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Green Accounting as a Measurement Framework for Circular Economy Transitions: An Integrated Environmental–Economic Accounting Approach for Advancing SDG 12

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Abstract

Purpose

This paper develops an integrated analytical framework that systematically links green accounting mechanisms, circular economy (CE) measurement indicators, and Sustainable Development Goal 12 (Responsible Consumption and Production) targets. It addresses the persistent fragmentation across environmental–economic accounting systems operating at national and corporate levels.

Design/methodology/approach:

The study employs a qualitative multi-method research design combining a systematic literature review (112 articles from Q1/Q2 journals, 2000–2025), comparative framework analysis of six major environmental accounting systems (SEEA, GRI, GHG Protocol, TCFD, LCA, MFCA), SDG indicator mapping, and cross-case evaluation of two national cases (European Union, Japan) and two corporate cases (Unilever, Signify/Philips). The methodology draws on institutional theory and ecological modernisation theory as complementary analytical lenses.

Findings:

The analysis reveals significant measurement fragmentation across national and corporate accounting domains. National-level systems (SEEA) provide robust macro-economic environmental data but lack product-level granularity, whilst corporate frameworks (GRI, TCFD) offer detailed organisational disclosures but are poorly integrated with national statistical systems. Circular economy indicators remain technically strong in measuring material flows but economically under-integrated. The proposed framework demonstrates how these complementary systems can be unified through digital measurement, reporting, and verification (MRV) technologies to create coherent SDG 12 monitoring infrastructure.

Originality/value:

This study makes a threefold contribution. Theoretically, it bridges institutional theory with ecological modernisation to explain the co-evolution of accounting systems and circular economy governance. Methodologically, it provides the first structured cross-framework mapping of green accounting instruments to SDG 12 sub-targets with accompanying case evidence. Practically, it offers actionable recommendations for policymakers, corporate sustainability officers, standard-setters (GRI, ISSB, EU Taxonomy), and financial institutions seeking to operationalise circularity measurement within existing accounting architectures.

Clinical trial registration

Not applicable. This study is not a clinical trial.

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1. Introduction

The dominant linear economic model—characterised by the sequential extraction, production, consumption, and disposal of resources—has been identified as a primary driver of ecological degradation, biodiversity loss, and accelerating climate change (Rockström et al., 2009; Steffen et al., 2015). The planetary boundaries framework demonstrates that several biophysical thresholds have already been breached, necessitating fundamental restructuring of production and consumption systems (Steffen et al., 2015). Systems-thinking scholarship further highlights that unsustainable resource throughput is reinforced by feedback loops between production, consumption, waste generation, and ecological degradation (Meadows, 2008). In response, the circular economy (CE) has emerged as a transformative paradigm that seeks to decouple economic growth from resource depletion through the systematic principles of reducing material inputs, extending product life cycles, enabling reuse and repair, and regenerating natural systems (Stahel, 2016; Kirchherr et al., 2017; Kalmykova et al., 2018).

However, the transition from a linear to a circular economy cannot proceed effectively without robust, standardised, and interoperable measurement systems capable of tracking material flows, environmental externalities, natural capital depreciation, and the economic value generated through circular activities. Green accounting—also termed environmental accounting, environmental–economic accounting, or sustainability accounting—extends traditional national and corporate accounting systems by internalising environmental costs, resource depletion, ecosystem degradation, emissions, and waste generation into economic decision-making frameworks (Pearce and Barbier, 2000; Schaltegger and Burritt, 2010; Gray, 2010; Arrow et al., 2004; Weisbrod, 2018). When systematically implemented, green accounting provides the foundational measurement infrastructure required for advancing Sustainable Development Goal 12 (Responsible Consumption and Production), which encompasses targets for sustainable resource management (12.2), responsible chemicals and waste management (12.4), substantial waste reduction through prevention, reduction, recycling, and reuse (12.5), and corporate sustainability reporting (12.6) (UNEP, 2020).

Despite significant progress in the development of individual accounting instruments—including the United Nations System of Environmental–Economic Accounting (SEEA), the Global Reporting Initiative (GRI) Standards, the Greenhouse Gas Protocol, the Task Force on Climate-related Financial Disclosures (TCFD), Life Cycle Assessment (LCA), and Material Flow Cost Accounting (MFCA)—the integration of these systems with circular economy measurement frameworks remains fragmented and inconsistent across national jurisdictions and corporate practice (Haupt and Hellweg, 2019; OECD, 2020). Existing frameworks tend to operate within institutional silos: national accounts emphasise macro-economic environmental stocks and flows, corporate disclosures focus on organisational-level sustainability performance, and CE indicators prioritise material circularity without monetary valuation. This fragmentation substantially undermines the capacity of governments, corporations, and international bodies to monitor SDG 12 progress coherently.

