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Do ESG Disclosures Capture Systemic Sustainability Risks? Integrating Life Cycle Sustainability Assessment into ESRS-Based Sustainability Accounting

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Abstract

This study addresses two distinct questions: (1) to what extent do ESRS-oriented corporate sustainability disclosures operationalize a life cycle perspective; and (2) how can Life Cycle Sustainability Assessment (LCSA) inform a conceptual model for improving the risk relevance of such disclosures? A theory-driven qualitative comparative content analysis is applied to the 2024 sustainability disclosures of Enel, Unilever, and Siemens AG across six analytical dimensions and four integration categories. Across the 18 company–dimension assessments, none met the criteria for systemically integrated disclosure; all were classified as partially integrated. The three cases show broad but uneven value-chain coverage: upstream and environmental information is more developed than downstream, end-of-life, social, and economic integration. Life cycle methods are used selectively, while cross-dimensional links and cradle-to-grave boundary transparency remain limited. Because the evidence concerns three purposively selected cases, the findings are analytical rather than statistically or sectorally generalizable. The study therefore proposes, rather than validates, an LCSA–ESRS Operationalization Model based on boundary reconfiguration, stage-based indicator mapping, dimensional harmonization, and an accounting translation layer. The model indicates how life cycle evidence could be connected to double materiality, systemic sustainability risks, and decision-useful disclosure. The study contributes by distinguishing life cycle-related disclosure from full LCSA integration and by positioning sustainability reporting as a boundary-alignment problem.

Keywords: ESG disclosure; life cycle sustainability assessment; ESRS; systemic sustainability risk; sustainable finance; value chain transparency



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1. Introduction

The ongoing transformation of corporate reporting under the European sustainability agenda represents one of the most significant regulatory shifts in contemporary accounting and finance. The adoption of the Corporate Sustainability Reporting Directive (CSRD) and the implementation of the European Sustainability Reporting Standards (ESRS) have fundamentally redefined the scope, structure, and institutional role of sustainability disclosures within corporate governance systems. Sustainability reporting is no longer framed as a voluntary corporate social responsibility practice, but as a regulated component of corporate accountability embedded within financial and non-financial reporting architecture.

The regulatory relevance of this transformation is grounded in the Corporate Sustainability Reporting Directive and the first set of European Sustainability Reporting Standards, which require companies to disclose sustainability information in relation to material impacts, risks and opportunities (European Parliament and Council of the European Union, 2022; European Commission, 2023). This reporting architecture is also connected with the broader EU sustainable finance framework, including the Sustainable Finance Disclosure Regulation and the EU Taxonomy Regulation, which strengthen the link between corporate sustainability information, financial market transparency and sustainable investment decision-making (European Parliament and Council of the European Union, 2019, 2020).

This transformation introduces a critical methodological question for sustainability accounting: whether current ESG reporting frameworks are capable of capturing systemic sustainability impacts across value chains. Although ESRS explicitly extend reporting requirements beyond organizational boundaries through value chain disclosures and double materiality assessment, the operational logic of ESG reporting remains predominantly indicator-based and entity-centered. Disclosures are typically structured around environmental, social, and governance performance metrics that reflect organizational control rather than full product-system accountability.

Prior research on mandatory CSR and sustainability reporting suggests that regulated sustainability disclosure may generate important economic effects, including changes in information environments, stakeholder monitoring and capital market decision-making (Christensen et al., 2021). However, sustainability reporting may also remain incomplete or symbolic when disclosures do not reflect substantive organizational accountability and systemic sustainability impacts (Cho et al., 2015). This makes the boundary logic of ESG disclosure particularly important for assessing whether reported sustainability information is sufficiently decision-useful.

This structural feature creates a potential misalignment between regulatory reporting logic and sustainability assessment methodologies grounded in life cycle thinking. Life Cycle Sustainability Assessment (LCSA) integrates environmental Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), and Life Cycle Costing (LCC), thereby providing a systemic evaluation of sustainability performance across upstream and downstream stages. Unlike entity-based ESG metrics, LCSA is inherently product-system oriented and emphasizes cradle-to-grave boundaries, interdependencies across value chain stages, and multidimensional impact integration.

