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Global Adoption of ISO 59000 Circular Economy Standards in Construction: A Cross-Country Benchmarking Study Using Normalized Circularity Indicators

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This paper benchmarks the global adoption of the ISO 59000 family of circular economy (CE) standards in the construction sector. This study develops a Circular Economy Standards Implementation Score (CESIS) that integrates ISO 59004 (principles and actions), ISO 59010 (business models and value networks), ISO 59020 (measurement and performance), ISO 59014 (traceability of secondary materials), and ISO 59040 (product circularity data sheets). Countries are assessed through a combination of policy review and quantitative resource-efficiency indicators, including material footprint (MF), domestic material consumption (DMC), and material productivity. To ensure comparability, CESIS values are normalized against socio-economic and environmental indicators rather than relying solely on Gross Domestic Product (GDP). Results reveal strong regional variation: EU countries score higher on measurement and reporting alignment, while non-EU high-income nations demonstrate mixed outcomes in material productivity and secondary materials traceability. The analysis identifies associations between CESIS and circularity indicators, offering a replicable benchmarking framework for policymakers, contractors, and educators. The study concludes with recommendations for integrating ISO 59020 indicators and ISO 59040 product data into construction project management and procurement practices to accelerate global circular economy transitions.

Keywords: Circular Economy, ISO 59000, Resource Efficiency, Benchmarking, Sustainable Development

Introduction

Construction's material intensity is both an opportunity and a challenge for sustainable development. Global material extraction has nearly quadrupled since 1970 and is projected to grow by approximately 60% by 2060, intensifying pressures on climate, biodiversity, water, and land systems (International Resource Panel (IRP), 2020; Organisation for Economic Co-operation and Development (OECD), 2019). In most economies, construction and the production of its inputs, aggregates, cement, steel, glass, and timber dominate domestic material consumption and a large share of consumption-based "material footprints," driving embodied energy and emissions in buildings and infrastructure (Hertwich et al., 2020; Zhu et al., 2022). While process efficiency, design optimization, and low-carbon materials are steadily improving, recent syntheses warn that efficiency

alone cannot meet sustainability targets without structural shifts in sourcing, circulation, and recovery of materials (Gallego-Schmid et al., 2020; International Resource Panel (IRP), 2020).

The circular economy (CE) concept has matured quickly in construction research. Systematic reviews document momentum in design-for-disassembly, adaptable buildings, high-value recycling, and product-service models, but also highlight persistent barriers: fragmented definitions, limited traceability for secondary materials, market uncertainty, and the absence of harmonized indicators (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Krajewska & Siewczyńska, 2025; Moustafa et al., 2025; Zink & Geyer, 2017). Construction and demolition waste (CDW) remains a key circularity vector, yet downcycling and quality uncertainty can blunt systemic gains unless paired with design standards, sorting protocols, and verified recycled content pathways (Papamichael et al., 2023; Pomponi & Moncaster, 2017). In parallel, digital construction research shows that information infrastructures, Building Information Modeling (BIM), material passports, and digital product passports (DPPs), can embed circularity upstream and derisk secondary markets by reducing information asymmetry and transaction costs (Akanbi et al., 2018; European Parliament. Directorate General for Parliamentary Research Services, 2024; Lima et al., 2023; Zhang & Seuring, 2024). Key terms used in this paper are defined as follows. A material passport is a structured record of a building's material composition, location, and recovery potential used to enable reuse and high-value recycling. A digital product passport (DPP) is a standardized digital record of product attributes (e.g., origin, content, environmental data) intended to support compliance, transparency, and circular procurement. Construction and demolition waste (CDW) management refers to regulated collection, sorting, recovery, and disposal pathways; CDW protocols are formal procedures that standardize sorting, quality assurance, and documentation for recovered materials. Product-as-a-service (PaaS) pilots are trial programs where suppliers retain ownership and provide performance-based access, enabling take-back and refurbishment.