This paper addresses these critical gaps through three interconnected research contributions. First, it develops an integrated conceptual framework that systematically maps green accounting instruments to circular economy measurement domains and SDG 12 sub-targets. Second, it provides empirical grounding through comparative case analysis at national (European Union, Japan) and corporate (Unilever, Signify) levels. Third, it proposes evidence-based recommendations for policymakers, standard-setters, and corporate practitioners to operationalise integrated environmental–economic accounting for circular economy governance.

The paper is organised as follows. Section 2 identifies specific research gaps and formulates research objectives. Section 3 presents the theoretical framework, drawing on institutional theory and ecological modernisation theory. Section 4 provides a comprehensive literature review. Section 5 details the research methodology. Section 6 presents the comparative framework analysis and SDG mapping results. Section 7 discusses case study evidence. Section 8 synthesises findings through cross-case analysis and discussion. Sections 9 and 10 address policy recommendations and managerial implications. Section 11 acknowledges limitations and identifies future research directions. Section 12 concludes the paper.

2. Research Gaps and Objectives

2.1 Research Gaps

Notwithstanding the extensive literature on green accounting and sustainability reporting, several significant gaps persist at the intersection of environmental–economic accounting, circular economy measurement, and SDG 12 monitoring:

Gap 1: Absence of systematic integration between green accounting frameworks and circular economy indicators. Existing systems such as SEEA, GRI, and GHG Protocol measure environmental impacts but do not fully capture circular flows including reuse, repair, remanufacturing, and product life extension (Stahel, 2016; Haupt and Hellweg, 2019). The accounting boundary typically terminates at waste generation rather than extending through recovery loops.

*Gap 2: Insufficient mapping between green accounting metrics and SDG 12 target-level indicators. National and corporate reporting systems frequently lack explicit alignment with SDG 12 sub-targets (12.2, 12.4, 12.5, 12.6), creating accountability deficits in sustainability governance (*Allen et al., 2021; UNEP, 2022; Eurostat, 2023; UN DESA, 2023*).*

Gap 3: Limited comparative empirical assessment across jurisdictions and scales. While individual case studies of green accounting implementation exist, no integrated comparative assessment examines how different national and corporate actors operationalise environmental–economic accounting for circularity measurement across diverse institutional contexts.

Gap 4: Methodological inconsistencies in natural capital and circular activity valuation. No standardised approach exists for assigning monetary value to material recovery loops, recycling flows, or product life extension within formal accounting systems (Bateman and Mace, 2020; Dasgupta, 2021).

Gap 5: Absence of a unified conceptual model. The literature remains fragmented across environmental accounting, CE measurement, and SDG monitoring disciplines, with no consolidated framework to guide integrated implementation (Schaltegger and Burritt, 2010).

2.2 Research Objectives

Guided by these gaps, the study pursues four objectives:

- RO1: To examine the conceptual and theoretical foundations of green accounting and its relevance to circular economy transitions.
- RO2: To develop a structured mapping between green accounting frameworks and SDG 12 targets and indicators.
- RO3: To analyse national and corporate case studies that apply environmental–economic accounting for circularity measurement.
- RO4: To propose an integrated conceptual framework and evidence-based policy, corporate, and financial recommendations for strengthening green accounting as a governance tool for SDG 12.

3. Theoretical Framework

This study draws on two complementary theoretical lenses—institutional theory and ecological modernisation theory—to explain how green accounting systems evolve, become institutionalised, and function as governance mechanisms within circular economy transitions.

3.1 Institutional Theory

Institutional theory, as developed by DiMaggio and Powell (1983) and extended to sustainability accounting by Deegan (2002) and Larrinaga-González (2007), explains how organisations adopt accounting practices in response to coercive, mimetic, and normative institutional pressures. Coercive isomorphism is evident in mandatory SEEA adoption by national statistical offices and corporate reporting requirements under the EU Corporate Sustainability Reporting Directive (CSRD). Mimetic isomorphism manifests when corporations adopt GRI or TCFD frameworks to emulate sustainability leaders. Normative pressures operate through professional accounting bodies, sustainability standard-setters (ISSB, GRI), and academic communities that codify best practices. Institutional theory illuminates why green accounting adoption varies across jurisdictions—stronger institutional environments (such as the EU) produce more comprehensive accounting integration, while weaker institutional settings exhibit fragmented implementation.

3.2 Ecological Modernisation Theory

Ecological modernisation theory (Mol and Sonnenfeld, 2000; Hajer, 1995) posits that environmental degradation can be addressed through the modernisation of industrial systems—including technological innovation, institutional reform, and market-based governance mechanisms—rather than through de-growth or systemic abandonment of market economies. From this perspective, green accounting constitutes a critical modernisation instrument: it provides the informational infrastructure necessary for internalising environmental costs, incentivising resource efficiency, and guiding investment toward circular business models. The theory explains how digital MRV technologies (artificial intelligence, blockchain, IoT) can accelerate environmental–economic integration by reducing measurement costs, improving data quality, and enabling real-time monitoring of circular flows. This lens is particularly relevant for understanding how Japan's MFCA innovation and the EU's digital product passport strategy represent ecological modernisation pathways within green accounting.

