

Linking natural resource accounting to the circular economy: towards an integrated framework for sustainability measurement and governance

Michael Amofa and Abigail Arthur

Department of Accounting, University of Professional Studies, Accra, Ghana

Abstract

Purpose – The purpose of this study is to examine how natural resource accounting (NRA) can operationalize circular economy (CE) principles to support responsible production, consumption and net-zero sustainability governance. This study explores how integrating physical and monetary resource information enhances measurement, accountability and decision-making at firm and national levels.

Design/methodology/approach – Using an integrative literature review, this study synthesizes research from accounting, environmental economics and sustainability science. A multi-level analytical lens links firm-level tools (MFCA and LCA) with economy-wide frameworks (MFA and SEEA). A conceptual framework is developed to explain how accounting structures, institutional forces and decision-making processes interact to enable circular and net-zero transitions.

Findings – The review finds that NRA provides the measurement infrastructure necessary to translate CE strategies into measurable and governable outcomes, including material efficiency, waste reduction and emissions mitigation. However, adoption remains uneven because of fragmented indicators, weak institutional capacity and limited integration between physical and monetary accounting systems. The findings of this study indicate that harmonized accounting standards and stronger institutional coordination are essential for linking micro-level circular practices with macro-level sustainability and net-zero objectives.

Practical implications – This study guides policymakers and organizations on aligning national accounting systems (SEEA-based MFA) with firm-level tools (MFCA and LCA) to advance circular business models, responsible production and evidence-based sustainability governance.

Originality/value – This paper positions NRA as a governance-enabling infrastructure rather than a complementary reporting tool. By integrating ecological modernization, institutional theory and stakeholder perspectives, the framework clarifies how accounting can support circularity and net-zero transitions across developed and developing economies.

Keywords Circular economy, Natural resource accounting, Material flow cost accounting, Sustainability reporting, Environmental governance

Paper type Conceptual paper



1. Introduction

The production and consumption responsibilities have become key components of global sustainability and net-zero transition strategies, with linear economic systems still perpetrating resource depletion, generation of waste and carbon emissions. Circular economy (CE) approaches are being incorporated as a way of decoupling economic activity and environmental degradation into the international policy agendas at both the European and United Nations (especially SDG 12) levels and national net-zero guidelines. Within this context, accounting systems play a critical role in making resource use, emissions and material recovery visible, comparable and governable.

However, the depletion of natural resources and increasing environmental demands generated by linear production systems have been an extreme burden on the global economy, thus creating considerable substantive worries concerning the sustainability of current accounting and management of resources. Serving as an alternative approach to developing sustainable development and resource efficiency, natural resource accounting (NRA) and the CE are steadily recognized as mutually supportive concepts (Ghisellini *et al.*, 2016; Geissdoerfer *et al.*, 2017). The accounting of natural resources provides the tools of quantifying, assessing and reporting natural asset stock and flows, and the CE highlights the processes of restorative and regenerative that reduce the extraction and generation of wastes (Kirchherr *et al.*, 2017; Nishitani *et al.*, 2022). The integration of these spheres provides new avenues of integrating environmental concerns in accounting mechanisms, thus harmonizing economic value with environmental limits. This crossroad has become a modern-day accounting problem as the conventional accounting models fail to reflect environmental expenses related to the natural depletion of the resources (Larrinaga *et al.*, 2021; Vysochan and Vysochan, 2024). Recent discussions in sustainability accounting support broader reporting models, including the System of Environmental-Economic Accounting (SEEA) and Material Flow Cost Accounting (MFCA), which internalize the environmental externalities and provide a more comprehensive picture of value creation and value depletion (Vardon *et al.*, 2025). This change is supported by the CE paradigm, where resources remain at their highest value as long as possible, which is directly related to accounting indicators of resource input, throughput and recovery (Di Vaio *et al.*, 2023).

Regardless of this increased convergence, a critical decoupling exists between organizational-level circular metrics and national-level sustainability accounts, preventing a coherent governance response to resource depletion. Most CE investigations on technologies, business logic or material recirculation strategies omit a sufficient discussion of how these practices become captured, evaluated and governed with accounting systems. In contrast, the studies of NRA tend to focus on the national-level measurement systems, including the SEEA-based ones, without clarifying how the firm-level decision-making and circularity result in the sustainability of the entire economy and the achievement of net-zero outcomes. NRA serves as the empirical bridge by which material circularity is converted into carbon-equivalent data, essential for net-zero monitoring. In spite of the increased awareness of CE, the lack of unified accounting procedures that would tie the use of resources to the achievement of the circle prevents the practical implementation of the concept (Di Vaio *et al.*, 2023a, 2023b; Palomero *et al.*, 2024). As a result, the proposed study will establish an integrated framework between NRA and CE to facilitate the measurement of sustainability and governance. The framework aims to conceptualize NRA to deliver circular results, balance indicators of sustainability and offer practical advice to make decisions at the firm, sectoral and national levels (Palomero *et al.*, 2024; Vysochan and Vysochan, 2024; Wiedenhofer *et al.*, 2024). Using NRA data and linkage with CE indicators allows firms and policymakers to make informed decisions that would lead to improved sustainability,

material efficiency and circular practices ([Larrinaga et al., 2021](#); [Nishitani et al., 2022](#); [Lederer and Schuch, 2024](#)).

Nevertheless, the topicality of such deliberations does not reduce itself to environmental stewardship but is rather like a redefinition of corporate responsibility and policymaking in a world of resource scarcity. As sustainable consumption and production are being increasingly highlighted by the European Green Deal, Africa's Agenda 2063 and the United Nations Sustainable Development Goals (SDGs 12 and 15), the purpose of accounting to measure natural resource consumption takes on both governance and strategic requirements ([United Nations Environment Programme \(UNEP\), 2023](#)). Furthermore, the practical implication of the adoption of CE principles in accounting practice involves resource efficiency, waste reduction and determining the circular business model ([Spreatico, 2022](#); [Goncalves et al., 2022](#)). However, empirical and conceptual studies show that there is still a structural fragmentation in associating accounting methods with such approaches as life-cycle assessment (LCA), material flow analysis (MFA) and MFCA to the outcomes of the CE ([Palomero et al., 2024](#); [Lederer and Schuch, 2024](#)). This, therefore, points to a clear research gap: while firm-level accounting tools (e.g. MFCA and LCA) and macro-level frameworks (e.g. MFA and SEEA) are conceptually aligned, the mechanisms through which accounting information is translated across scales remain under-theorized and weakly operationalized. As a result, the role of accounting in enabling responsible production, circularity and net-zero governance is underexplored in literature.

