

Implementing the Circular Economy in Poland's Industrial Sectors

Wdrażanie gospodarki o obiegu zamkniętym w polskich sektorach przemysłu

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This study examines the Circular Economy (CE) in Poland's energy and resource-intensive industries specifically in the steel and metallurgy, cement, chemical and petrochemical, pulp and paper, and glass sectors between 2010 and 2025, using a data-driven benchmarking approach based on national and international statistics. It evaluates how (CE) strategies have mitigated traditionally less efficient industrial practices, characterized by excessive consumption of energy, water, and raw materials. The sectors achieved 15–30% reductions in energy and CO₂ intensity and up to 40–50% savings in water use, reflecting measurable progress toward industrial modernization and sustainability. These gains stem from the gradual adoption of CE principles, technological innovation, and alignment with EU environmental frameworks, though progress remains uneven. Continued investment and cross-sector cooperation are essential to accelerate Poland's transition from regulation to circularity and meet 2050 climate goals.

Key words: resource-intensive industries, industrial sectors, recycling, water intensive, circularity, waste heat recovery

Niniejsze opracowanie koncentruje się na zagadnieniach gospodarki o obiegu zamkniętym (GOZ) w energo, zasobo i materiałochłonnych gałęziach przemysłu w Polsce, w wybranych sektorach: stalowym i metalurgicznym, cementowym, chemicznym i petrochemicznym, papierniczym oraz szklarskim, w latach 2010–2025. Analiza opiera się na podejściu benchmarkingowym wykorzystującym krajowe i międzynarodowe dane statystyczne. Oceniono, w jaki sposób strategie (GOZ) przyczyniły się do ograniczenia tradycyjnych, mniej efektywnych praktyk przemysłowych, cechujących się nadmiernym zużyciem energii, wody i surowców. Sektory te osiągnęły 15–30% redukcję zużycia energii i emisji CO₂, oraz do 40–50% oszczędności w zużyciu wody, co odzwierciedla postęp w kierunku modernizacji przemysłu i zrównoważonego rozwoju. Osiągnięcia te wynikają ze stopniowego wdrażania zasad (GOZ), innowacji technologicznych oraz dostosowywania się do unijnych ram środowiskowych. Niezbędne są jednak dalsze inwestycje i współpraca międzysektorowa, aby przyspieszyć przejście Polski od regulacji do pełnego wdrożenia (GOZ) oraz realizacji celów klimatycznych do 2050 roku.

Słowa kluczowe: branże o wysokim zużyciu zasobów, sektory przemysłowe, recykling, wodochłonne, gospodarka o obiegu zamkniętym, odzysk ciepła odpadowego

Topic Overview and Purpose

Between 2010 and 2025, Poland's policy landscape for circularity and resource efficiency advanced in step with EU legislation, although implementation occurred in a staggered manner across energy, water, and material-intensive sectors. Key milestones include the national Circular Economy Roadmap (2019), updates to the National Energy and Climate Plan (drafted 2024 with subsequent refinements in 2025) [9][19], and market instruments such as the nationwide deposit-return scheme (in force from 1 Oct 2025) alongside an overhauled extended-producer-responsibility framework for packaging now being rolled out [3].

Sector-focused CE actions for steel, cement, chemicals and glass prioritize: Best available techniques (BAT), industrial emissions directive (IED) compliance and process electrification; high-efficiency heat recovery and fuel switching; closed-loop water sys-

tems with tighter water-law permitting; secondary raw-material uptake (slag, fly ash, cullet); product-design and extended producer responsibility (EPR) alignment; and digital monitoring, reporting and verification (MRV) enabling industrial symbiosis in clusters [10]. Barriers remain significant: legacy coal-based energy inputs, capex constraints for deep retrofits, permitting complexity (water and integrated), heterogeneous waste/feedstock quality, and skills gaps for advanced process control. Nonetheless, the combination of EU compliance pressure, national CE instruments, and company-level investments is beginning to shift heavy industry toward lower-carbon, lower-water, and higher-circularity operations [8].