3.3 Complementary Theoretical Integration

By combining institutional theory with ecological modernisation, the study captures both the structural drivers of green accounting adoption (institutional pressures, regulatory frameworks, professional norms) and the substantive mechanisms through which accounting systems enable circular transitions (information provision, cost internalisation, performance measurement). This dual-lens approach addresses Schaltegger and Burritt's (2010) call for sustainability accounting research that bridges institutional analysis with operational measurement. The integrated conceptual framework developed in Section 6 operationalises this theoretical synthesis by mapping institutional adoption mechanisms to ecological modernisation outcomes across national and corporate accounting scales.

4. Literature Review

4.1 Conceptual Foundations of Green Accounting

Green accounting emerged from the intellectual traditions of ecological economics and environmental valuation, which challenged the adequacy of conventional GDP-based national accounting systems (Daly and Farley, 2011; Costanza et al., 1997; Weisbrod, 2018). Pearce and Barbier (2000) established foundational arguments for modifying national accounts to reflect natural capital depreciation, environmental damage costs, and resource depletion, while resource consumption and ecosystem-services scholarship reinforces the need for sustainability thresholds and intergenerational accounting (Arrow et al., 2004; Polasky et al., 2019). At the national level, green accounting modifies the System of National Accounts (SNA) through environmental satellite accounts, yielding environmentally adjusted net domestic product or so-called "Green GDP" measures (United Nations, 2021). At the corporate level, green accounting provides structured tools for tracking energy consumption, greenhouse gas emissions, waste generation, material throughput, water use, and ecosystem service impacts (GRI, 2020; IFRS, 2023; Schaltegger et al., 2017). Gray (2010) and Bebbington and Unerman (2018) extended this foundation by arguing that accounting systems serve not merely as neutral measurement instruments

but as active governance technologies that shape organisational and societal responses to environmental challenges.

4.2 Key Green Accounting Frameworks

4.2.1 System of Environmental–Economic Accounting (SEEA). The SEEA, maintained by the United Nations Statistical Commission, constitutes the only internationally agreed statistical framework for integrating economic and environmental data (United Nations, 2021). It provides standardised accounts for material flows, water resources, energy, land use, ecosystem services, emissions, and waste, with implementation guidance supporting adoption by national statistical systems (UNSD, 2021). The SEEA Central Framework and the SEEA Ecosystem Accounting module together enable measurement of natural capital stocks, environmental flows, and ecosystem degradation. SEEA directly supports SDG 12 indicators, particularly targets 12.2 (sustainable resource management), 12.4 (chemicals and waste management), and 12.5 (waste reduction).

4.2.2 Global Reporting Initiative (GRI). The GRI Standards represent the most widely adopted corporate sustainability reporting framework globally (GRI, 2020). Relevant disclosure standards include resource use (GRI 301, 302), water management (GRI 303), emissions (GRI 305), and waste (GRI 306). The 2020 revision of GRI 306 strengthened circularity-related disclosures by requiring organisations to report on waste generation, diversion, and recovery pathways. GRI is strongly aligned with SDG 12.6 on corporate sustainability reporting.

4.2.3 Greenhouse Gas Protocol. The GHG Protocol provides globally standardised methodologies for accounting and reporting Scope 1, 2, and 3 greenhouse gas emissions (WRI and WBCSD, 2022). Recent developments emphasise product-level carbon footprinting, value chain emissions accounting, and the integration of circularity scenarios—including reuse, refurbishment, and end-of-life recycling—into emissions calculations. The Protocol supports SDG 12.4 and SDG 12.2 through its resource efficiency and supply chain orientation.

4.2.4 Task Force on Climate-related Financial Disclosures (TCFD). TCFD recommendations have become the dominant framework for corporate climate risk governance and financial disclosure (TCFD, 2017). Its four pillars—governance, strategy, risk management, and metrics/targets—have been substantially incorporated into the IFRS S2 Climate-related Disclosures standard, creating regulatory convergence for corporate environmental transparency aligned with SDG 12.6 (IFRS Foundation, 2023).

4.2.5 Life Cycle Assessment (LCA) and Material Flow Cost Accounting (MFCA). LCA quantifies environmental impacts across complete product life cycles from raw material extraction through end-of-life (ISO 14040, 2018), enabling identification of environmental hotspots and circularity improvement opportunities. MFCA, codified as ISO 14051, integrates physical material flow tracking with monetary cost accounting to identify and quantify the costs of material losses and inefficiencies within production

systems (Kokubu and Kitada, 2015). Japan's pioneering MFCA implementation demonstrates its value for simultaneously advancing green accounting and circular economy objectives.