The ISO 59000 family (2024-2025) arrives as a timely "language" for translating CE ideals into implementable governance: ISO 59004 clarifies vocabulary and principles; ISO 59010 orients business models and value-network transitions; ISO 59014 establishes principles and requirements for the traceability and quality of recovered secondary materials; ISO 59020 specifies indicators and performance assessment; and ISO 59040 operationalizes product-level circularity data sheets (PCDS) for sectoral use, including construction (ISO, 2024a, 2024b, 2024c, 2024d, 2024e). These standards describe inputs, what effective CE governance should contain, not the outcomes per se. This separation matters because governance can move faster than economy-wide material flows, especially in construction where capital stocks turn over slowly (Hertwich et al., 2020).

Two research strands frame our study. First, the decoupling literature tests whether economies can grow while stabilizing or reducing material use; recent cross-country analyses show mixed progress, with some EU countries exhibiting relative or episodic absolute decoupling and high-consumption contexts remaining material-intensive per unit GDP (Guo et al., 2025; Schandl et al., 2024). Second, implementation studies emphasize that standardized indicators and product-level data are preconditions for scale, without credible measurement and traceability, pilots remain pilots and secondary markets stay thin (European Commission, 2020, 2022; European Parliament. Directorate General for Parliamentary Research Services, 2024). Building on these strands, we evaluate CE governance inputs independently from outcomes and then examine their association.

1.1 Contributions and research questions

We contribute a replicable governance index, CESIS, aligned one-to-one with the ISO 59000 series, and we benchmark CESIS against synchronized 2019 material-flow outcomes. The design enables

transparent, construction-specific comparison without mixing policies and outcomes into a single composite. Our four research questions (RQs) are:
RQ1. To what extent have countries adopted ISO-aligned CE governance across five domains relevant to construction (ISO 59004/59010/59014/59020/59040)?
RQ2. How do CESIS scores relate to 2019 outcomes (MF/GDP, DMC/capita, GDP/DMC)?
RQ3. Do groupwise patterns among EU27, USA, Canada, and emerging economies reveal governance-performance alignment versus structural drivers?
RQ4. Which governance domains align most with efficiency outcomes, indicating near-term policy levers?

Methodology

Study design and scope

This is a cross-country benchmarking study that deliberately separates governance inputs from material-flow outcomes. Governance is operationalized through a new, standards-aligned index, the Circular Economy Standards Implementation Score (CESIS), that records whether a country has put in place instruments consistent with the ISO 59000 family. Outcomes are captured with globally comparable economy-wide material flow indicators synchronized to 2019 (material footprint intensity, domestic material consumption per capita, and material productivity). The sample comprises EU27 (aggregate), Germany, France, the Netherlands, the United States, Canada, Japan, China, India, Brazil, South Africa, and Romania, selected as a purposeful benchmark set spanning (i) high-policy-maturity contexts, (ii) high-income non-EU economies with differing governance structures, and (iii) emerging economies with distinct construction growth and material-intensity trajectories. While not globally representative, the set enables transparent cross-context benchmarking and replication for future expansion. Although ISO 59000 standards were published in 2024-2025, CESIS is designed to capture whether countries have governance instruments consistent with ISO-aligned principles and domain requirements, many of which predate formal publication. Outcomes are synchronized to 2019 to maximize cross-country comparability and avoid pandemic-era volatility (Eurostat, 2025; Schandl et al., 2024); governance-to-outcome relationships are therefore interpreted as lagged and associative rather than immediate effects.

CESIS: standards-aligned governance index

CESIS maps to five ISO 59000 domains scored 0-2 each: 59004 (principles/framework), 59010 (business models and value networks), 59014 (traceability and quality for secondary materials), 59020 (indicators/monitoring with custodianship and methods), and 59040 (product-level circularity data, PCDS/DPP, relevant to construction). Scores reflect national-level instruments; sub-national or pilot-only activity scores “1.” A “2” requires a national instrument or wide deployment with construction levers (e.g., public procurement language for product data; national protocols for recycled aggregates/steel; official indicator portals with documented methods/frequency). The unweighted composite ranges 0-10 and is purposefully transparent.
A three-point scale (0/1/2) was selected to reduce false precision and improve reliability in cross-country policy coding while still representing governance maturity (absent → partial/pilot → institutionalized). A score of 1 reflects sub-national instruments, pilots, or sectoral programs without nationwide implementation. A score of 2 requires a national mechanism (or equivalent broad deployment) with explicit construction leverage (e.g., procurement requirements, mandated reporting, national quality/traceability protocols, or recurring indicators with an official custodian).