Between 2010 and 2025, Poland's implementation of EU Circular Economy directives proved gradual and challenging. Limited technological capacity, high investment needs, and administrative fragmentation slowed progress, particularly in waste man-

agement and resource intensive industrial sectors. Despite these barriers, continuous reforms and EU funding have gradually strengthened Poland's ability to align with European environmental and (CE) standards [14].

Poland's resource-intensive industries comprising steel, cement, chemical, pulp & paper, and glass remains the nation's core consumer of energy and materials, and a major source of inefficiency and waste. Huge losses of energy, water, and raw materials make these sectors central to (CE) action, where improved resource recovery and process efficiency can drive decarbonisation, industrial modernization, and support sustainability toward future goals. Recent EU-wide research confirms that economic, technological, and environmental drivers jointly accelerate the transition from regulation to circularity in industrial systems [16].

This study examines trends in energy, water, material, and CO₂ intensity in Poland's energy-intensive industries over 2010–2025

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using a data-driven benchmarking approach based on national and international statistics [2][12] [18]. Using a data-driven baseline indicators were derived from EU (BAT), best available techniques (BAT) reference document (BREF) benchmarks, Eurostat, GUS, and sectoral reports, with efficiency gains modeled through sector-specific reduction rates [3][4] [13][15][17]. The used data in the next figures are provisional, based on the latest available estimates as of October 2025, and are methodologically justified despite their projected nature.

Methodology

This study applies a data-driven benchmarking approach to evaluate trends in energy, water, material, and CO₂ intensity in Poland's energy-intensive industries for the period 2010–2035. Baseline values were derived from EU BAT/BREF benchmarks, Eurostat, GUS, and sectoral reports, complemented by the most recent national projections available as of October 2025 [3-4][12-13] [15][17-18]. Due to inconsistencies in data coverage and methodology across sectors, all indicators were harmonized and normalized to a 1–10 scale. This scale reflects relative performance, enabling transparent cross-sector comparisons of transformation dynamics without implying absolute efficiency levels.

Sector-specific reduction rates and historical efficiency trends were used to model indicative improvement pathways. The harmonized dataset supports comparative assessment across heterogeneous indicators and highlights differences in sectoral progress toward cleaner technologies. Although the most recent values are provisional, the adopted normalization and benchmarking approach ensures methodological consistency across all sectors.

The 2030–2035 values shown in the figures represent model-based projections derived from extrapolated historical trends, sector-specific efficiency improvement rates, and EU reference climate and energy scenarios. Given uncertainties related to policy development, technology uptake, and macroeconomic conditions, these values should be interpreted as indicative rather than predictive. An uncertainty range of ±10–20% is assumed, which aligns with typical variability in long-term industrial performance modelling.

CE Policy Evolution and Industrial Decarbonisation Opportunities

This section provides an integrated overview of the evolution of circular economy (CE) policies in the EU and Poland (2008–2025) and their relevance for Energy-, water-, and material-intensive industrial sectors. It presents the main CE-related technological processes, sector-specific decarbonisation opportunities, and indicative CO₂ reduction potentials. The aim is to contextualise Poland's industrial trans-

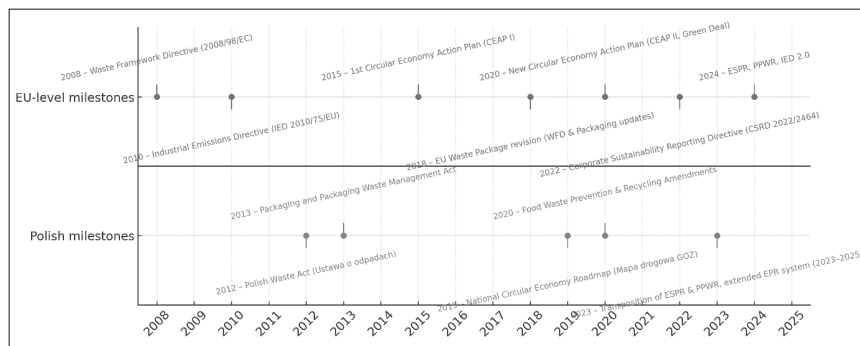


Figure (1) Overview of (CE) policy development (EU) and Poland (2008-2025)

Figure (2) Circular Economy evolution in the (EU) and Poland (2008–2024)