4.2.6 Integrated Reporting and Natural Capital Accounting. The International Integrated Reporting Framework encourages holistic corporate reporting that connects financial, manufactured, intellectual, human, social, and natural capitals (International Integrated Reporting Council (IIRC), 2021). Natural Capital Accounting (NCA) assigns monetary values to ecosystem services and natural resource stocks, providing essential data for evaluating the economic implications of circular economy investments (Bateman and Mace, 2020; Dasgupta, 2021).

4.3 Circular Economy Measurement Frameworks

Circular economy measurement has advanced through several complementary indicator frameworks. Material-flow scholarship shows that global circularity remains limited and that robust economy-wide material accounting is necessary for assessing circular transitions (Haas et al., 2015). The OECD CE indicator framework (2020) provides cross-country comparability for resource productivity and material consumption. The European Commission's Eurostat CE Monitoring Framework (2022) tracks production, consumption, waste management, secondary raw materials, and innovation across EU member states. The Ellen MacArthur Foundation's Material Circularity Indicator (EMF, 2019) enables product and company-level circularity assessment. Stahel's (2016) performance economy concept further grounds CE measurement in economic value creation through product-life extension, remanufacturing, and service-based business models.

However, CE metrics remain fragmented and operate largely independently of environmental–economic accounting systems (OECD, 2020). Key measurement domains include resource inputs (material consumption, water, energy), circular flows (reuse, recycling, remanufacturing, product life extension), environmental outcomes (GHG emissions reduction, waste diversion), and socio-economic effects (circular employment, added value). The absence of integration between CE indicators and green accounting frameworks represents a significant governance deficit.

4.4 Linking Green Accounting and Circular Economy Measurement

Despite substantial conceptual overlap, green accounting and CE measurement systems continue to operate in parallel institutional domains. Green accounting prioritises environmental impacts, natural capital stocks, and resource depletion metrics, whilst CE indicators focus on material loops, product recovery rates, and resource productivity. Recent scholarship (Masi et al., 2018; Haupt and Hellweg, 2019; Schaltegger et al., 2017) emphasises the need to merge environmental–economic accounts (SEEA) with material circularity measures, LCA-based lifecycle impacts, and corporate sustainability disclosures to create coherent measurement architectures. The alignment of these systems with SDG 12

—whose eleven targets require data on resource efficiency, waste generation, recycling rates, hazardous chemicals management, and corporate sustainability reporting (UN DESA, 2023)—remains an urgent research and policy priority.

4.5 Summary of Literature Gaps

The literature review reveals five interconnected gaps: (i) frameworks remain institutionally siloed across national and corporate domains; (ii) circular economy indicators lack standardisation and monetary integration; (iii) natural capital valuation methods are inconsistent across jurisdictions; (iv) digital MRV capabilities remain underutilised in environmental–economic accounting; and (v) no unified framework links green accounting, CE measurement, and SDG 12 monitoring. These gaps motivate the integrated framework developed in this study.

5. Methodology

5.1 Research Philosophy and Design

This study adopts an interpretivist research philosophy, recognising that environmental accounting systems are socially constructed institutional arrangements whose meanings and effectiveness are context-dependent (Burrell and Morgan, 1979; Deegan, 2002). The research employs a qualitative, integrative, and comparative analytical design combining four complementary methods: (i) systematic literature review of peer-reviewed scholarship; (ii) comparative framework analysis of major green accounting and CE measurement instruments; (iii) SDG indicator mapping; and (iv) synthesis-based conceptual framework development informed by cross-case evaluation. This design is appropriate for theory-building and normative model development in sustainability accounting research (Eisenhardt, 1989; Webster and Watson, 2002; Snyder, 2019).

5.2 Systematic Literature Review Procedure

A structured literature review was conducted across five databases: Scopus, Web of Science, ScienceDirect, SpringerLink, and Wiley Online Library. Search strings combined terms including: “green accounting” OR “environmental accounting” AND “circular economy measurement” OR “material circularity” OR “CE indicators” AND “SEEA” OR “environmental–economic accounts” AND “SDG 12” OR “sustainable consumption and production” AND “environmental reporting” OR “GRI” OR “TCFD” AND “natural capital accounting” AND “MRV systems” OR “digital sustainability.”

Inclusion criteria: Peer-reviewed articles from Q1 and Q2 ranked journals; publications from 2000–2025; documents referencing SDG 12, SEEA, CE metrics, or environmental accounting. *Exclusion criteria*: Grey literature without methodological rigour; non-environmental accounting papers; non-English publications.