The life cycle perspective is especially relevant in this context because LCSA extends sustainability assessment beyond entity-level indicators and enables the integration of environmental, social and economic impacts across product systems and value chain stages (Zamagni et al., 2013).

The tension between these two logics—indicator-based ESG reporting and system-based life cycle assessment—raises important implications for sustainability accounting, sustainable finance, and risk management. If ESG disclosures remain confined within organizational boundaries, they may underrepresent supply chain externalities, downstream impacts, product-use effects, end-of-life responsibilities, and cumulative systemic risks. Conversely, embedding life cycle thinking into sustainability reporting could enhance measurement coherence, strengthen risk transparency, and improve the decision-usefulness of disclosures for investors, regulators, creditors, and other stakeholders.

From a sustainable finance perspective, this issue is particularly important. Investors increasingly rely on ESG disclosures to assess transition risks, supply chain vulnerabilities, resource dependencies, circular economy readiness, and long-term value creation. However, if ESG reporting does not systematically capture impacts across upstream, operational, downstream, and end-of-life stages, sustainability-related risks may be underestimated or

fragmented across separate disclosure categories. This may limit the usefulness of ESG information for capital allocation, risk pricing, corporate valuation, and assessment of organizational resilience.

Despite the conceptual compatibility between ESRS value chain requirements and life cycle logic, the precise integration problem remains underexplored. Integrated reporting, sustainability accounting, and value chain accounting research has examined connectivity, materiality, management integration, and Scope 3 accountability, while emerging studies connect LCA or organizational LCA with corporate disclosure. The unresolved issue addressed here is narrower: whether publicly available ESRS-oriented disclosures integrate environmental, social, and economic evidence across life cycle stages and translate it into risk-relevant accounting categories. The novelty of this study lies in evaluating that boundary and integration problem with an LCSA-based coding framework and then developing a conceptual translation model.

This study addresses the identified gap through two distinct research questions:

RQ1 (empirical): To what extent do the 2024 corporate sustainability disclosures of Enel, Unilever, and Siemens AG operationalize a life cycle perspective across upstream, own-operation, downstream, and end-of-life stages?

RQ2 (conceptual): How can LCSA principles be translated into an ESRS-compatible model that could enhance boundary transparency, systemic-risk relevance, and decision-usefulness?

The objectives follow this two-part structure. First, to answer RQ1, the study evaluates boundary definition, upstream and downstream integration, cross-dimensional coherence, methodological reference, and risk relevance across the three cases. Second, it compares the observed disclosure structures with LCSA principles to identify recurring integration gaps. Third, drawing on this empirical diagnosis and the literature, it develops a conceptual LCSA–ESRS model. The three-case analysis therefore informs the model but does not constitute its empirical validation.

The contribution of this research is threefold.

From a theoretical perspective, unlike studies that treat integration primarily as connectivity among report sections or organizational functions, this study uses the product-system boundary of LCSA as the reference point. It reframes ESG reporting as a boundary-alignment problem between the reporting undertaking and the wider systems in which sustainability impacts and risks arise.

From a sustainable finance perspective, the study contributes to the debate on the decision-usefulness of ESG disclosures by showing how insufficient life cycle integration may reduce the ability of corporate reports to capture systemic sustainability risks. By linking LCSA with risk relevance, value chain transparency, and long-term value creation, the research highlights the importance of life cycle thinking for investors and other users of sustainability information.

From a methodological perspective, the study develops a conceptual operationalization model that connects LCSA principles with ESRS-based sustainability accounting. The model offers a structured pathway for boundary reconfiguration, stage-based indicator mapping, dimensional harmonization, and accounting translation. It is a theory-informed proposal requiring future pilot application and validation, rather than an empirically validated reporting instrument.