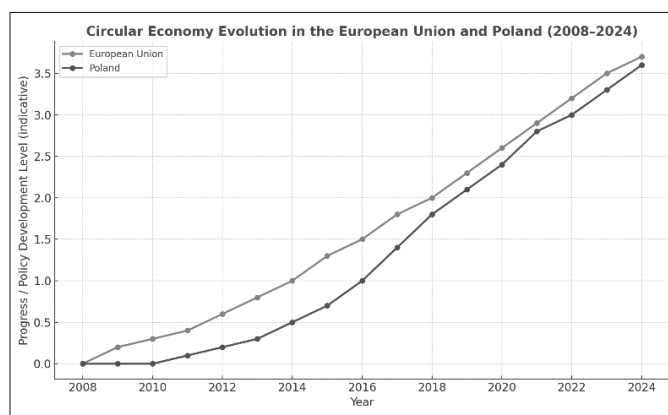


Table (1) Main Energy intensive technological processes and key (CE) decarbonisation opportunities

| Industrial Sector | Main Energy-Intensive Processes | Temperatures (°C) Typical Process | Main CE Decarbonisation Opportunities |
|--------------------------|--|---|---|
| Steel & Metallurgy | Coke ovens, sinter plants, blast furnace (BF), basic oxygen furnace (BOF), electric arc furnace (EAF), reheating & rolling mills | BF hot blast 1100–1350; molten steel 1500–1650; reheating 1100–1250 | <ul style="list-style-type: none"> Shift to scrap-based EAF production Waste heat recovery (sinter, BF stoves) Hydrogen/electric reheating pilots Slag reuse in cement CCS/CCU & digital efficiency upgrades |
| Cement | Raw milling, preheater/precalciner, rotary kiln, clinker cooler, finish grinding | Clinker 1400–1450; flame up to 2000; preheater 300–900 | <ul style="list-style-type: none"> High alternative fuels (>80%) Clinker substitution (slag, fly ash, calcined clay) Waste heat recovery Electrified kilns/CCUS readiness Low-clinker cement standards |
| Chemical & Petrochemical | Steam generation, urnaces (crackers, reformers), compressors, distillation, hydrogen units | Steam cracking 700–950; steam 150–540 | <ul style="list-style-type: none"> Electrify heaters/furnaces Heat integration & recovery Circular feedstocks (plastic pyrolysis, bio-based) CO₂ utilisation & CCS Efficiency upgrades at Orlen/Azoty sites |
| Pulp & Paper | Digesters, recovery boiler, lime kiln, paper machine drying | Digester 150–180; drying 100–180; boiler >400 (gas side) | <ul style="list-style-type: none"> Black liquor energy recovery Heat pumps & condensate reuse Biomass residues to bio-products Electrify lime kilns Higher recycled fibre share |
| Glass | Batch preheating, melting furnace, forehearth, forming, annealing lehrs | Melting 1400–1600; forehearth 700–1200; regenerators ~1550 | <ul style="list-style-type: none"> Increase cullet content Hybrid/electric furnaces Waste heat recovery (regenerators, lehrs) Lightweighting & product design CCS readiness on large furnaces |

formation within broader EU strategic frameworks and to identify key leverage points for improving resource efficiency and reducing environmental impacts.

Figure (1) illustrates the progressive alignment between the milestones established at the EU level defined as major progress checkpoints or targets agreed upon by EU institutions and member states to monitor the implementation of EU-wide goals, reflecting the evolution of European Union policies (upper part of the Figure 1) and the corresponding national implementation milestones in Poland (lower part of the Figure 1). It highlights how Poland's (CE) framework has evolved in parallel with EU directives and strategic objectives from 2008 to 2025 [1].

Figure (2) compares the progressive development of (CE) frameworks in the EU and

Poland 2008-2024. The EU shows an earlier and steadier policy evolution, while Poland's progress accelerates after 2015 with the transposition of EU directives and adoption of national CE strategies, reaching near alignment by 2024 [11].

