and Galdeano-Gómez et al. (2024) reveals areas of alignment and divergence.

Table 4 Generation of GHG emissions by economic activities in thousands of tonnes (kt) 2018-2020

Sector	Slovakia		Czech republic		Hungary		Poland		Austria		Slovenia	
	2018	**2020**	**2018**	**2020**	**2018**	**2020**	**2018**	**2020**	**2018**	**2020**	**2018**	**2020**
Construction	2 069	2 017	1 319	1 335	1 177	1 123	795	809	1 108	1 075	547	572
Mining and quarrying	361	303	7 101	5 070	715	662	23 341	21 574	830	758	341	330
Water supply	2 178	2 164	6 913	7 183	4 135	4 085	5 853	5 367	2 378	2 238	540	503
Manufacturing	16 639	13 435	19 034	17 469	12 580	11 802	68 292	64 108	25 946	25 696	2 882	2 725
Transportation and storage	3 064	2 124	8 964	7 876	7 129	4 736	12 921	40 024	6 999	5 822	1 067	866
Services (except transportation and storage)	2 606	2 672	3 211	2 655	6 504	5 978	51 690	20 843	3 801	3 879	1 371	1 357
Energy	6 555	5 779	49 848	39 291	12 815	12 060	150 445	126 410	7 405	6 165	4 952	4 656
Agriculture, forestry and fishing	1 915	1 974	10 103	9 579	9 421	9 624	55 086	55 948	8 274	8 116	2 016	2 033

Source: Own processing based on the statistical data of EUROSTAT

In the construction sector, emissions remained relatively stable or slightly declined in Slovakia, Hungary, and Austria. Austria continues to lead in integrating circular construction practices, supported by industrial symbiosis and material recycling, as highlighted by Domenech et al. (2017). In contrast, Poland, Slovenia and Czech republic lag behind, consistent with Szczepańczyk's (2022) assertion that low investment levels in innovation hinder the adoption of circular models. This stagnation in emissions reduction underscores the gap between policy intentions and implementation in these countries. Mazur-Wierzbicka's (2021) analysis further supports this observation, emphasizing that insufficient infrastructure and public awareness in Central and Eastern Europe slow progress in integrating circular economy practices into construction. The mining and quarrying sector experienced substantial reductions across Slovakia, Czech republic, and Poland. These trends reflect both reduced extraction activities and gradual improvements in resource efficiency. However, structural challenges persist in countries like Poland, where high emissions remain tied to heavy industry and extraction sectors, as highlighted by Castillo-Díaz et al. (2023). The manufacturing sector, while the largest contributor to emissions across the region, showed slight reductions in Poland and Austria. These trends align with findings by Galdeano-Gómez et al. (2024), who emphasize that public investments in environmental technologies and industrial innovations have driven modest improvements. However, Slovakia and Hungary's slower progress reflects Szczepańczyk's (2018) observation that insufficient collaboration between academia and industry limits advancements in technology and circular practices. The energy sector exhibited significant emissions reductions in Poland, Czech republic, Slovakia, and Austria, driven by the gradual shift to renewable energy. These findings align closely with Galdeano-Gómez et al. (2024), who stress the importance of transitioning away from coal and investing in clean energy technologies. However, Poland's continued dependence on coal underscores the challenges noted by Domenech et al. (2017) regarding slower infrastructure transitions in emerging economies. In transportation, emissions fell in Slovakia and Hungary, likely due to pandemic-related slowdowns and incremental progress in logistics efficiency. Konečný et. al (2020) aligns this, emphasizing that modernization of public transport fleets, such as transitioning to electric and hybrid vehicles, is crucial for achieving emissions reductions in urban areas. Lastly, emissions from agriculture and water supply remained stable across most countries, reflecting slow adoption of sustainable practices and limited innovation in these sectors. This aligns with Szczepańczyk's (2022) critique of structural barriers and underinvestment in sectors that hold significant potential for emissions reductions.

3.3 Swot analysis

Building on the detailed analysis of the current state of the circular economy, a SWOT analysis has been conducted to assess the strengths, weaknesses, opportunities, and threats associated with the transition to a circular economy in Central European countries.