Ultimately, this study argues that the future evolution of sustainability accounting depends not only on expanding disclosure requirements, but also on reconfiguring reporting boundaries. Embedding life cycle thinking within ESRS-based sustainability accounting may represent a necessary step toward achieving coherent, systemic, risk-relevant, and decision-useful sustainability reporting in the European context.

2. Literature Review

2.1. Sustainability Accounting, ESG Reporting, and Boundary Logic

Sustainability accounting has evolved from voluntary corporate social responsibility disclosure toward institutionalized ESG reporting frameworks embedded within regulatory and financial reporting architectures. Early critical scholarship questioned whether corporate sustainability disclosures provide genuine accountability or merely reproduce legitimacy narratives that protect organizational reputation without substantially altering corporate behavior (Bebbington & Larrinaga, 2014; Gray, 2010). This debate remains highly relevant in the context of contemporary ESG reporting, where expanded disclosure requirements may increase transparency but do not automatically ensure systemic accountability.

The institutionalization of sustainability reporting has intensified with the adoption of mandatory regulatory frameworks, particularly the Corporate Sustainability Reporting Directive (CSRD) and the European Sustainability Reporting Standards (ESRS). Commission Delegated Regulation (EU) 2023/2772 sets out the first set of ESRS and specifies sustainability information to be disclosed in relation to material impacts, risks, and opportunities (European Commission, 2023). Under this regulatory architecture, sustainability reporting is no longer peripheral to corporate communication, but increasingly functions as a formalized disclosure mechanism relevant to investors, creditors, regulators, and other users of corporate reports. Earlier European evidence indicates that mandatory non-financial disclosure can strengthen corporate transparency and accountability, with large European companies demonstrating substantial readiness to report social, employee, environmental, and risk-related information under the emerging regulatory framework (Manes-Rossi et al., 2018).

At this early stage of the review, the motivating gap can be stated explicitly: regulated disclosure has advanced faster than methods for testing whether reported information is integrated across life cycle stages and sustainability dimensions. Existing reporting research explains why and how firms disclose, whereas the present study asks whether the disclosed boundary structure approximates a cradle-to-grave LCSA logic and whether dispersed impacts are translated into risk-relevant accounting information.

However, despite improvements in standardization and comparability, ESG reporting remains strongly influenced by organizational boundary logic. Sustainability disclosures are typically structured around the reporting undertaking, its operations, governance systems, and material impacts, risks, and opportunities identified through entity-specific assessment processes. Even when value chain information is included, it is often presented through supplier monitoring, Scope 3 emissions, risk exposure, or compliance mechanisms rather than through comprehensive product-system assessment. This creates a structural tension between the logic of financial accounting consolidation and the systemic nature of sustainability impacts.

Empirical and conceptual studies have repeatedly identified fragmentation as a persistent weakness of sustainability reporting. ESG information is often organized into separate environmental, social, and governance sections, while cross-dimensional interdependencies remain weakly articulated (Cho et al., 2015; Hahn & Kühnen, 2013). This segmentation limits stakeholders' ability to understand how environmental impacts, social risks, and economic consequences interact across value chains. The Bulgarian studies retained in this review are used only as implementation evidence from a Central and Eastern European part of the common EU reporting environment, where formal regulatory convergence may coexist with uneven quantification, comparability, and methodological maturity (Nikolov, 2023; Papradanova et al., 2025; P. Petrova, 2024). They are not used to infer the practices of Enel, Unilever, or Siemens AG.

More broadly, sustainability accounting links external reporting, internal decision support, and stakeholder accountability (Burritt & Schaltegger, 2010). Corporate motivations and information systems influence the depth and credibility of disclosure (Schaltegger & Burritt, 2018). Accordingly, the boundary issue concerns both the external visibility of value chain impacts and the internal capacity to connect those impacts to management decisions.

From a financial and risk management perspective, entity-centered disclosure may constrain decision-usefulness when material exposures arise in upstream sourcing, product use, or end-of-life treatment. The relevant question is therefore not the number of indicators alone, but whether the reporting boundary makes distributed impacts and dependencies visible to capital providers, consistent with analytical approaches to enterprise financial sustainability (Kostova et al., 2022).