Furthermore, while the convergence of NRA and CE is conceptually recognized, a significant theoretical and operational disconnect persists. Most CE research focuses on isolated innovation ecosystems ([Antelo et al., 2025](#)) or sectoral performance ([Salesa et al., 2025](#)), often overlooking how these micro-level circularities are captured within formal national accounting infrastructures. Conversely, NRA literature remains largely focused on macro-statistical frameworks (SEEA), failing to provide a clear causal link to firm-level managerial decision-making. This study moves beyond a mere synthesis of these fields. It addresses a critical governance gap: the lack of a "translation mechanism" between physical material flows and monetary accounting systems across scales. By positioning NRA as a governance-enabling infrastructure, this paper theorizes how accounting data can move from a back-end reporting obligation to a front-end strategic tool for net-zero transitions. Consequently, this study asks:

RQ. How can natural resource accounting systems be integrated with circular economy principles to support sustainability measurement and governance across organizational and policy levels?

This paper contributes to the literature by:

- proposing a multi-scalar framework that bridges the micro-macro divide;
- integrating circular innovation ecosystem perspectives ([Antelo et al., 2025](#)) into formal accounting theory; and
- providing an evidence-based roadmap for aligning corporate MFCA with national SEEA objectives.

2. Theoretical foundations

This section valuates accounting structures that support circular transitions, theoretical perspectives pre-eminent and trend methodological approaches and conceptual and contextual gaps that restrain operationalization of accounting devices, particularly in

developing economies with limited information of data and institutional barriers (Wiedenhofer *et al.*, 2024; Vysochan and Vysochan, 2024). This review summarizes theoretical, methodological and empirical developments that have linked NRA and CE practices. The integration of interdisciplinary insights provides a foundation for understanding how accounting can increase resource cycling and guides future research and policy directions. CE has been conceptually defined in over 100 ways (Kirchherr *et al.*, 2017). The practicalization of CE in accounting and governance frameworks has not been studied well. Current models focus on the environmental or economic aspects separately and usually ignore how accounting systems can be used to promote the shift to circular practices (Di Vaio *et al.*, 2023; Palomero *et al.*, 2024). Such a gap in the theory makes it clear that NRA should be critically applied in combination with CE principles to achieve a more holistic approach to measuring sustainable resource usage (Vardon *et al.*, 2022; Vysochan and Vysochan, 2024). Despite the literature's potential of NRA to facilitate CE practices (Wiedenhofer *et al.*, 2024; Vysochan and Vysochan, 2024), the literature remains descriptive (that is, it describes the structures of the accounting) without showing how these structures effectively lead to measurable outcomes in terms of CE practices. This gap means a conceptual disjuncture: the existing theoretical approaches revolve around measurement but do not incorporate social, political and equity into operations (Palomero *et al.*, 2024; Larrinaga *et al.*, 2021).

2.1 Systems thinking and ecological modernization

Ecological modernization (EM) frames environmental protection as not necessarily opposite to economic growth but as a field where a combination of technological innovation (TI), institutional change (IC) and market mechanisms (MM) can be used to decouple environmental strains and economic functioning. EM is complemented by systems thinking, which focuses on stocks, flows and feedbacks in socio-technical and material systems (Geissdoerfer *et al.*, 2017; Ghisellini *et al.*, 2016). The application of EM in NRA and CE literature primarily focuses on measurement and techno-institutional solutions to reduce extraction and waste. However, it insufficiently addresses distributional trade-offs, power dynamics and political-economic constraints, leaving critical questions about who benefits from circular transitions largely unexplored (Larrinaga *et al.*, 2021). Integrating systems thinking with EM provides a multi-level perspective, connecting firm-level material flows with macroeconomic sustainability, yet empirical implementations remain limited in addressing social and equity dimensions.

The materials accounting in many CE reviews and methodological papers has a systems perspective, which supports the use of economy-wide material accounting (MFA) and life-cycle-based methods because they help to capture circular loops (Kirchherr *et al.*, 2017; Wiedenhofer *et al.*, 2024; Palomero *et al.*, 2024). Empirical research, which implements MFA and economy-wide stock-flow models, clearly operationalizes the assertion by EM that better measurement and technological/design solutions can prevent extraction and waste (Wiedenhofer *et al.*, 2024; Lederer and Schuch, 2024). Although EM and systems thinking are efficient in the drive toward measurement, they are under-theorized toward power relations, inequality and political-economic constraints that organize the use of resources (Larrinaga *et al.*, 2021). As a result, even though the EM recommends techno-institutional fixes, it lacks a strong explanation of who gains through circular transitions and how accounting can be used to bring about distributional trade-offs. Empirical applications often ignore social inequities and fail to examine who benefits from circular transitions, leaving a critical gap in linking theory to actionable accounting solutions (Larrinaga *et al.*, 2021; Geissdoerfer *et al.*, 2017). Natural capital approaches characterize ecosystems and resource

stocks as assets, the change of which has to be measured and (where feasible) monetized. This notion is achieved through the System of Environmental-Economic Accounting (SEEA) that applies to the standardized statistical accounting constructs (UNEP/SEEA; [Vardon et al., 2025](#)). As much as SEEA helps monitor and offer policy insights at the national level, it does not always offer concrete actionable information on the firm level. Ecological values, which find their interpretation in economics, may conceal non-market values and ethics, restricting the ability to make pragmatic decisions under circular projects ([Larrinaga et al., 2021](#); [Vysochan and Vysochan, 2024](#)). Although SEEA has standardized systems of accounting national resources, their application to firm or product-level decisions is under-researched. The assumption that the ecological values may be commoditized in the same way as economic resources jeopardizes the absence of the non-market and ethical perspective, which is the area where theory and practice of CE are not connected ([Vysochan and Vysochan, 2024](#); [Larrinaga et al., 2021](#)).

However, there are also methodological and policy-based studies that set SEEA and natural capital accounting as the basis of the environmental data record in the national accounts and green recovery policies ([Vardon et al., 2025](#); [United Nations Environment Programme \[UNEP\], 2023](#)). The cost accounting would be promoted in natural capital logic to use the material flow (MFCA) and material flow accounts to determine the depletion and service flows ([Nishitani et al., 2022](#)). Natural capital accounting tends to presume that ecological values can be measured on the same scale as economic, and critics believe that this may mask non-market values and ethical factors that are important to intrinsic ecological value ([Larrinaga et al., 2021](#)). In addition, the statistical orientation of SEEA does not offer as much information for firm-level managerial use connected to product-level circularity ([Vysochan and Vysochan, 2024](#)), which introduces a mismatch in scales between the macro-level accounting and the corporate practice.