The assessment covers five key resource-intensive industries: steel and metallurgy, cement, chemical and petrochemical, pulp and paper, and glass. It draws on the most recent policy, technical, and statistical sources, including the European Environment Agency (EEA)'s (CE) country profile – Poland (2024), WiseEuropa's Poland Heavy Industry Decarbonisation Roadmap (2024), sector-specific Best Available Techniques (BAT) and BAT reference documents, and reports from the Ministry of Climate and Environment (2024–2025) [6].

Table (2) Main water intensive technological processes and key (CE) opportunities

| Industrial Sector | Main water-Intensive Processes | Specific Water Use (m ³ / t product) | Functions/Uses of water | Circular / Efficiency Opportunities |
|--------------------------|--|--|--|---|
| Steel & Metallurgy | • Cooling for BF, BOF, EAF, casting, rolling • Wet gas cleaning, quenching, descaling | 5 – 15 m³/t crude steel (older open circuits); < 3 m³/t in modern recirculating systems | ~90 % cooling (indirect or direct); remainder for process, steam, gas cleaning | • Closed-loop cooling (> 95 % reuse achievable) • Dry gas cleaning • Descaling water recycling • Condensate recovery |
| Cement | • Equipment cooling • Wet milling and slurry prep (if any) • Dust suppression | 0.1 – 1.5 m³/t clinker (dry process at lower end) | Cooling, dust control, service water | • Dry-process kilns • Closed-loop cooling • Quarry-pit & rainwater reuse • Dry dust suppression |
| Chemical & Petrochemical | • Cooling towers, heat exchangers • Steam generation, process washing • Feedstock purification | 10 – 100 m³/t product , wide range depending on process: e.g. ammonia/fertiliser ≈ 20–40 m ³ /t; petrochemicals ≈ 10–25 m ³ /t | Cooling > 80 %; process & washing; boiler feed | • Recirculating cooling systems • Advanced tower control • Treated-effluent reuse • Membrane/ZLD pilots • Industrial-park water loops (Plock, Puławy) |
| Pulp & Paper | • Pulp washing, bleaching • Paper machine forming, pressing, drying | 10 – 50 m³/t paper (best available < 10 m ³ /t; Polish average ≈ 20 m ³ /t) | Process water for washing, dilution, cooling; steam; seal water | • White-water & condensate reuse • Counter-current washing • Closed-loop water circuits • Dry forming & improved pressing |
| Glass | • Furnace & forehearth cooling • Mould andlehr cooling • Cullet washing, gas-scrubber water | 1 – 5 m³/t glass (container glass ≈ 1–2; flat glass ≈ 3–5) | Cooling, washing, quenching | • Closed-loop cooling • Air-cooled systems • Dry gas cleaning • Cullet-wash water reuse |

Table (3) Main material intensive technological processes and key CE opportunities