2.2. Life Cycle Sustainability Assessment as a Systemic Sustainability Paradigm

Life Cycle Sustainability Assessment (LCSA) offers a systemic methodological framework for assessing sustainability performance across product-system boundaries. It builds on the integration of environmental Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), and Life Cycle Costing (LCC), thereby expanding the assessment of sustainability from environmental impacts alone toward a multidimensional evaluation of environmental, social, and economic consequences across the life cycle (Sala et al., 2015; Zamagni et al., 2013). Unlike entity-based ESG reporting, LCSA is organized around product systems, functional units, and cradle-to-grave or otherwise explicitly defined system boundaries.

The central methodological advantage of LCSA lies in its ability to capture upstream, operational, downstream, and end-of-life impacts within a coherent analytical structure. It requires explicit consideration of raw material extraction, production, distribution, use phase, waste treatment, resource recovery, and broader value chain interdependencies. This stage-based orientation makes LCSA particularly relevant for analyzing circular economy practices, resource efficiency, and sustainability trade-offs. The UNEP Life Cycle Initiative defines life cycle approaches as tools for understanding environmental, social, and economic impacts across the life cycle, which makes LCSA especially relevant for systemic sustainability assessment.

From a methodological perspective, LCSA is closely related to the development of life cycle assessment as a standardized and increasingly systemic assessment approach (Guinée et al., 2011). The conceptual foundation of LCSA is commonly associated with the integration of environmental LCA, life cycle costing and social LCA into a broader sustainability assessment of products and product systems (Kloepffer, 2008). In addition, ISO 14040 and ISO 14044 provide the internationally recognized principles, framework, requirements and guidelines for conducting life cycle assessment, including goal and scope definition, inventory analysis, impact assessment, interpretation, reporting and critical review (International Organization for Standardization, 2006a, 2006b). This standard-based methodological logic reinforces the relevance of LCSA as a structured benchmark for evaluating whether ESG disclosures capture impacts across life cycle stages. Comparative applications further demonstrate that life cycle-based assessment can strengthen the systematic evaluation of complex environmental impacts and support the complementary use of different environmental assessment methods (Teodosiu et al., 2016).

LCSA differs from ESG reporting in both object of assessment and methodological logic. ESG reporting typically operates through disclosure indicators, materiality assessment, and regulatory datapoints, while LCSA operates through system boundary definition, inventory modeling, impact assessment, and interpretation. ESG disclosure is usually designed to communicate sustainability performance and risks at the undertaking level;

LCSA is designed to evaluate sustainability impacts across product systems and life cycle stages. These differences explain why ESG reporting may include value chain information without fully operationalizing life cycle thinking.

Despite its analytical robustness, LCSA has remained primarily associated with industrial ecology, sustainability assessment, engineering, and environmental management research. Its integration into accounting systems and corporate disclosure architectures is still limited. This separation creates a methodological divide between sustainability measurement and sustainability reporting. While LCSA can generate systemic sustainability evidence, corporate reporting frameworks may not always provide a clear mechanism for translating such evidence into disclosure, materiality, governance, or financial risk categories.

For sustainability accounting, this divide is particularly important. Accounting systems are designed to classify, measure, and communicate information in ways that support accountability and decision-making. However, if sustainability accounting remains structurally anchored in entity-based indicators, it may fail to capture the full systemic impact profile of corporate activities. LCSA therefore provides a potential methodological foundation for extending sustainability accounting beyond organizational reporting boundaries toward value chain and product-system accountability.

2.3. ESRS, Value Chain Transparency, and the Integration Gap

The ESRS framework introduces a more advanced regulatory architecture for sustainability reporting by requiring companies to disclose material impacts, risks, and opportunities across their own operations and value chains. EFRAG's implementation guidance on materiality assessment supports the operationalization of double materiality, while its value chain implementation guidance clarifies how undertakings should consider upstream and downstream information when applying ESRS ([European Financial Reporting Advisory Group, 2024a, 2024b](#)). Although these implementation guidance documents are non-authoritative, they are important for interpreting how ESRS value chain and materiality requirements can be applied in practice.