Ecological economics and social metabolism put economic activity in the context of biophysical constraints, whereas political ecology emphasizes distributional impacts and access to resources ([Wiedenhofer et al., 2024](#); [Larrinaga et al., 2021](#)). Material-flow accounting (MFA) and models of the economy-wide stock-flow are also reasonable because they represent the way to prove the physical scale of the economies and become circular ([Wiedenhofer et al., 2024](#); [Lederer and Schuch, 2024](#)). The political ecology lenses are located in the critical accounting literature, in which the issue of who benefits in terms of circular transitions is raised ([Larrinaga et al., 2021](#)). Mainstream accounting practices have not fully involved ecological economics and political ecology, and the operational guidance to operationalize social-metabolic diagnostic into accounting metrics that can be used by corporates and national statisticians has little to provide ([Palomero et al., 2024](#)). These approaches justify MFA and stock-flow accounting at the macro level but remain under-integrated in mainstream NRA. Operationalizing social-metabolic diagnostics into corporate or national accounting metrics is limited, leaving social and equity outcomes largely invisible in current practice ([Palomero et al., 2024](#)). Although ecological economics and social metabolism offer frameworks to contextualize economic activity within biophysical limits, they are rarely integrated into operational accounting practices. Measurement frameworks (LCA, MFA and MFCA) complement each other, yet there is no unified theory to guide their harmonization or to embed equity and distributional concerns into resource accounting. Critical accounting perspectives emphasize plural valuation, but practical methodologies to implement these approaches at both firm and national scales remain underdeveloped ([Palomero et al., 2024](#); [Larrinaga et al., 2021](#); [Vysochan and Vysochan, 2024](#)). However, while SEEA provides the macro-scale, recent literature ([Salesa et al., 2025](#))

suggests that, “Aero-circularity” and sectoral-specific pathways are needed to make these biophysical limits actionable.

2.2 Organizational and innovation theories

The institutional theory focuses on the impact of formal rules, norms and cognitive frames on organizational decisions; hence, it represents the reason why some firms embrace circular practices and others do not. This framework is furthered by accountability theory to explain the reporting behaviors (Di Vaio *et al.*, 2023; Larrinaga *et al.*, 2021). However, most studies are descriptive, leaving causal mechanisms between institutional change and actual resource outcomes underexplored. The influence of informal institutions, especially in developing contexts, is rarely accounted for, limiting the applicability of insights across diverse settings (Wiedenhofer *et al.*, 2024; Vysochan and Vysochan, 2024). The introduction of MFCA, environmental disclosure and circular business models have been attributed to institutional explanations in the context of empirical accounting studies, with regulatory incentives, stakeholder pressures and normative expectations being some of the major contributors (Goncalves *et al.*, 2022; Di Vaio *et al.*, 2023). Firm-level MFCA implementation case studies point to enabling and weakening institutions (Usul *et al.*, 2025). Institutional accounts, on the other hand, have the propensity of remaining descriptive, and they face challenges of explaining the causal process that relates institutional change to the real resource outcomes. Besides, the available literature pays insufficient attention to informal institutions and situational restrictions in developing nations where circular routes can vary (Wiedenhofer *et al.*, 2024; Vysochan and Vysochan, 2024).

Additionally, the stakeholder theory holds firms responsible to a set of varying actors such as investors, regulators and communities, which explains the rationale of reporting beyond the financial statement to include environmental measures and the concept of circular performance (Goncalves *et al.*, 2022; Vysochan and Vysochan, 2024). Yet, while it provides rationale for reporting, it lacks guidance on indicator design, standardization and materiality determination, leaving unresolved how LCA/MFA outputs should inform managerial and investor decisions in circular contexts.

Studies of CE accounting also often rely on the stakeholder logic to understand the phenomenon of sustainability disclosures, green audits and product-level reporting to include LCA and circular indicators (Palomero *et al.*, 2024; Spreafico, 2022). Although the stakeholder theory justifies reporting, it provides comparatively weak advice on the design of indicators, their standardization and the epistemic basis of the materiality of their use in circular situations – questions that are at the center of the reconciliation of the LCA/MFA outputs in managerial and investor decisions. While the Resource-Based View (RBV) correctly identifies circularity as a source of competitive advantage, it fails to account for the collaborative nature of innovation ecosystems (Antelo *et al.*, 2025). Integrating NRA into these ecosystems allows for the “visibility” of resource flows that transcend firm boundaries, shifting the focus from individual value retention to systemic value recovery (Salesa *et al.*, 2025). RBV interprets firm resources and capabilities as sources of competitive advantage. In CE literature, maintaining product value through repair, remanufacturing and recycling is viewed as a firm capability (Geissdoerfer *et al.*, 2017; Spreafico, 2022). Circular business models are empirically found to be associated with financial performance and firm strategy, and it is proposed that accounting is required to record retained economic value in terms of remanufacturing or service models (Goncalves *et al.*, 2022). The accounting tools that are introduced as a methodology of quantifying such retained value are MFCA and life-cycle cost approaches. RBV, despite its focus on the competitiveness of firms, does not emphasize systemic externalities and the need to have economy-wide metrics of resource depletion,

which means that it is not very helpful in offering theoretical support to policy-level net resource accounting (NRA). Accounting tools such as MFCA and life-cycle cost approaches quantify retained value, yet RBV's focus on firm competitiveness does not extend to systemic resource depletion or macro-level accounting, limiting its utility for national CE strategies. [Antelo et al. \(2025\)](#) argue that circularity is not just a firm-level choice but also a result of Collaboration Patterns in Innovation Ecosystems. This moves the theory from "Individual firm strategy" to "Systemic collaboration."