$$\mathrm{CESIS} = \sum_{d=1}^{5} S_d \ , \ S_d \in \{0, 1, 2\}, \text{ range 0-10}$$

Evidence identification and coding protocol

For each country, we assembled an evidence pack of laws/strategies, programs and procurement frameworks, regulatory guidance and quality protocols for CDW/secondary materials, official statistical portals (DMC/MF/productivity), and product-data pilots or requirements. A two-pass coding protocol was used (primary coding + audit), resolving disagreements by consensus and defaulting to the conservative lower score when uncertainty remained. Economy-wide measures counted fully only when at least one explicit construction lever was present. We tracked raw agreement and noted recurring ambiguities, most commonly in 59010 (boundary between program announcements and operational platforms) and 59040 (fast-moving pilots vs. formal tender requirements).

Outcomes and normalization

We benchmark governance against three outcomes: MF/GDP (kg per US$; consumption-based raw-material equivalents via Multi-Regional Input-Output (MRIO)), DMC/capita (t/person; territorial apparent consumption), and Material Productivity (US$/kg = GDP/DMC). We exclude EU's Circular Material Use Rate (CMUR) due to limited global coverage. Units were harmonized before ratio formation; GDP and DMC were aligned to 2019; missing MF values were not imputed. To support comparability, we report groupings (EU27, USA, Canada, Other Developed, Emerging) and rely on internationally harmonized series (IRP; Eurostat; Organisation for Economic Co-operation and Development (OECD)/Our World in Data (OWID)) rather than heterogeneous national estimates. Normalization used min-max scaling:

$$X'i = (Xi - \min(X)) / (\max(X) - \min(X))$$

where Xi is the country value and X′i is the normalized value in [0,1]. Figure 1 summarizes the overall study workflow, showing how ISO-aligned governance evidence is translated into CESIS domain scores and then benchmarked against normalized 2019 material-flow performance indicators.

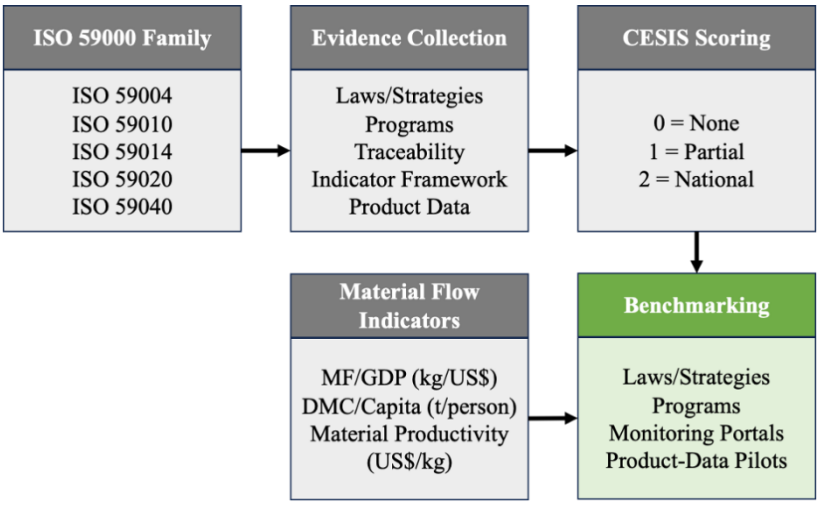

Figure 1. Methodology workflow linking ISO-aligned governance inputs and outcomes