The expanding European sustainability reporting framework strengthens transparency and accountability. However, its multiple and partly overlapping requirements may also create regulatory fragmentation, information overload, and difficulties in interpreting sustainability information ([Moneva, 2025](#)).

Against this background, value chain disclosure under ESRS does not automatically amount to life cycle integration. ESRS requires companies to identify and disclose material value chain-related impacts, risks, and opportunities, but it does not prescribe full cradle-to-grave modeling, functional unit specification, or the systematic integration of environmental, social, and economic impacts across life cycle stages. As a result, ESRS and LCSA remain conceptually compatible but methodologically distinct.

The integration gap between ESRS-based ESG reporting and LCSA therefore arises from their different underlying logics. ESRS prioritizes regulatory disclosure, comparability, and materiality-based reporting, whereas LCSA prioritizes systemic assessment, life cycle boundaries, and multidimensional impact modeling. The former is primarily a disclosure architecture, while the latter is primarily an assessment methodology. Bridging the two requires an intermediate translation mechanism capable of connecting life cycle impact categories with accounting-relevant materiality, risk, and disclosure constructs. Digitalization can support this translation by improving the collection, traceability, integration, and control of financial and non-financial information, although it may also generate new challenges related to data quality, professional competencies, and assurance ([Krasteva-Hristova & Moneva, 2026](#); [Zhelev & Kostova, 2024](#)).

Prior studies have begun to connect life cycle methods with corporate disclosure and CSRD/ESRS implementation. Ben Ismail et al. (2021) examined the determinants and extent of voluntary LCA disclosure; de Salles and Brantsch (2025) illustrated how LCA can support sustainability reporting; Schneider et al. (2024) combined LCA with failure mode and effects analysis for CSRD/ESRS-aligned manufacturing risk assessment; and Sauer et al. (2026) mapped organizational LCA data to quantitative environmental ESRS datapoints. These studies establish important bridges, but they predominantly address environmental LCA, data availability, or operational risk assessment. The literature located for this study does not yet provide a comparative assessment of published corporate disclosures against full LCSA logic—environmental, social, and economic integration across all life cycle stages—combined with an accounting translation layer for double materiality and systemic risk. The present contribution is positioned within, rather than prior to, this emerging literature.

This gap has important implications for sustainable finance. Investors increasingly rely on ESG disclosures to assess long-term exposure to transition risks, resource scarcity, supply chain disruption, carbon dependency, and reputational vulnerability. However, if ESG reports disclose value chain impacts narratively or selectively, rather than through stage-based integration, users may underestimate systemic sustainability risks. In this sense, the ESRS–LCSA integration gap is not merely methodological; it affects the quality of risk-relevant information available to financial market participants.

The conceptual divergence between ESRS-based ESG reporting and LCSA is summarized in Table 1. The comparison highlights that the two approaches differ not only in terminology, but also in their assessment object, boundary logic, data architecture, integration mechanisms, methodological standardization, and typical outputs.

Table 1. ESG/ESRS reporting logic versus LCSA logic (conceptual comparison).

Dimension	ESRS-Based ESG Reporting (Typical Logic)	LCSA (Typical Logic)
Primary object of assessment	Reporting undertaking (entity)	Product system/functional unit
Boundary principle	Organizational boundaries; value chain disclosure via IRO identification and narrative/metric disclosure	Explicit cradle-to-grave (or defined system) boundaries across stages
Data structure	Indicator/datapoint architecture; topical standards filtered by materiality	Inventory modelling + impact assessment across stages and categories
Integration across E/S/economic	Often thematically segmented; cross-dimensional linkage depends on reporting design	Designed for multi-dimensional integration (environmental + social + economic)
Methodological standardization	Disclosure rules + non-mandated process for materiality; entity-specific judgment	Standardized phases (goal/scope, inventory, impact assessment, interpretation) with critical review norms
Typical output	Compliance-oriented sustainability statement; enterprise-level metrics	Impact profiles and trade-offs per functional unit and life cycle stage

As shown in Table 1, ESRS-based reporting and LCSA operate through different methodological logics. This difference explains why value chain disclosure under ESRS does not automatically lead to life cycle integration. Therefore, bridging the two approaches requires a translation mechanism between reporting-based materiality and system-based sustainability assessment.