2.3 Critical and reflexive accounting

The measurement frameworks, LCA of environmental impact, MFA of physical balances and MFCA of monetized material losses, presuppose that physical and monetary measures will enhance the decision-making process of the circular transition ([Nishitani et al., 2022](#); [Palomero et al., 2024](#)). Hybrid metrics are trying to bring those viewpoints together, for example, by adding LCA and material circularity index but harmonization and standardization are not fully accomplished. Hybrid metrics have tried to combine these viewpoints, a good example of this is a joint measurement of LCA environmental impact and material circularity indices. These approaches to measurements are operationalized in a significant part of the reviewed corpus in gauging product life cycles, stocks in urban areas, inefficiencies in firm processes and circularity in the economy ([Palomero et al., 2024](#); [Lederer and Schuch, 2024](#); [Spreafico, 2022](#)). MFA at the scale of an economy receives the statistical framework provided by UNEP/SEEA guidance (United Nations Environment Programme [UNEP], 2023). Theoretical tensions persist where LCA emphasizes environmental effects without circularity; MFA balances mass but ignores impacts; MFCA monetizes flows but may overlook ecological services over time. No coherent framework guides the integration of these tools ([Palomero et al., 2024](#); [Nishitani et al., 2022](#)). However, critical accounting challenges the normative base of accounting practice, which questions the political decisions made in the context of valuation, measurement and reporting ([Larrinaga et al., 2021](#)). It postulates that accounting is not neutral and that the choice of metrics creates realities regarding the application of resources. The critical views can be seen in the calls of reflexive, pluralistic NRA and CE where the over-reliance on monetization is discouraged and plural ways of valuation are suggested ([Larrinaga et al., 2021](#); [Vysochan and Vysochan, 2024](#)). As powerful as they may be in the critique, the approaches demand rather more constructive connections to methodological remedies that can scale; in other words, they must construct pluralistic accounting systems that are operationally viable to both firms and national statisticians. By synthesizing these institutional and organizational perspectives, this study moves beyond describing why firms report to theorizing how accounting acts as a coordination mechanism within innovation ecosystems ([Antelo et al., 2025](#)). This shifts the theoretical focus from individual firm legitimacy to the collective performance of circular supply chains ([Salesa et al., 2025](#)).

3. Methods

This study uses an integrative literature review method to synthesize fragmented research across accounting, economics and sustainability science. Unlike a systematic review that focuses on narrow empirical effects, an integrative approach allows for the conceptual bridging of different scales from firm-level MFCA to national-level SEEA ([Vardon et al., 2022](#)). Literature was retrieved from Scopus, Web of Science and Google Scholar using keywords such as "Material Flow Cost Accounting," "Circular Economy Governance" and "Natural Resource Accounting." The search was updated in late 2025 to include emerging studies on circular innovation ecosystems ([Antelo et al., 2025](#)) and sectoral performance

(Salesa *et al.*, 2025). Inclusion was based on a study's ability to link physical resource metrics with either monetary valuation or governance outcomes. The synthesis followed a three-stage procedure:

- (1) *Initial coding*: identifying the primary accounting tools (LCA, MFA and MFCA) used in each study;
- (2) *Thematic categorization*: grouping studies based on their scale of application (Micro, Meso and Macro) and theoretical orientation; and
- (3) *Integrative synthesis*: mapping these themes to identify the “Micro-to-Macro” disconnect. This process directly informed the development of the conceptual framework in Section 6, ensuring that each component of the model (Figure 1) is grounded in specific empirical gaps identified during the review.

3.1 Methodological trend and limitations

Although multiple improvements in methodology have been achieved in natural resource accounting, as well as the investigation of the CE, there are still many limitations that undercut the strength, comparability and policy value of the current research. A large part of the problem is the ongoing lack of fit between micro-level accounting (MFCA and LCA) and macro-level accounting (MFA and SEEA) that makes it difficult to translate interventions on the firm level into national or sectoral policy implications. Many firm-level MFCA and LCAs lack stringent methods of scaling up outcomes to sector-level MFA/System of SEEA models, thereby creating a separation between micro and macroeconomic accounting (Nishitani *et al.*, 2022). This hinders inferences of economy-wide effects and poses obstacles

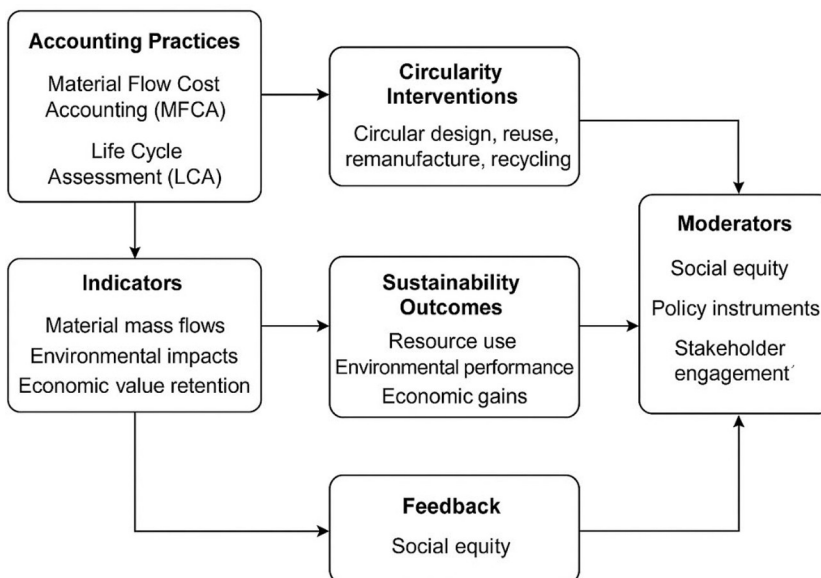


Figure 1. Multi-scalar governance loop

Source: Authors' own construct

in integrating corporate-level interventions with national CE plans. Another critical limitation concerns indicator fragmentation and lack of harmonization. The literature relies on diverse circularity metrics, Material Circularity Indicator (MCI), Circularity Index (CI), throughput measures and recycling rates without standardized guidance, impeding comparability and meta-analytical assessment. Corporate process and production data is commonly proprietary, incomplete or inconsistently reported, and national MFA relies on trade and industry statistics, which may not be reliable in low-income or developing markets (United Nations Environment Programme [UNEP], 2023; Wiedenhofer *et al.*, 2024). These gaps increase uncertainty in quantitative results and limit policy applicability. The methodological rigor is further constrained by insufficient longitudinal designs and a lack of causal inference, which restricts the ability to assess how accounting innovations influence resource efficiency or circularity outcomes over time. Social and distributional dimensions are mostly neglected; MFA, LCA and MFCA focus primarily on biophysical and environmental impacts, rarely capturing effects on employment, equity and community well-being (Larrinaga *et al.*, 2021). Uncertainty and sensitivity analyses are often technically inadequate, undermining robustness (Palomero *et al.*, 2024). Finally, evidence is geographically skewed toward high-income contexts, leaving developing countries, informal economies and resource-limited settings underexplored (Wiedenhofer *et al.*, 2024; Vysochan and Vysochan, 2024). Moreover, the absence of participatory and stakeholder-oriented practices diminishes practical legitimacy and practical use of implementers and accounting products. There are only a handful of studies that explore co-design of indicators and include significant stakeholders such as communities, workers and small businesses, which further renders the findings socially applicable and relevant, as well as useful to resource communities. Issues of methodology raise important areas for future progress, such as harmonized indicators, integration of social indicators, stronger causal design, higher data transparency and context-sensitive methods to ensure that accounting-related research results are relevant to facilitating CE transitions at all scales.