Results

Overview of CESIS governance adoption

Material-flow performance varies systematically across countries (see Table 1), consistent with the workflow separating governance inputs from outcomes (see Figure 1). As the 2019 indicators show, Japan anchors the low-intensity/high-efficiency end with MF per GDP of 0.20 kg/US$, the lowest DMC/capita (10.2 t/person), and the highest material productivity (5.0 US$/kg). EU economies occupy a favorable band; EU27 (0.26 kg/US$, 13.0 t/person, 3.8 US$/kg), France (0.25, 11.5, 4.0), Netherlands (0.23, 13.3, 3.6), and Germany (0.30, 11.7, 4.2). North America records higher intensity and scale; United States (0.40, 20.5, 2.5) and Canada (0.42, 24.8, 2.4). Emerging economies are more dispersed, from India (0.70, 9.5, 1.2) and China (0.55, 23.0, 1.8) to Romania (0.30, 14.0, 3.1). Overall, Table 1 indicates that efficiency (lower MF/GDP, higher GDP/DMC) does not necessarily track with consumption scale (DMC/capita), which is shaped by structural factors such as settlement patterns, industrial mix, and stock turnover.

Table 1. Material flow indicators (2019 baseline)

Country	MF (t/capita)	MF per GDP (kg/US$)	DMC per Capita (t/capita)	Material Productivity (US$/kg)	Evidence	Group
EU27 (aggregate)	14.1	0.26	13	3.8	EU CEAP (2020)	EU27
Germany	15.98	0.3	11.7	4.2	KrWG (circular economy law)	Other Developed
France	13.4	0.25	11.5	4	AGEC (EPR for building products)	Other Developed
Netherlands	12.5	0.23	13.3	3.6	NL CE 2050	Other Developed
United States	26.7	0.4	20.5	2.5	US Buy Clean	USA
Canada	30.5	0.42	24.8	2.4	Canada FSDS 2022-26	Canada
Japan	11.7	0.2	10.2	5	Japan SMCS Act	Other Developed
China	20.8	0.55	23	1.8	China CE Promotion Law	Emerging
India	8.1	0.7	9.5	1.2	India C&D Rules 2016	Emerging
Brazil	14.9	0.38	16.5	2.6	Brazil PNRS	Emerging
South Africa	17.6	0.46	18.2	2.2	SA National Waste Strategy	Emerging
Romania	12.3	0.3	14	3.1	EU acquis applies in Romania	Emerging

ISO-aligned governance helps explain these efficiency differences (Table 2). The CESIS scores show EU27, Germany, and the Netherlands leading at 9/10, France at 8/10, Japan at 7/10, while the United States and Canada cluster at 4/10, alongside several emerging cases. Read against Table 1, this pattern suggests a consistent governance-efficiency alignment: higher CESIS coincides with lower MF/GDP and higher material productivity (EU/Japan), whereas moderate CESIS aligns with higher intensity and mid-range productivity (USA/Canada). The domain breakdown highlights 59020 (indicators/monitoring) and 59040 (product-level data) as the main discriminators separating strategy-heavy jurisdictions from those with institutionalized measurement and product information. At the same time, DMC/capita remains weakly tied to governance in the near term, underscoring that bending per-capita consumption requires longer-horizon structural interventions beyond standards adoption.

Table 2. Circular Economy Standards Implementation Score (CESIS) by country and by ISO 59000 domain

Country	**ISO 59004**	**ISO 59010**	**ISO 59014**	**ISO 59020**	**ISO 59040**	**CESIS Total**
EU27 (aggregate)	2	2	2	2	1	9
Germany	2	2	2	2	1	9
France	2	1	2	2	1	8
Netherlands	2	2	2	2	1	9
United States	1	1	1	1	0	4
Canada	1	1	1	1	0	4
Japan	2	2	2	1	0	7
China	1	1	1	1	0	4
India	1	1	1	1	0	4
Brazil	1	1	1	1	0	4
South Africa	1	1	1	1	0	4
Romania	1	1	1	1	0	4

Figure 2 spatializes CESIS totals from Table 2. Western/Central Europe forms a high-adoption cluster, Japan is a higher-scoring outlier, and North America and major emerging economies cluster in the moderate band where national measurement and product-data infrastructures are less cohesive.