| Industrial Sector | Main Material-Intensive Processes | Material Input Intensity (t input / t product) | Key Raw Materials | CE / Material Efficiency Opportunities |
|--------------------------|---|--|--|--|
| Steel & Metallurgy | • Iron ore sintering/pelletizing • Coke and coal for reduction • Fluxes (limestone, dolomite) • Scrap melting in EAF • Slag handling & recycling | Iron route: 1.4–1.6 t iron ore + 0.4 t coke + 0.05 t flux → 1 t crude steel EAF route: ~1.05 t scrap → 1 t steel | Iron ore, coking coal, scrap, limestone/dolomite, alloys | • Increase scrap-based EAF share (currently ~40–45% in Poland) • Slag recycling into cement/construction • Dust and sludge recovery for Zn/Fe • By-product circular loops (tar, ammonia, BF gas) |
| Cement | • Quarrying & crushing (limestone, marl, clay) • Raw meal preparation • Clinker production (calcination of CaCO ₃) • Additive blending (gypsum, SCMs) | ~1.5–1.6 t raw materials → 1 t clinker ~1.2–1.3 t clinker + additives → 1 t cement | Limestone/marl, clay/shale, sand, iron ore, gypsum, SCMs (slag, fly ash) | • Replace clinker with SCMs (slag, fly ash, calcined clay) • Use waste-derived raw materials (spent foundry sand, ash) • Quarry rehabilitation and material recovery • CO ₂ and dust capture for reuse |
| Chemical & Petrochemical | • Steam cracking, reforming, ammonia, fertilizer, polymerization • Feedstock: hydrocarbons, natural gas, naphtha, air (N ₂), water | Highly variable: Ammonia: ~0.9 t natural gas → 1 t NH ₃ Ethylene: ~3.3 t naphtha → 1 t ethylene Methanol: ~0.8 t natural gas → 1 t MeOH | Natural gas, naphtha, air, sulfur, catalysts, water | • Feedstock substitution (bio-based, recycled CO ₂ , circular plastics oil) • Internal by-product recovery (H ₂ , CO ₂) • Waste-stream valorisation (e.g., pyrolysis oils) • Chemical recycling of plastics • Material integration within industrial clusters (e.g. Plock, Puławy) |
| Pulp & Paper | • Wood debarking, chipping • Pulping (mechanical or chemical kraft) • Bleaching • Paper forming and coating | 3–5 t wood (or equivalent fibre) → 1 t pulp 1.1–1.3 t pulp → 1 t paper Recycled fibre route: ~1.05 t recovered paper → 1 t paper | Wood (spruce, pine), recycled paper, chemicals (NaOH, Na ₂ S, ClO ₂ , fillers, starch) | • Increase recycled fibre share (>70% achievable) • Fibre loss recovery and sludge valorisation • Ash and lime mud reuse • Bio-based chemical recovery • Product lightweighting and recyclability |
| Glass | • Batch mixing (silica sand, soda ash, limestone, dolomite) • Melting and refining • Cullet addition | 1.2–1.4 t raw materials → 1 t glass Each 10% cullet reduces virgin raw need by ~12% | Silica sand, soda ash, limestone, dolomite, feldspar, cullet | • Increase cullet share (container glass up to 90%) • Waste glass collection & DRS integration • Fines reuse and remelting • Batch optimization and dust recycling • Lightweighting of bottles and flat glass |

Due to limited cross-sector data consistency, results were normalized on a 1–10 scale to reflect relative progress and performance levels rather than absolute values [5]. This method provides a transparent, comparative view of sectoral transformation, highlighting where progress is most advanced and where systemic barriers remain. Table (1) presents the main technological processes and key (CE), Poland relevant decarbonisation opportunities for Poland's energy-intensive industries [1–6][11–13][15–18].

Table (2) presents the main technological processes and key (CE), Poland relevant decarbonisation opportunities for Poland's water-intensive industries [1–6][11–13][15–18].

Table (3) presents the main technological processes and key (CE), Poland relevant decarbonisation opportunities for Poland's material-intensive industries [1–6][11–13][15–18].

Table (4) presents CO₂ emissions from Poland's energy-intensive industries (2010–2025) and the impact of (CE) implementation in resource-intensive industries [1–6][11–13][15–18].

Table (5) presents the reductions achieved in energy use (GJ/t), water consumption (m³/t), material input (t input/t product), and CO₂ intensity (t CO₂/t product) over the 15-year period (2010–2025),

Table (4) Estimated CO₂ reductions and the main mechanisms of CO₂ reductions

| Industrial Sector | Estimated CO ₂ Reduction by CE Actions | Indicative CO ₂ Intensity Change (t CO ₂ /t product) | Mechanisms of Reduction |
|--------------------------|---|--|--|
| Steel & Metallurgy | 15–25 % reduction vs 2010 baseline | 2010 ≈ 2.0 → 2025 ≈ 1.6 | • Using scrap avoids CO ₂ from ore reduction • Reduced coke use • Energy savings from recycling routes |
| Cement | 20–30 % reduction | 2010 ≈ 0.75 → 2025 ≈ 0.55 | • Lower clinker ratio cuts process (calcination) CO ₂ • Waste-derived fuels offset fossil CO ₂ • Efficiency improvements |
| Chemical & Petrochemical | 10–15 % reduction | 2010 ≈ 1.5 → 2025 ≈ 1.3 | • Recycled/biogenic feedstocks lower Scope 1 & 3 emissions • Process integration reduces fuel use |
| Pulp & Paper | 25–35 % reduction | 2010 ≈ 0.9 → 2025 ≈ 0.6 | • Recycled fibre avoids forest carbon emissions • Biomass fuels replace fossil heat • Heat recovery lowers fossil energy |
| Glass | 15–25 % reduction | 2010 ≈ 0.8 → 2025 ≈ 0.6 | • Each 10 % cullet reduces furnace CO ₂ ≈ 5 % • Electric/hybrid melting lowers fossil combustion |