3.2 Methodological improvement opportunities

The methodological survey of natural resource accounting and CE studies does pinpoint the existing constraints and outlines tangible prospects for advancing the quality, comparability and policy relevance of research. To begin with, interventions of firms-level MFCA and LCA research and sectoral MFA/national SEEA accounts should be worked out. These protocols enable consolidation of micro-level accounting information in a systematic manner, correlating corporate behavior with the results of national circularity (Nishitani *et al.*, 2022; United Nations Environment Programme [UNEP], 2023). Second, the harmonization and interoperability of indicators are needed. Developing a set of fundamental circularity metrics, such as material mass, environmental impacts and economic value retention, will enhance cross-study comparability, increase interpretability and allow conducting meta-analytical research (Kirchherr *et al.*, 2017; Palomero *et al.*, 2024). Thirdly, the policy of open data, common reporting templates and publicly available data sets should enhance transparency and accessibility of the data, which enhances replicability and evidence-based decision-making (Vardon *et al.*, 2025). Fourthly, uncertainty and sensitivity analysis ought to be regularly used, and publication of confidence intervals should be done for LCA, MFCA and MFA research. This increases the policy utility and reliability of findings (Palomero *et al.*, 2024). Fifth, to make the techniques applicable to a variety of economic environments, the approaches to use should be able to respond to resource-scarce and informal situations with the use of proxies, remote sensing, expert elicitation and modeling (Wiedenhofer *et al.*, 2024). Finally, mixed method approaches that combine

quantitative MFA/LCA/MFCA with qualitative institutional analysis and process tracing allow researchers to capture both the material and social drivers of circularity, bridging explanatory gaps (Di Vaio *et al.*, 2023; Gonçalves *et al.*, 2022). Taken together, these methodological advances give a guide to future studies to enhance the future evidence and practice worth of natural resource accounting in the promotion of CE goals.

3.3 Recommended methodological roadmap

The development of natural resource accounting in the CE may be guided by a strictly developed methodological roadmap. In the short term, scientists are encouraged to use standardized reporting templates in MFCA and LCA studies, to perform complete uncertainty and sensitivity analysis and to focus on an open-data publication. Such practices increase transparency, replicability and comparability of studies; thus, some of the most relevant methodological shortcomings are addressed. Multi-scale aggregation protocols are suggested for development in the medium run. These protocols would be used to systematically match firm-level MFCA and LCA outputs to sector MFA models and, eventually, with national SEEA, to achieve the ability to incorporate micro interventions into macroeconomic frameworks. This is important to close the divide between national CE indicators and organizational practices. In the long-term, methodological activities must entrench distributional and social measures and seek participatory strategies, especially involving stakeholders at communities, workers and the informal sector. The increase of the geographic coverage to include low-income and informal economies will enhance the contextual relevancy and equity concerns such that the accounting of the CE fully represents the variety of socio-economic environments. To sum up, despite the strong analytical underpinning of the field via MFA, LCA and MFCA, there are still problems of integration, comparison and adaptation to settings. Overcoming these methodological bottlenecks is critical in producing evidence that can significantly relate the accounting practice with the outcomes of the CE. Key Themes and Findings of the studies reviewed are synthesized into the following section, which presents a full table, matching the paper with its theoretical basis, methodology and main findings. The analytical basis of the field is quite solid (MFA, LCA and MFCA), but it has problems with integration, comparability and ability to adapt to context. The challenges of overcoming these bottlenecks will be important in generating evidence that relates meaningfully to how accounting practice can be related to the outcomes of the CE. In this regard, short-term strategies should focus on standardized MFCA/LCA reporting, complete uncertainty analysis and open-data publication to improve transparency and comparability.

The medium-term plans include the creation of multi-scale aggregation protocols within the context of which the firm-level outputs are correlated with the sectoral MFA and national SEEA accounts to make corporate practices compatible with the policy-relevant indicators. Social and distributional metrics, participatory stakeholder policies and increased geographical reach to low-income and informal economies should be a part of long-term strategies to make the CE more contextually relevant and equitable in its accounting. All these methodological advances tackle the lack in integration, comparability and context adaptation and improve the capacity of natural resource accounting to make meaningful contributions to interventions in the CE.

4. Key themes and findings

4.1 Toward an integrated framework for natural resource accounting and circular economy

In this section, theoretical and methodological knowledge is combined to suggest an elaborate framework that will combine NRA with CE principles. The framework deals with

reviewer issues of scale, harmonization of indicators and actionable governance outcomes. [Table 1](#) draw up the main empirical and conceptual conclusions, which stem out of the literature reviewed under thematic subheadings. Furthermore, the literature identifies a tiered structure of circularity measurement. At the micro-level, MFCA remains the dominant tool for monetizing material losses, as evidenced by [Nishitani et al. \(2022\)](#). However, recent evidence suggests that individual firm efficiency is insufficient without considering Innovation Ecosystems; [Antelo et al. \(2025\)](#) demonstrate that circular outcomes are largely dependent on the collaborative patterns within these ecosystems.

Moving to the meso and macro-levels, the integration of LCA and circularity indices ([Palomero et al., 2024](#)) provides the necessary environmental guardrails. This is particularly vital in high-impact sectors like aviation, where [Salesa et al. \(2025\)](#) highlight the direct correlation between circular material flows and overarching sustainability performance. Despite these advancements, the governance gap persists because macro-accounting systems (SEEA) rarely reflect these nuanced, sector-specific micro-level improvements.

4.2 Conceptual rationale

NRA provides systematic accounting of resource stocks, flows and associated economic and environmental impacts, forming a quantitative foundation for circular strategies. CE emphasizes resource loops, reuse and waste minimization. By integrating NRA and CE, firms and policymakers can link material efficiency with economic valuation, enabling informed decisions that promote sustainability and circularity ([Barreiro-Gen and Lozano, 2020](#); [Christ and Burritt, 2019](#)).