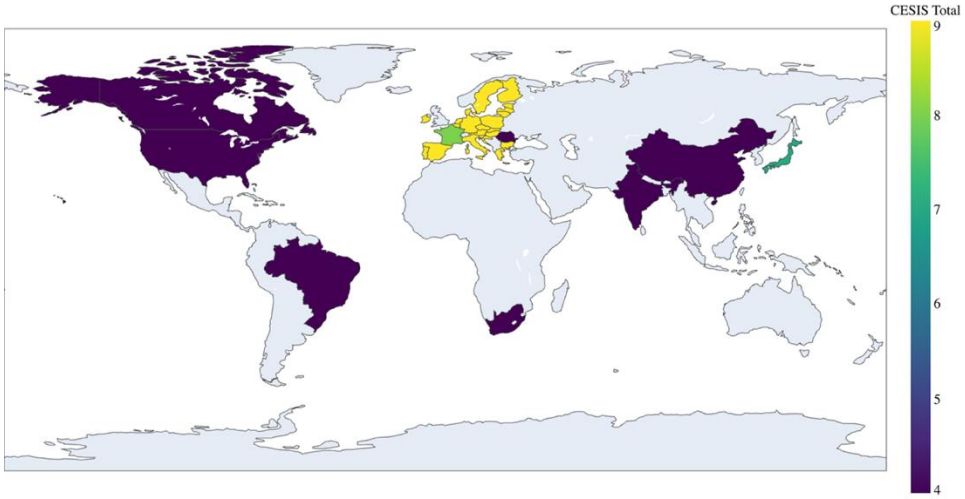

Figure 2. Global distribution of CESIS (0-10) for construction-related circular economy governance

Governance-efficiency alignment

Comparing Tables 1-2 reveals two robust patterns. First, higher CESIS aligns with lower MF/GDP: EU-aligned cases (8-9/10) occupy the low-intensity band (0.23-0.30), and Japan (7/10) posts the sample's lowest intensity (0.20). USA/Canada (4/10) sit at 0.40-0.42, while several emerging economies combine mid-low CESIS with higher intensities (e.g., China 0.55; India 0.70). Second, higher CESIS aligns with higher GDP/DMC: EU and Japan pair CESIS ≥7 with productivity ≥3.8 US$/kg, whereas USA/Canada hover around 2.4-2.5. By contrast, DMC/capita exhibits weak, heterogeneous association with CESIS, confirming it is primarily structural over the medium term.

Discussion

Because CESIS captures governance inputs while material-flow outcomes reflect structural drivers and time-lag dynamics in capital stocks, the relationships reported here are interpreted as associations rather than causal effects.

Extent of ISO-aligned governance adoption across the five domains

Our CESIS assessment shows uneven, but discernible, adoption of ISO-aligned circular economy (CE) governance across countries. EU27 (aggregate) exhibits the most complete package, pairing clear principles and frameworks (ISO 59004) with active programs/procurement for circular business models (ISO 59010), national quality/traceability instruments for secondary materials (ISO 59014), and mature indicator custodianship (ISO 59020). Product-level data in construction (ISO 59040) is advancing yet still more pilot-oriented than fully mandated. Germany and the Netherlands sit close to the EU27 aggregate, while France trails slightly on 59040 deployment despite strong 59004/59014/59020. Japan presents a high-competence monitoring regime (59020) and sectoral guidance but fewer construction-specific product-data requirements. The United States and Canada show robust sub-national activity but fragmented national-level alignment, which limits composite CESIS to the mid-range. Emerging economies display heterogeneous profiles: several have strengthened C&D management and released regular DMC/productivity statistics, yet traceability depth (59014) and product-data pilots (59040) remain nascent. In summary, domains 59020 (indicators/monitoring) and 59040 (product-level data) are the principal differentiators at this stage of adoption; they separate "strategy-heavy" jurisdictions from those that have begun to institutionalize measurement and product-information infrastructures that markets can rely on.

Association between CESIS and material-flow outcomes (MF/GDP, DMC/capita, material productivity)

Two clear associations emerge. First, CESIS is negatively associated with MF/GDP (material-footprint intensity): countries with more complete ISO-aligned governance tend to require fewer raw-material equivalents per unit of GDP. Second, CESIS is positively associated with material productivity (GDP/DMC): higher governance alignment coincides with greater economic value per unit of territorial material use.