Table (5) Reductions achieved in energy, water, material consumption and reduction of CO₂

| Industrial Sector | Saved Energy (GJ/t) | Saved Water (m ³ /t) | Saved Material (t input/t product) | Reduction of CO ₂ (t CO ₂ /t product) |
|-------------------------------------|-------------------------------|---------------------------------|------------------------------------|---|
| Steel & Metallurgy | 5.0 (22 → 17; ≈23%) | 5.0 (10 → 5; 50%) | 0.16 (1.50 → 1.34; ≈11%) | 0.40 (2.0 → 1.6; 20%) |
| Cement | 0.6 (3.6 → 3.0; ≈17%) | 0.5 (1.0 → 0.5; 50%) | 0.18 (1.55 → 1.37; ≈12%) | 0.20 (0.75 → 0.55; ≈27%) |
| Chemical & Petrochemical | 4.0 (32 → 28; ≈13%) | 7.0 (35 → 28; ≈20%) | 0.26 (3.00 → 2.74; ≈9%) | 0.20 (1.5 → 1.3; ≈13%) |
| Pulp & Paper | 3.0 (12.5 → 9.5; ≈24%) | 13.0 (25 → 12; ≈52%) | 0.17 (1.25 → 1.08; ≈14%) | 0.30 (0.9 → 0.6; ≈33%) |
| Glass | 3.5 (16 → 12.5; ≈22%) | 1.0 (3.0 → 2.0; ≈33%) | 0.15 (1.25 → 1.10; ≈12%) | 0.20 (0.8 → 0.6; ≈25%) |

resulting from the implementation of (CE) measures across the mentioned intensive industry sectors in Poland [1–6][11–13][15–18].

Interpretation: In this table each value is presented as absolute saving (2010 → 2025; % reduction). For example, 5.0 (22 → 17;

≈ 23%) means that intensity fell from 22 to 17 units per tonne, saving 5 units. So 23% decrease over 2010–2025. The same format applies to energy (GJ/t), water (m³/t), materials (t/t), and CO₂ emissions (t CO₂/t).

Presentation of Results

The results of the analysis show that implementing (CE) measures has led to measurable reductions in energy, water, material, and CO₂ intensity across Poland's resource-intensive industries between 2010 and 2025. The greatest improvements oc-

curred in the cement and steel sectors, driven by actions such as waste heat recovery, material substitution, and scrap-based production. In contrast, the chemical and petrochemical sectors showed slower progress due to high energy demands and limited substitution options. Overall, CE-driven measures outperformed baseline trends, confirming their essential role in advancing industrial efficiency and decarbonisation in Poland. The Figures 3, 4, 5 below present the energy, water, material intensity trend by mentioned industrial sectors (2010–2025) [1–6][11–13][15–18].

Figure (6) shows Poland's Energy intensity reduction and CO₂ emissions intensity for the mentioned industrial sectors (2010–2025) vs. (2010) baseline [1–6][11–13][15–18].

Figure (7) presents two line charts illustrating trends in recycling and circular material use in Poland from 2010 to 2025 across five industrial sectors [1–6][11–13][15–18]. The data represent the share of material resources recovered from waste and reintroduced into the economy relative to total material use. The left chart shows national recycling and circular material use trends (2010–2025), while the right chart illustrates the progress in recycling rates by sector over the same period, measuring the proportion of waste materials that are collected, processed, and reintegrated into production.

Figure (8) illustrates the long-term trends in recycling, circular material use, and land-filling in Poland from 2010 to 2035, showing an expected shift toward more sustainable waste management practices. The figure also presents the share of total waste disposed of in landfills, indicating the extent to which waste management relies on land burial rather than material recovery or recycling.

Figure (8) indicates that Poland is expected to undergo a significant transition toward a (CE), with recycling and material reuse projected to rise steadily while landfilling is anticipated to decline rapidly. The trend suggests that by 2035, Poland could have a high-recycling, low-landfill waste management system with a strong circular material loop.