4.3 Measurement, metrics and indicator development

One of the prevailing trends within the literature is devoted to the creation, testing and criticism of measurement instruments that can trace physical flows of resources to environmental effects and financial expenses. The methodological framework is mainly focused on MFA, LCA and MFCA; composite measures and indices of circularity are increasingly used, but they are not applied consistently across the literature ([Palomero et al., 2024](#); [Nishitani et al., 2022](#); [Kirchherr et al., 2017](#)). Its consequences are that the measurement activity not only confirms the existability of the quantification of circularity

Table 1. Summary key findings

Author(s)	Focus/theory	Primary method	Mapping to Figure 1	Key findings
Antelo et al. (2025)	Innovation ecosystems	Horizon Europe evidence	Meso (innovation)	Collaboration patterns drive CE adoption; cross-sectoral Links aviation circularity directly to sustainability KPIs
Salesa et al. (2025)	Aero-circularity	Sectoral performance	Macro (Net-Zero)	
Palomero et al. (2024)	Hybrid metrics	LCA + CI review	Meso (impact)	Harmonization of LCA and CI reduces metric trade-offs
Nishitani et al. (2022)	MFCA and performance	Case studies	Micro (efficiency)	Monetizing material loss improves internal decision-making
Larrinaga et al. (2021)	Critical accounting	Conceptual critique	Governance context	Warns against monetization without social equity filters
Source(s): Authors				

and resource depletion but also demonstrates a plurality of indicators and continuous difficulties with harmonization of mass-based and impact-based measures.

4.4 *Economy-wide stock-flow and urban metabolism analyses*

MFA studies of economies and the social metabolism model the physical size of economies and show where the most meaningful systemic impacts can be made via circular interventions (Wiedenhofer *et al.*, 2024; Lederer and Schuch, 2024). These analyses cannot be avoided in national policy but require quality statistical contributions. This means that macro-scale MFA will offer a global view of material stocks and possible circular flows to policymakers, but real-life challenges of data harmonization and informal flows remain.

4.5 *Firm-level accounting, managerial decision-making and business models*

Several research focus on MFCA, life-cycle costing and circular business models and demonstrate how accounting structures can create a business case around the concept of circularity and cost savings associated with material efficiency (Nishitani *et al.*, 2022; Usul *et al.*, 2025; Goncalves *et al.*, 2022). Managerial accounting tools have the potential to make circular practice incentivization, but the existing empirical evidence on long-term financial effects and scalability is sparse.

4.6 *Life cycle assessment, trade-offs and environmental impacts*

The environmental trade-offs (such as remanufacturing and recycling having impacted each other, etc.) are revealed by LCA studies used in relation to circular strategies, and the latter is used to prevent transferring the problem to the other categories of impact (Palomero *et al.*, 2024; Spreafico, 2022). LCA may be essential in measuring the environmental impacts of circular strategies, but it needs to be combined with mass-flow measures to have a complete picture of circularity.

4.7 *Policy, governance and national accounting (including SEEA)*

The proponents of policy-oriented research suggest that natural capital accounting should be integrated into recovery and sustainability planning (Vardon *et al.*, 2025; United Nations Environment Programme [UNEP], 2023). It is suggested to use SEEA compatible MFA to monitor the progress of the CE nationally. Although standardized national accounts are more useful in informing policies on materials, the translation of national accounts into legally binding tools has not been studied well.

4.8 *Finance, markets and economic evaluation of circularity*

A smaller but growing body of literature focuses on financial implications, information requirements of investors and how CE adoption can be linked to the performance or valuation of a firm (Goncalves *et al.*, 2022). It implies that as financial indicators are crucial to scaling a circular business model, there is no standardized format of disclosure for circular information or established materiality in investor context.

4.9 *Critical perspectives, justice and distributional concerns*

Contributions to critical accounting and political ecology underline the importance of focusing on justice, power and possible circular transitions to recreate inequalities in the event of overlooking governance and redistribution (Larrinaga *et al.*, 2021; Wiedenhofer *et al.*, 2024). Accounting should move beyond technocratic measurement to include social

and distributional metrics and should be able to make visible the normative decisions being made in valuation.

4.10 Sectoral case studies and applied circular strategies

Case studies at both the sectoral and product levels (manufacturing, construction and urban waste) show practical CE pathways such as repair, remanufacturing, material substitution and measure results in terms of LCA/MFCA/MFA ([Spreafico, 2022](#); [Lederer and Schuch, 2024](#)). Although case evidence is important in the demonstration of best practice, it tends to be rather situational and hard to generalize.

4.11 Identified empirical and conceptual gaps

The findings from this review reveal five distinct structural gaps, conceptual, theoretical, methodological, contextual and decision-oriented which prevent the full integration of NRA and CE. These gaps are analyzed as a foundation for a future research agenda in Section 5.

5. Research gaps and future directions

While there have been some important advances in linking NRA with the CE, the literature surveyed in this article still has significant blind spots that undermine the unification of theory, the validity of the methods and the contemporaneity of policy implications. This part integrates five main research gaps: conceptual, theoretical, methodological, contextual and decision-making and suggests practical guidance on the way to pursue the research in the future, including research questions to illustrate each gap.

5.1 Fragmented integration of accounting and circular economy principles

Most studies consider natural resource accounting and CE separate entities and do not pursue an integrated framework that relates accounting indicators to the goals of a CE ([Kirchherr et al., 2017](#); [Di Vaio et al., 2023](#); [Palomero et al., 2024](#)). Current models normally measure resource depletion or efficiency but rarely include regenerative and restorative mechanisms that are the focus of the CE paradigm. This distinction of methodology reduces the ability of accounting to guide circles of policy design. The future studies must thus come up with combined models that will match accounting indicators (e.g. MFCA and SEEA) with the measures of the circularity performance (e.g. The future studies must, thus, come up with combined models that will match accounting indicators (e.g. MFCA and SEEA) with the measures of the circularity performance (e.g. the material circularity index and resource productivity). These frameworks should be able to trace resource trajectories between production-consumption cycles and value-recovery phases. Some possible research questions include the following:

- RQ1. How can natural resource accounting frameworks be reconceptualized to embed circular economy principles?
- RQ2. What hybrid measurement models best capture the restorative value of materials and ecosystem services in accounting records?

5.2 Limited development of accounting theories for circular transitions

Although the adoption of environmental accounting has been explained by the application of institutional theory, stakeholder theory and ecological modernization theory, the systemic and regenerative logic behind the idea of circular transitions cannot be partially addressed by

these perspectives (Larrinaga *et al.*, 2021; Bianchi and Cordella, 2023). The existing theoretical uses are mainly descriptive and not predictive and mostly ignore the dynamics across scales among firms, industries and ecosystems. New theoretical extensions are needed, which would combine systems thinking and natural capital theory and institutional change models. These extensions would help achieve the dynamic elucidation of the way accounting is modified to meet ecological demands and circular business logics.