Practical construction use of CESIS is direct. ISO 59020 indicators can be operationalized as project KPIs (e.g., verified recycled-content reporting, recovery rates, and material-efficiency targets) embedded in project controls and dashboards. ISO 59014 supports specification language requiring traceability and quality documentation for secondary aggregates, metals, and reclaimed products. ISO

59040 enables product-level circularity data to be integrated into submittals and procurement scoring, strengthening contractor decision defensibility and supply-chain transparency.

Groupwise patterns

Groupwise contrasts distill a consistent story. EU27 combines high CESIS with low MF/GDP and high productivity, reflecting the compounding effects of monitoring, procurement, and traceability instruments. Japan broadly matches this alignment, with slightly less visible product-data penetration in construction but strong indicator custodianship. United States and Canada fall into a "capability without coordination" quadrant: technological competence and private-sector initiatives deliver respectable productivity, yet material intensity remains elevated relative to EU/Japan peers, aligning with more fragmented national governance. Emerging economies are heterogeneous: where C&D protocols, indicator reporting, and targeted procurement are maturing (e.g., Eastern Europe), MF/GDP improves relative to peers; where construction booms and primary extraction dominate, intensity remains high. These group patterns reinforce the interpretation that governance alignment is most visibly expressed in efficiency metrics (lower MF/GDP, higher GDP/DMC), while absolute consumption per person reflects deeper structural trajectories that require long-horizon interventions in urban form, infrastructure, and industrial structure.

Country deviations from trend lines help diagnose bottlenecks. High CESIS with moderate intensity signals structural dependencies (e.g., export-oriented heavy industry) that require industrial strategy beyond standards. Low CESIS with high intensity suggests institutional adoption gaps; here, policy sequence matters, standards and monitoring first, procurement triggers next, then product-data obligations. Moderate CESIS with decent productivity indicates firm-level practices and technology are partially compensating for national fragmentation; codifying those practices into procurement and reporting can lock in gains and spread them.

Conclusion

This study set out to clarify how standards-aligned governance relates to material-flow performance in construction. We developed the Circular Economy Standards Implementation Score (CESIS), a five-domain index mapped one-to-one to ISO 59004/59010/59014/59020/59040 and benchmarked it against globally comparable 2019 outcomes: MF/GDP, DMC/capita, and material productivity. By keeping governance inputs analytically separate from outcomes, we avoided circularity and created a replicable way to compare countries at different points in their circular transition.

Three conclusions stand out. First, countries with more complete ISO-aligned adoption tend to show lower material intensity (MF/GDP) and higher material productivity (GDP/DMC). This governance-efficiency alignment is robust across alternative weightings, leave-one-out checks, and scale transformations, and it is most pronounced where indicator custodianship (ISO 59020) and product-level data (ISO 59040) are in place alongside traceability/quality protocols (ISO 59014). Second, DMC/capita is only weakly associated with governance and is better interpreted as a structural metric, reflecting long-lived stocks, settlement patterns, sectoral mix, and income levels. Third, groupwise contrasts are informative for policy sequencing: the EU27 and Japan pair strong governance with favorable efficiency; the United States and Canada illustrate how fragmented national alignment can dampen economy-wide gains despite technological capacity; and emerging economies exhibit heterogeneous combinations of improving monitoring and rapid construction growth.

For practice and policy, the near-term levers are clear. Institutionalizing recurring, method-based indicators with named custodians (ISO 59020), codifying traceability and quality requirements for

secondary materials (ISO 59014), and embedding product-level circularity data in procurement and submittals (ISO 59040) reduce information frictions, build market confidence, and make high-value recovery bankable. These moves can be specified today in public works and large private projects, integrated with Building Information Modeling (BIM) and building logbooks, and reinforced through performance-based specifications. Over the longer term, bending DMC/capita will require structural strategies, material-efficient building typologies, design for adaptability/disassembly, compact urban form, and industrial reconfiguration, that extend beyond standards but are enabled by the same information and measurement spine.

CESIS offers a transparent, standards-aligned governance index that can be re-scored over time as ISO 59000 adoption deepens. Future work should extend CESIS longitudinally and conduct sectoral deep dives (e.g., concrete, steel, timber) linking product data and recovery protocols to verified recycled content and procurement outcomes.

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