Discussion of Results

This study consolidates evidence on energy, water, material, and CO₂ intensity trends across Poland's five energy-intensive industries: steel and metallurgy, cement, chemical and petrochemical, pulp and paper, and glass between 2010 and 2025, using benchmarks consistent with EU (BAT) and (BREF), national and international statistics and sources.

In steel and metallurgy, greater use of electric-arc furnaces, scrap recycling, and heat recovery reduced energy and CO₂ intensity by roughly 20–25% and water use by over 50%.

In the cement sector, clinker substitution, alternative fuels, and waste-heat recovery supported 15–20% energy and 25–30% CO₂ savings.

Chemical and petrochemical plants improved heat integration and adopted circular feedstocks, achieving around 10–15% efficiency gains.

The pulp and paper industry reduced energy by 20–30%, water by up to 50%, and CO₂ by 25–35% through fibre recycling, circuit closure, and bioenergy use.

In glass manufacturing, higher cullet ratios and hybrid/electric furnaces enabled 15–25% energy and CO₂ reductions.

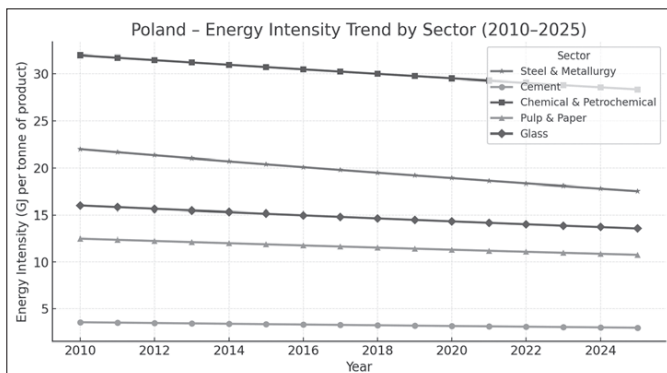


Figure (3)
Poland's energy intensity trend

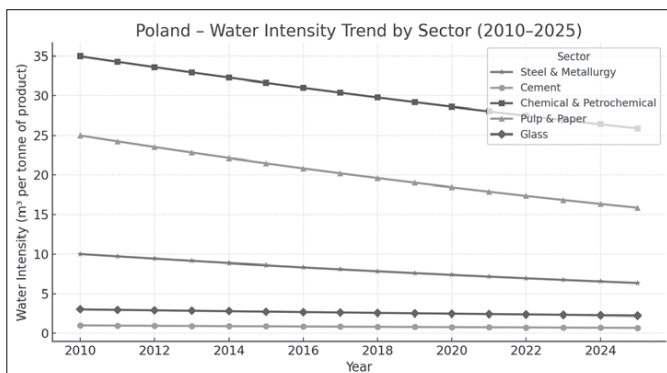


Figure (4)
Poland's water intensity trend

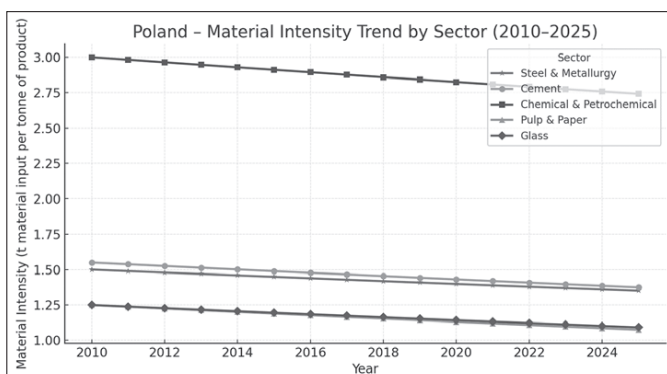


Figure (5)
Poland's material intensity trend

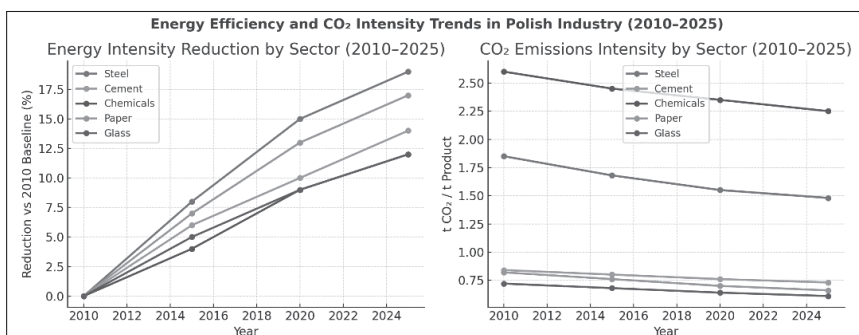


Figure (6)
Poland's energy intensity reduction (on left) and CO₂ emissions intensity (on right) vs. (2010) baseline

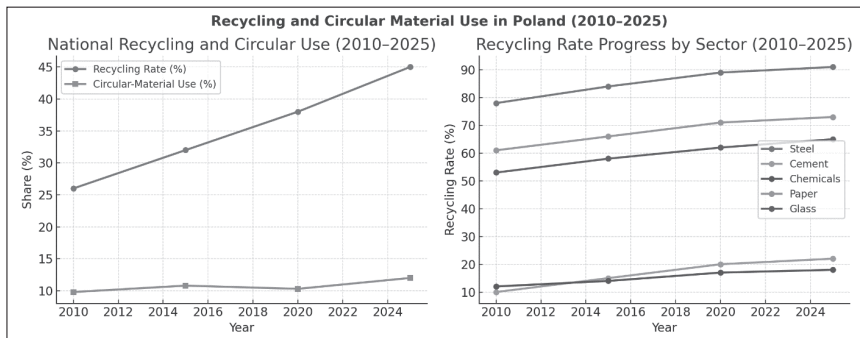


Figure 7) Recycling and circular material use in Poland (2010–2025), national recycling and circular use (on left) and recycling rate progress by sector (on right)

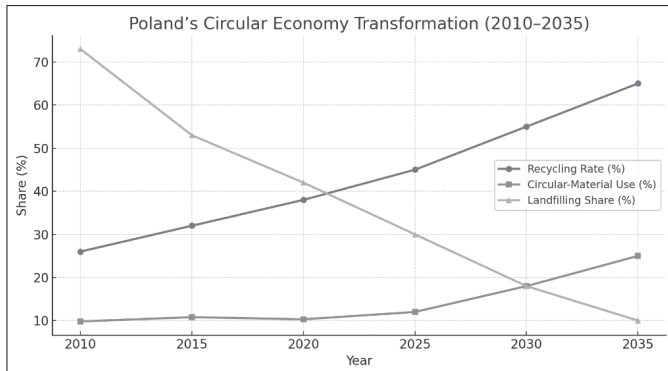