Possible Research Question:

RQ3. How can systems theory strengthen the explanatory power of environmental accounting in a circular context?

5.3 *Insufficient empirical rigor and lack of longitudinal evidence*

Most of the studies use cross-sectional case studies or conceptual studies (Nishitani *et al.*, 2022; Usul *et al.*, 2025), and therefore, it is difficult to make causal conclusions on how accounting innovations affect the efficiency of resources or circular results. Methodological pluralism is not highly developed; there are not many studies that should be able to incorporate physical, financial and environmental data to evaluate holistic performance. The mixed-method and longitudinal designs should be embraced in future studies that will incorporate firm-level MFCA and national MFA data to determine how productivity of resources changes over time. Empirical validation and scalability could be enhanced through the use of big data analytics, remote sensing and AI-assisted accounting tools.

Possible Research Questions:

RQ4. What are the longitudinal trends observed in influencing circular performance indicators with reference to natural resource accounting practices?

RQ5. What ways can strengthen the credibility of resource accounting across LCA, MFCA and SEEA with data integration?

5.4 *Limited research in developing and resource-dependent economies*

Most of the empirical studies are based on Europe, Japan and North America, and little is known about how the natural resource accounting works in the context of Africa, Asia or Latin America (Vardon *et al.*, 2025; Vysochan and Vysochan, 2024). These areas are facing distinctive challenges that may worsen the situation of resources being lost and mismanaged, such as poor institutional capacity, large informal sectors and a lack of data. The context-specific research in developing economies must focus on how SEEA and MFCA frameworks can be implemented in low-data conditions and analyze the institutional motivation behind implementation. The comparative work may provide information on how to mainstream the use of circular accounting in the Global South.

Possible Research Questions:

RQ6. How can natural resource accounting frameworks be localized for data-scarce economies in Africa and Asia?

RQ7. What institutional and policy conditions enable the integration of accounting practices into national circular economy strategies?

5.5 *Insufficient correlation between accounting evidence and decision-making*

Although the policy interest in CE and sustainability transitions is increasing, very little research has an empirical focus on the impact of accounting information on a decision-making process by the people or corporations (Vardon *et al.*, 2025; United Nations Environment Programme (UNEP), 2023). Accounting data tend to be technocratic products, which are not connected to policy instruments, corporate planning or public awareness. Future studies need to evaluate how accounting evidence can influence the environment governance, fiscal policy and green investment. Policy-based research with corporate participants can be used to secure that accounting knowledge is reflected in meaningful, practicable strategies of the resource circularity.

Possible Research Questions:

RQ8. To what extent does natural resource accounting influence government policy and fiscal decisions in circular transitions?

RQ9. How can accounting information systems be redesigned to inform corporate strategy and investor decisions related to circular business models?

Collectively, these five research gaps highlight the need for a transdisciplinary research agenda that bridges theory.

6. Conceptual framework

The proposed framework (Figure 1) advances sustainability accounting theory by moving beyond static reporting to a multi-scalar governance infrastructure. While existing models treat MFCA, LCA and SEEA as isolated tools, this framework theorizes their interdependent causal chain. The framework's novelty lies in two distinct theoretical advancements:

- (1) *Scale interoperability*: It provides a translation protocol where micro-level material losses (monetized via MFCA) are aggregated to inform meso-level innovation ecosystems (Antelo *et al.*, 2025). This ensures that firm-level efficiency directly contributes to sectoral sustainability performance (Salesa *et al.*, 2025).
- (2) *Reflexive governance loops*: Unlike descriptive reviews, this model incorporates a governance feedback mechanism. It illustrates how national SEEA indicators act as pressure points that trigger policy shifts (e.g. carbon taxes or resource quotas), which in turn redefine the materiality thresholds used in corporate accounting.

Moreover, it installs institutional and critical accounting prisms, expressly touching on equity, informal economies and contextual barriers gaps, which have often been overlooked in previous reviews (Larrinaga *et al.*, 2021; Vysochan and Vysochan, 2024; Wiedenhofer *et al.*, 2024). This placement enables the framework to build upon the literature in terms of operationalizing the concept of circularity in a multi-scale, integrative and context-sensitive fashion, developing both the theory and applicability of a concept. The arrows in Figure 1 represent the flow of information: from the biophysical mass balance of the product (LCA), through the monetary efficiency filters of the firm (MFCA), to the aggregate national resource balance (SEEA).

The theoretical, methodological and empirical implications of the natural resource accounting conceptual framework in the CE can be used to describe the interdependence between accounting practice, circularity intervention and sustainability outcome. The core of this framework is firm level. MFCA records resource inputs, outputs and monetary losses in operating activities and aids in retaining value and decision-making in the company (Goncalves *et al.*, 2022; Usul *et al.*, 2025). Circularity outcomes are directly related to

firm-level interventions, which are applied to implement the ecological modernization principles by showing how technology, design and management can minimize extraction and waste. The hybrid metrics and LCA combine the indices of environmental impact and material circularity and offer a standardized tool to assess the product and service sustainability (Palomero *et al.*, 2024; Spreafico, 2022). This layer fills in the previous gaps of harmonization between the design of indicators and comparability of the operational metrics (MFCA) and general sustainability outcomes.