Following PRISMA guidelines (Moher et al., 2009), 2,380 articles were initially identified. Title and abstract screening reduced this to 740 articles. Full-text assessment yielded 186 relevant papers, of

which 112 were retained for final analysis following quality appraisal. This procedure aligns with established best practices in sustainability research synthesis (Tranfield et al., 2003; Denyer and Tranfield, 2009).

5.3 Comparative Framework Analysis

Six major green accounting and CE measurement frameworks were systematically compared: SEEA, GRI, GHG Protocol, TCFD, LCA/MFCA, and the Eurostat/OECD CE indicator sets. Comparison criteria included: measurement domain, data units (physical, monetary, hybrid), reporting scale (national, corporate, product), methodological robustness, and alignment with SDG 12 sub-targets. Data were extracted from official UN, OECD, Eurostat, GRI, and GHG Protocol documentation, supplemented by peer-reviewed academic literature.

5.4 Analytical Procedure

Analysis proceeded through four stages. Stage 1 (Domain Extraction) identified key variables from each framework: resource use, environmental impact, circularity metrics, economic value, emissions, waste flows, reporting scope, and data structure. Stage 2 (Cross-Framework Coding) developed a coding matrix to identify overlaps, gaps, and complementarities across frameworks (Miles and Huberman, 1994). Stage 3 (SDG Mapping) aligned each indicator and system with relevant SDG 12 sub-indicators using structured alignment analysis (Allen et al., 2021). Stage 4 (Model Synthesis) integrated findings to construct the conceptual framework.

5.5 Case Study Selection and Analysis

Four cases were selected using purposive sampling to capture institutional diversity across national and corporate scales. National cases (European Union, Japan) were selected for their advanced green accounting and CE policy integration, representing distinct institutional traditions. Corporate cases (Unilever, Signify/Philips) were selected for their recognised sustainability leadership and circular business model innovation. Case data were drawn from official corporate sustainability reports, government publications, Eurostat databases, OECD datasets, and peer-reviewed literature. Within-case analysis identified implementation patterns, whilst cross-case comparison revealed convergences and divergences in measurement practice.

5.6 Validity and Reliability

Rigour was ensured through multiple strategies. Data triangulation integrated diverse sources (academic, governmental, corporate). Theory triangulation employed institutional theory and ecological modernisation as complementary analytical lenses. Construct validity was strengthened through the use of globally validated frameworks (SEEA, GRI, TCFD). Reliability was enhanced through systematic, replicable literature review protocols following PRISMA guidelines. External validity was supported by using internationally recognised SDG indicators as the alignment benchmark.

6. Comparative Framework Analysis and SDG 12 Mapping

6.1 Framework Comparison

Table 1 presents a systematic comparison of the six major green accounting and CE measurement frameworks across key analytical dimensions.

Table 1
Comparison of Green Accounting and Circular Economy Measurement Frameworks

Framework	Domain	Measurement Type	Strengths	Weaknesses	SDG 12 Alignment
SEEA	National material, energy, waste, ecosystems	Physical + Monetary	UN-approved; strong national consistency	Limited corporate integration; product-level gaps	12.2, 12.4, 12.5
GRI	Corporate ESG performance	Qualitative + Quantitative	Widely adopted; investor relevance	Variability in reporting quality; aggregation challenges	12.6
GHG Protocol	Scope 1, 2, 3 emissions	CO_2e quantitative	Precise carbon metrics; global standard	Limited resource-loop connection	12.4
LCA	Product lifecycle impacts	Environmental quantitative	Product-level precision; hotspot identification	Not easily scalable nationally	12.2
MFCA	Resource cost efficiency	Physical + Monetary	Links waste to cost savings; ISO standardised	Limited national-level adoption	12.5
Eurostat/OECD CE	CE performance and resource efficiency	Physical quantitative	EU-standardised; broad applicability	Geographic limitations; requires national datasets	12.2, 12.5

6.2 SDG 12 Indicator Mapping

Table 2 maps each SDG 12 sub-target to the required data categories and the most relevant accounting frameworks.

Table 2
Alignment of Measurement Frameworks with SDG 12 Sub-Targets

SDG 12 Target	Required Data Categories	Relevant Frameworks
12.2 Resource Efficiency	Resource productivity, domestic material consumption, material intensity	SEEA, MFA, LCA, OECD CE indicators
12.4 Chemicals and Waste	Hazardous waste generation, chemical releases, emissions inventories	SEEA, GHG Protocol, UNEP databases
12.5 Waste Reduction and Recycling	Waste generation rates, recycling rates, material recovery, waste diversion	SEEA, MFA, Eurostat CE, MFCA
12.6 Corporate Sustainability Reporting	Environmental disclosures, ESG performance, climate risk reporting	GRI, TCFD, IFRS S2

6.3 Integration Gaps Identified

The comparative analysis reveals four critical integration deficits. First, SEEA provides robust national-level environmental data but lacks the product-level granularity required for circular economy measurement, necessitating supplementation with LCA and MFCA instruments. Second, GRI and TCFD generate detailed corporate disclosures but lack mechanisms for aggregation into national statistical systems, creating a micro–macro disconnect. Third, CE indicators effectively capture material circularity metrics but lack monetary valuation capabilities, limiting their integration with economic accounting. Fourth, SDG 12 monitoring requires harmonised metrics across these domains, yet no existing framework provides comprehensive, cross-scale measurement coverage.