Figure 8) Poland's (CE) transformation (2010–2035)

As illustrated in Figure (8), Poland is experiencing a dynamic transition toward a (CE). Recycling and reuse rates are steadily increasing, while landfilling is rapidly declining. If current trends continue, Poland is expected to establish by 2035 a highly recycling-oriented, low-landfill waste management system supported by a robust circular material flow.

Conclusion:

The main outcomes of this research can be summarized in the following key points:

- The analysis reveals moderate but steady improvements in energy, water, material, and emissions performance across Poland's energy-intensive industries between 2010 and 2025, which are driven mainly by (CE) initiatives, improved resource management, regulatory alignment with EU policies, and the gradual adoption of sustainable industrial practices.
- Across the steel and metallurgy, cement, chemical and petrochemical, pulp and paper, and glass sectors, the data show gradual progress in energy efficiency, resource optimization, and emission reduction, although the scale and pace of improvement varied by industry.
- Overall, the sectors achieved 15–30% reductions in energy and CO₂ intensity and up to 40–50% water savings, reflecting growing alignment with (CE) principles and EU sustainability policies.
- Progress remains uneven across sectors, underscoring the need for continued

technological innovation and stronger regulatory and financial support.

Achieving Poland's 2050 climate and sustainability goals is expected to require deeper integration of the (CE), broader deployment of low-carbon technologies, and enhanced cross-sector collaboration.

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