6.1 Suggested empirical strategies to test the model

To empirically substantiate the proposed conceptual framework that connects natural resource accounting to CE outcomes, various complementary strategies may be used. It is advisable to use mixed-scale multi-method case studies that integrate firm-level MFCA with product-level LCA and regional or national MFA. MFCA is positioned as not just a cost-cutting tool but also the empirical baseline for all circular claims. Without MFCA, circular strategies lack the “monetary teeth” to influence board-level decisions. This design enables scholars to analyze the relationship between firm activities and macroeconomic performance. This approach tackles the micro-to-macro problem head-on by linking intervention at the operational level to national and sectoral resource accounting (Nishitani *et al.*, 2022; United Nations Environment Programme [UNEP], 2023). Panel data and quasi-experiment designs enable derivation of causal inference. By evaluating how delayed MFCA practices, reporting or initiatives aimed at promoting the CE among companies or countries impact resource use, environmental outcomes and corporate outcomes, researchers can eliminate the methodological gap in causal inference (Bianchi and Cordella, 2023). The comparisons can be made easier and consistent by conducting experiments in indicator interoperability. The latter projects the design and confirmation of mapping regulations between the outputs of MFCA and the inputs of SEEA/MFA, thereby determining robust aggregation protocols and limiting the current level of fragmentation of the circularity metrics (Kirchherr *et al.*, 2017; Palomero *et al.*, 2024). Drawing on Antelo *et al.* (2025), this layer emphasizes that circularity happens in clusters. NRA acts as the “shared language” between partners in an innovation ecosystem to track shared resource loops. Contextual comparative studies can analyze firms and industries in both high-income and low-income environments, encompassing informal economic sectors, to uncover institutional constraints, localized barriers and informal material flows. As highlighted by Salesa *et al.* (2025), this level links sectoral material flow to the net-zero mandates, providing the Performance Dashboard for the state. This approach is instrumental in bridging the geographical and contextual gaps that exist in the existing literature (Wiedenhofer *et al.*, 2024; Vysochan and Vysochan, 2024). Finally, stakeholder experiments and experiment-based surveys can determine whether hybrid, multidimensional circularity indicators contribute to more investor or managerial decision-making than unidimensional indicators; in doing so, it would address a gap in policy relevance and relevant decision-support applications for accounting outputs (Di Vaio *et al.*, 2023; Goncalves *et al.*, 2022). These empirical strategies together provide a strong and multi-scalar framework to test, validate and push on the conceptual model, linking micro-level accounting practices to macro-level CE outcomes while improving extant methodological and contextual limitations. The framework contributes to theory by synthesizing ecological modernization, institutional theory, critical accounting and measurement theories into a single operationalizable model.

7. Practical implications

The conceptual framework provides manageable actionable guidance to businesses, national statisticians and policymakers and converts meaningful methodological and empirical development into useful practices. Rather than viewing accounting as a compliance burden, managers should leverage MFCA as a strategic tool for ecosystem orchestration. As highlighted by [Antelo et al. \(2025\)](#), circularity depends on innovation ecosystems; therefore, firms should use monetized material-loss data to co-design closed-loop contracts with suppliers, turning NRA data into a competitive asset. For national statisticians, using SEEA-compatible MFA with detailed metadata makes it easier to connect with firm-level data and helps with multi-scale accounting. It encourages comparability, reproducibility and evidence-based decision-making and focuses on open data activities ([United Nations Environment Programme \[UNEP\], 2023](#)). In practice, it provides principles of integrating firm-level accounting and macro-level monitoring and circularity reporting, offering practical options of firms and policymakers. The novelty lies in its multi-scale, multi-theoretical design that explicitly addresses contextual, equity and methodological gaps identified in prior literature, thus extending the current understanding of how accounting can operationalize CE principles. Governance should shift from broad circularity targets to sector-specific performance mandates. Following the aero-circularity logic of [Salesa et al. \(2025\)](#), regulators can use NRA-integrated data to design Extended Producer Responsibility schemes that reward verified material retention, directly linking firm-level accounting to national net-zero milestones.

Decision-makers may apply MFA- and LCA-based scenarios when planning for an action to underpin targeted CE policies like extended producer responsibility schemes, material taxation and incentives for circular production. To make these policies effective and standalone, we must invest in data infrastructure ([United Nations Environment Programme \[UNEP\], 2023](#); [Vardon et al., 2025](#)). It has a causal chain that begins with natural resource stocks, containing accounting causal mechanisms, decision-making processes to the result of a CE and modulating contextual factors and feedback loop. Based on the results of the studies, it enables a testable research model, hypothesis development and real-world applications for mitigating the methodological and context-based research gap. This model serves as a basis for multi-scale empirical initiatives, indicator standardization endeavors and policy experiments, thus transforming natural resource accounting from a predominantly technical task into a pivotal tool for CE governance and strategic decision-making. Again, there is an urgent need for “Multi-Scale Interoperability Protocols.” Harmonizing the functional units of firm-level LCA with the mass-balance requirements of national SEEA will reduce the reporting friction that currently hinders circular transitions.

8. Conclusion

This review examined the intersection of NRA and the CE, which is perhaps a novel area in sustainability-oriented accounting research. The review is based on empirical evidence over the years and illustrates the growing convergent nature of circularity-based practices and accounting-related frameworks to serve the society with its urgent issues such as resource depletion, environmental degradation and waste production under the umbrella goal of sustainable development. Statistics indicate that while there have been excellent developments in theory and method, NRA-Integrated Circular Governance relationship is unstable and incomplete across settings and sectors. Although reasonably well-constructed theoretical concepts, to a considerable extent through institutional theory, stakeholder theory and natural capital theory, offer a foundation for explanation, they fall short and capture only a partial part of the systemic and regenerative mind-set that pervades circularity

(Di Vaio *et al.*, 2023; Larrinaga *et al.*, 2021). This review, however, identifies a paradigm shift: NRA is no longer a peripheral environmental tool but the core measurement infrastructure for the CE. This study's primary contribution is the development of a multi-scalar framework that resolves the "micro-macro disconnect" by providing a causal bridge between firm-level material flows and national sustainability governance.

By integrating recent insights on circular innovation ecosystems (Antelo *et al.*, 2025) and sectoral sustainability performance (Salesa *et al.*, 2025), the framework moves beyond descriptive synthesis toward a predictive model of resource governance. Future research must now move from "what to measure" to "how to scale," specifically through longitudinal studies that test the causal impact of NRA-integrated policies on global net-zero trajectories.

Empirical evidence shows growing but uneven NRA application in circular practices across sectors and geographies but without operationalization, alignment of policies and integration of measurement instruments that include MFA, LCA and MFCA. The research confirms that the principles of CE are conceptually developed but do not find their application in accounting practice, especially in the field of emerging economies and data deficiency. This review has a theoretical contribution in that it provides an integrative framework, which the author suggests connecting ecological modernization, systems thinking and institutional theory with circularity-oriented accounting, which contrasts with traditional models of sustainability accounting which are based on either environmental or financial reporting. The framework focuses on resource management, circular innovation and sustainability outcomes at the same time and provides a systematic way of operationalizing CE principles at firm and country level. In the future, this paper outlines the opportunities in the research, namely:

- longitudinal and mixed-method research to evaluate the causal effects of NRA on the outcome of circularity;
- refining measurement frameworks to harmonize results of LCA, MFA and MFCA; and
- the design of context-dependent frameworks that consider equity, distribution and governance factors in the adoption of CE.

To sum up, the assimilation of NRA and CE is a revolutionary step in the accounting theory and practice.

By linking resource accounting with circularity, the proposed framework provides actionable guidance for policymakers, managers and scholars, enabling accounting to move beyond traditional reporting toward a regenerative and systemically informed approach that supports sustainable economic transformation.

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Corresponding author

Michael Amofa can be contacted at: amofamicheal2@gmail.com