7. Case Study Evidence

7.1 National Case: European Union

The European Union represents the most advanced example of integrated environmental–economic accounting and circular economy governance globally. The updated Circular Economy Action Plan (European Commission, 2020) establishes binding lifecycle-based product policies, sustainable design requirements, mandatory recycling targets, digital product passports, extended producer responsibility (EPR), and waste prevention frameworks directly linked to SDG 12. The Eurostat CE Monitoring Framework (2022) tracks performance across four domains: production and consumption, waste management, secondary raw materials, and competitiveness and innovation, while the wider EU SDG monitoring architecture provides complementary evidence on responsible consumption and production progress (Eurostat, 2023). SEEA implementation across EU member states provides consistent environmental accounts for air emissions, energy flows, material flows, environmental taxation, waste, and ecosystem service valuation (European Environment Agency, 2021). From an institutional theory perspective, the EU exemplifies strong coercive isomorphism: regulatory mandates (CSRD, EU Taxonomy, CEAP) create binding institutional pressures for comprehensive environmental–economic accounting

adoption. The EU's progress on SDG 12.5 (waste reduction) and SDG 12.6 (corporate reporting under CSRD) demonstrates how robust institutional environments drive measurement system integration.

7.2 National Case: Japan

Japan represents a distinctive institutional model for circular economy–oriented environmental accounting, grounded in the Basic Law for Establishing a Sound Material-Cycle Society (2000), the 3R Initiative, and comprehensive industrial waste management legislation. Japan's global leadership in MFCA implementation—which became the ISO 14051 standard—demonstrates ecological modernisation through accounting innovation. The Ministry of Economy, Trade and Industry (METI) supported over 300 companies in MFCA adoption, generating documented waste reduction and cost savings by linking physical material losses to monetary costs (Kokubu and Kitada, 2015). Japan's Eco-Town model further illustrates circular accounting in practice through urban industrial symbiosis, closed-loop resource flows, and municipal–industry partnerships (Fujita and Hill, 2021). Japan's high material productivity (OECD, 2020), advanced waste management systems, and strong corporate adoption of GRI, integrated reporting, and TCFD frameworks position it as a normative exemplar for circular economy–accounting integration.

7.3 Corporate Case: Unilever

Unilever exemplifies corporate-level green accounting integration through its adoption of GRI Standards, the Integrated Reporting Framework, TCFD-aligned climate disclosures, and natural capital valuation tools. Product-level LCA applications inform packaging redesign, emission hotspot identification, and end-of-life scenario modelling (Bocken et al., 2014). Unilever's circular plastics commitments—targeting 100% reusable, recyclable, or compostable packaging, 25% recycled content, and reduction of virgin plastic use by 100,000 tonnes annually (Unilever, 2020)—directly advance SDG targets 12.2, 12.4, 12.5, and 12.6. From an ecological modernisation perspective, Unilever demonstrates how corporate accounting innovation can drive measurable circularity outcomes through value chain integration and stakeholder transparency.

7.4 Corporate Case: Signify (formerly Philips Lighting)

Signify represents a pioneering application of circular business model innovation integrated with environmental measurement. Its "Lighting-as-a-Service" product–service system (PaaS), where customers pay for lighting performance rather than owning fixtures, supports product lifetime extension, remanufacturing, reverse logistics, and resource circularity (Mont, 2004). Signify's circularity measurement employs the Material Circularity Indicator (MCI), reusability and recyclability metrics, component modularity assessment, and energy efficiency indicators (Philips, 2018). Lifecycle assessments inform reductions in energy consumption, embodied emissions, material inputs, and end-of-life impacts. Signify's model contributes to SDG 12.2 through energy-efficient materials, SDG 12.5 through waste reduction and reuse, and SDG 12.6 through comprehensive sustainability reporting. This case illustrates Stahel's (2016) performance economy concept operationalised through integrated green accounting.

8. Cross-Case Synthesis and Discussion

8.1 National and Corporate Comparison

Table 3 summarises the comparative positioning of the four cases across key analytical dimensions.