Strengths

Central European countries share several strengths in their circular economy practices, particularly in waste management and recycling. Austria stands out as a regional leader, excelling in municipal waste recycling, innovation, and the use of secondary raw materials, which sets a benchmark for other countries. Slovakia demonstrated remarkable progress in circular material use, achieving the highest increase among all analyzed countries, driven by effective legislative reforms and investments in waste sorting systems. Slovenia and the Czech Republic also performed well, with Slovenia maintaining high recycling rates and the Czech Republic showing steady progress in circular material use, nearing the EU average. Across the region, reductions in GHG emissions, particularly in the energy sector, reflect positive shifts toward renewable energy sources and improved energy efficiency.

Weaknesses

Austria struggles with rising waste generation per capita, highlighting the difficulty of balancing high consumption levels with sustainability goals. Hungary and Poland consistently underperform in waste management and recycling, with declining plastic packaging recycling rates and limited circular material use. Innovation activity remains a significant weakness for Slovakia and Hungary, limiting their ability to adopt advanced circular economy practices. Structural barriers, such as inadequate recycling infrastructure and underinvestment in critical sectors like transportation and agriculture, hinder broader progress across the region.

Opportunities

Expanding recycling infrastructure and public awareness campaigns in countries like Hungary and Poland offer significant potential to improve recycling rates and waste management outcomes. Promoting circular economy strategies in the manufacturing sector, as seen in Poland and Austria, presents an opportunity for further waste reductions through cleaner technologies and digitalization, as also suggested by Del Rio Castro et al. (2020). The transition to renewable energy offers additional opportunities for reducing waste and emissions. Poland's success in reducing waste in the energy sector illustrates the potential for broader adoption of renewables across the region. Strengthening public and private collaboration, as highlighted by Szczepańczyk (2022), could drive technological advancements and enhance the implementation of circular models, particularly in lagging sectors such as manufacturing and energy.

Threats

Economic and structural barriers, including inadequate waste processing infrastructure and low investment levels, pose significant challenges for countries like Hungary and Slovakia. These limitations hinder their progress in adopting circular economy practices and may exacerbate regional disparities. The temporary reductions in waste and emissions observed during the COVID-19 pandemic could obscure underlying inefficiencies, delaying necessary long-term reforms. Despite the implematation of circular economy policies across the region, wide gap between high-performing countries like Austria and lagging ones such as Hungary and Poland is seen. Rising waste generation in key sectors, including construction in Slovakia and Austria and household waste in Poland and Hungary, presents a growing threat to achieving circular economy goals without targeted interventions. The import of non-recyclable materials, such as composites or non-standardized plastics, poses a threat by undermining recycling efforts and increasing reliance on landfills. Without stricter regulations on product design and import standards, such materials could hinder circularity and add environmental burdens.

4 Conclusions

This article analyzes the progress of circular economy implementation in six Central European countries: Slovakia, Hungary, the Czech Republic, Austria, Poland, and Slovenia, focusing on indicators such as waste generation, recycling rates, circular material use, and GHG emissions. The findings reveal diverse performances, with Austria leading in recycling efficiency, innovation, and secondary raw materials use, while Slovakia achieved the largest improvement in circular material use. Slovenia maintained high municipal waste recycling rates, but declines in plastic recycling and circular material use highlight areas needing attention. Hungary and Poland face significant challenges, including declining recycling rates and insufficient infrastructure, particularly in managing household and manufacturing waste. Poland demonstrated some progress by reducing manufacturing waste and achieving the lowest municipal waste per capita, but overall circularity performance remains inconsistent. The Czech Republic showed moderate progress in circular material use but experienced notable declines in plastic recycling.The sectoral analysis highlights critical challenges in construction and manufacturing, where rising waste generation, particularly in Slovakia and Austria,

points to gaps in recycling systems. Energy sector improvements, especially in Poland and Austria, are attributed to shifts toward renewable energy and reduced fossil fuel reliance, aligning with broader sustainability goals. Despite this, the analysis faces several limitations. The data, primarily sourced from EUROSTAT, is constrained by availability, covering only 2018 and 2020, and focuses on a limited set of indicators and countries. Sophisticated statistical methods were not applied, limiting the depth of the findings, and the study could not fully capture the broader dimensions of circular economy dynamics, such as innovation spillovers, or policy interconnections.

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