Table 3
Cross-Case Comparative Analysis

Dimension	European Union	Japan	Unilever	Signify
Data Scale	National	National + Industrial	Corporate	Corporate
Primary Measurement Systems	SEEA, Eurostat CE Framework	MFCA, SEEA	GRI, LCA, TCFD	MCI, LCA, PaaS metrics
Strategic Focus	Waste and CE policy integration	Resource cost efficiency via MFCA	Plastics, value chain sustainability	Circular product design, service models
SDG 12 Strength	12.5, 12.6	12.2	12.6	12.5
Institutional Mechanism	Coercive (regulation)	Normative (professional standards)	Mimetic (industry leadership)	Normative + innovative

8.2 Synthesis of Key Findings

The cross-case analysis yields four principal findings that directly address the identified research gaps:

Finding 1: Persistent measurement fragmentation across institutional domains. All four cases demonstrate partial integration of green accounting with CE measurement, but none provides a fully unified system. SEEA excels at macro-level environmental–economic integration but cannot capture product-level circularity. GRI and TCFD offer comprehensive corporate disclosure but lack mechanisms for aggregation into national accounts. CE indicators effectively measure material flows but remain economically unintegrated. This fragmentation confirms the institutional theory prediction that organisations adopt accounting practices within their existing institutional boundaries, creating isomorphic convergence within domains but divergence across them.

Finding 2: Complementary strengths across scales. The EU and Japan demonstrate strong policy–accounting integration at the national level, while Unilever and Signify illustrate corporate innovation in operationalising circular measurement. The complementarity of these approaches suggests that effective SDG 12 governance requires coordinated adoption across both scales—a multi-level institutional strategy rather than a single unified system.

Finding 3: Digital MRV as an integration accelerator. Evidence from all cases indicates that digital technologies—AI-based waste classification, blockchain-enabled supply chain traceability, IoT-enabled

material tracking, and satellite-based environmental monitoring—offer transformative potential for bridging the national–corporate measurement gap. This finding aligns with ecological modernisation theory, which predicts that technological innovation within existing institutional structures can accelerate environmental governance outcomes without requiring radical systemic change.

Finding 4: Monetary valuation as the critical missing link. Across all cases, the integration of physical CE metrics with monetary valuation remains the most significant unresolved challenge. MFCA (Japan) provides the most promising bridge, but its adoption remains concentrated in manufacturing sectors and specific geographies. Natural capital accounting (Bateman and Mace, 2020; Dasgupta, 2021) offers complementary approaches but requires substantial methodological development for practical application to circular economy activities.

8.3 Proposed Integrated Conceptual Framework

Drawing on the literature review, framework analysis, SDG mapping, and case evidence, this study proposes an integrated model comprising three core measurement layers: (1) national environmental–economic accounts (SEEA, SEEA Ecosystem Accounting), (2) corporate sustainability accounting systems (GRI, TCFD, IFRS S2, integrated reporting), and (3) circular economy indicators (MCI, MFA, MFCA, LCA). These layers feed into SDG 12 targets and indicators through structured alignment mechanisms. Digital MRV systems—including artificial intelligence, blockchain, IoT, and satellite monitoring—form the enabling infrastructure for data quality, interoperability, and traceability across scales. The framework positions green accounting as the foundational measurement architecture supporting circular economy transitions and SDG 12 governance. Importantly, the model operationalises the theoretical integration of institutional pressures (coercive regulations, normative standards, mimetic practices) with ecological modernisation mechanisms (technological innovation, cost internalisation, information-based governance).

9. Policy Recommendations

9.1 Strengthen national SEEA implementation. Governments should mandate comprehensive SEEA adoption, expand SEEA Ecosystem Accounting to include ecosystem degradation and nature-based solutions, integrate material flow analysis and CE indicators into SEEA modules, and establish dedicated National Environmental Accounts Units within statistical offices for SDG 12 monitoring.

9.2 Harmonise corporate and national reporting standards. Regulators should enforce alignment between GRI, IFRS S2, and SEEA to enable upward aggregation of corporate data into national statistics. Standardised digital reporting formats and mandatory CE metric disclosure in corporate sustainability reports would reduce fragmentation.

9.3 Integrate CE indicators into regulatory frameworks. Policymakers should introduce mandatory circular product design guidelines, enforce extended producer responsibility with measurable CE

indicators, implement CE-oriented fiscal incentives (reduced taxation for refurbished or remanufactured goods), and require CE reporting in corporate sustainability disclosures.

9.4 Accelerate digital MRV deployment. National governments should invest in AI-based MRV systems for emissions, waste flows, and recycling rates; blockchain-based material traceability across supply chains; IoT-enabled real-time resource monitoring; and open data platforms for SDG 12 policy evaluation.

9.5 Build institutional capacity. Targeted programmes should provide industry incentives for MFCA, LCA, and MCI adoption; train policymakers and practitioners in green accounting methodologies; and establish academic–government–industry partnerships to advance SDG 12 research and implementation.

10. Managerial and Practical Implications

For businesses

The integrated framework provides visibility into resource inefficiencies and environmental liabilities, enabling evidence-based decision-making. MFCA and CE indicators identify cost-saving opportunities through waste reduction. Companies adopting circular business models—as demonstrated by Signify's PaaS approach—gain competitive differentiation and investor confidence through alignment with TCFD and IFRS S2 requirements.

For policymakers

Harmonised green accounting and CE metrics improve SDG 12 tracking accuracy, strengthen evidence-based regulatory design, and enable effective climate policy integration with economic accounting systems. Countries leading in CE measurement (EU, Japan) demonstrate enhanced industrial resilience and international competitiveness.

For investors and financial institutions

The framework improves ESG risk assessment and due diligence by providing standardised, comparable environmental–economic data. Alignment with sustainable finance taxonomies (EU Taxonomy, ISSB standards) supports green investment flows and enables systematic comparison of corporate circularity performance across sectors and jurisdictions.

11. Limitations and Future Research Directions

11.1 Limitations

This study acknowledges several limitations. First, SEEA adoption varies substantially across countries, constraining the comparability of national-level evidence. Second, corporate disclosures under GRI and TCFD may lack completeness or standardisation, potentially affecting the reliability of corporate case

analysis. Third, the study examines four purposively selected cases; additional cases across different geographies, industries, and institutional contexts may reveal further nuances. Fourth, the framework primarily focuses on SDG 12 and does not comprehensively explore spillover effects on related goals (SDGs 6, 7, 13, 14, 15). Fifth, the rapid evolution of sustainability reporting standards (IFRS S1/S2, CSRD, EU Taxonomy) necessitates ongoing framework updates.

11.2 Future Research Directions

Five priority research avenues emerge from this study. First, empirical validation of the integrated framework through industry-specific applications (textiles, cement, electronics, food systems) and country-level SDG assessments would strengthen external validity. Second, quantitative modelling—including CE-adjusted GDP models, natural capital–adjusted productivity indices, and MRV-enabled environmental–economic simulations—could operationalise the framework computationally. Third, further research into AI-based waste classification, blockchain-enabled CE value chains, and IoT-based material tracking would advance the digital MRV component. Fourth, investigation of behavioural, organisational, and cultural factors affecting circular economy adoption and green accounting practice would complement the institutional analysis. Fifth, longitudinal studies examining the evolution of green accounting–CE integration over time, particularly in response to new regulatory requirements (CSRD, ISSB), would capture institutional dynamics currently beyond this study's scope.

12. Conclusion

This study contributes to the growing body of scholarship at the intersection of green accounting, circular economy measurement, and SDG 12 governance by proposing a novel integrated conceptual framework that addresses the persistent fragmentation across environmental–economic measurement systems. Through systematic literature review, comparative framework analysis, SDG indicator mapping, and cross-case evaluation of the European Union, Japan, Unilever, and Signify, the study demonstrates that current measurement systems offer strong individual capabilities but remain institutionally siloed across national and corporate domains.

The proposed framework integrates SEEA environmental–economic accounts, corporate sustainability accounting systems (GRI, TCFD, IFRS S2), circular economy measurement instruments (MCI, MFA, MFCA, LCA), and SDG 12 indicators through a coordinated architecture enabled by digital MRV technologies. Grounded in institutional theory and ecological modernisation theory, the framework explains both the institutional drivers of green accounting adoption and the substantive mechanisms through which accounting systems enable circular economy transitions.

The study makes three interconnected contributions. Theoretically, it bridges institutional and ecological modernisation perspectives to provide a multi-level explanation of green accounting–circular economy integration. Methodologically, it offers the first structured cross-framework mapping of green accounting instruments to SDG 12 sub-targets with accompanying multi-case evidence. Practically, it provides

actionable recommendations for policymakers, corporate sustainability officers, standard-setters, and financial institutions seeking to operationalise circularity measurement within existing accounting architectures.

Ultimately, this research demonstrates that integrated green accounting constitutes essential governance infrastructure for accelerating circular economy transitions and advancing global SDG 12 performance. As environmental pressures intensify and stakeholder expectations for transparency increase, the capacity to measure, report, and verify circular economy progress through rigorous accounting systems will determine the pace and effectiveness of the sustainability transition.

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• Ethics declaration: Not applicable. This study does not involve human participants, human data, human tissue, animals, or clinical intervention.

• Consent to Participate declaration: Not applicable.

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• Data availability: The datasets analysed during the current study are derived from publicly available sources cited in the manuscript, including peer-reviewed literature, official reports, and publicly accessible databases. No new datasets were generated for this study.

Author Contribution

Abhinav Kumar GV conceptualized the study, designed the framework, conducted the literature review and comparative analysis, and prepared the original manuscript. Srinivas Tunguturi supervised the research, contributed to methodology and interpretation, and critically reviewed the manuscript. Rajeshwar Kumar Palthy supported literature synthesis, case analysis, and manuscript revision. All authors reviewed and approved the final manuscript.

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