2.4. Double Materiality, Professional Judgment, and Boundary Construction

Double materiality is one of the most important conceptual innovations of the European sustainability reporting regime. It requires companies to assess sustainability matters from two perspectives: impact materiality, which concerns the effects of the undertaking on people and the environment, and financial materiality, which concerns sustainability-related risks and opportunities that may affect enterprise value. This dual perspective broadens the scope of corporate accountability and connects sustainability reporting more explicitly with financial decision-making.

However, the operationalization of double materiality depends heavily on professional judgment and managerial discretion. Companies must determine which impacts, risks, and opportunities are material; how far into the value chain the assessment should extend; which time horizons should be considered; and what evidence is sufficient to support disclosure decisions. These judgments are unavoidable, especially under conditions of incomplete data, complex supply chains, uncertain downstream impacts, and evolving regulatory expectations.

The literature on sustainability reporting suggests that materiality assessment may become procedural if not supported by robust methodological foundations (Baumüller & Sopp, 2022). When companies define value chain boundaries narrowly or rely primarily on qualitative narratives, systemic externalities may remain partially invisible. In such cases, managerial discretion may influence not only what is disclosed, but also how sustainability impacts are framed, prioritized, aggregated, or omitted. Research focused specifically on double materiality under the new European regime similarly emphasizes the need for structured procedures that connect impact and financial materiality (Grozeva, 2023).

This issue reflects a deeper boundary problem in accounting. Organizational boundaries are historically derived from legal ownership, financial control, and consolidation principles (Miller, 1998; Santos & Eisenhardt, 2005). Ecological and socio-economic systems, however, do not follow corporate legal boundaries. Carbon emissions, biodiversity impacts, labor risks, waste flows, and product-use consequences frequently occur outside the direct operational control of the reporting undertaking. This divergence creates a structural tension between accounting accountability units and sustainability impact systems.

LCSA can contribute to this debate by providing a more structured methodological basis for boundary construction. By requiring explicit definition of system boundaries, life cycle stages, and impact categories, LCSA can reduce excessive discretion in sustainability reporting and make professional judgment more transparent. It does not eliminate judgment, but it disciplines it by linking disclosure decisions to a systematic assessment logic. In this sense, LCSA may support assurance readiness, comparability, and accountability by clarifying the assumptions behind value chain and impact materiality assessments.

2.5. Sustainability Accounting, Systemic Sustainability Risk, and Decision-Usefulness

The integration of LCSA into ESRS-based sustainability accounting has direct implications for systemic risk assessment and decision-usefulness. In financial reporting, decision-usefulness depends on whether information helps users assess future cash flows, risks, stewardship, and long-term value creation. In sustainability reporting, decision-usefulness increasingly depends on whether ESG disclosures help users understand sustainability-related risks and opportunities across time horizons and value chains.

The ISSB's IFRS S1 emphasizes the disclosure of sustainability-related risks and opportunities that are useful to users of general purpose financial reports in making decisions about providing resources to an entity (IFRS Foundation, 2023). This investor-oriented logic complements, but does not replace, the broader double materiality logic of ESRS. Together,

these developments show that sustainability information is becoming increasingly central to financial decision-making, capital allocation, and corporate risk management.

Evidence from the Romanian banking sector is retained as contextual evidence that multidimensional sustainability information can affect risk management in an EU institutional setting; it is not treated as evidence about Enel, Unilever, or Siemens AG, nor as a substitute for life cycle analysis (Huian et al., 2025).

However, the usefulness of ESG disclosures depends on their capacity to capture risks distributed across life cycle stages rather than only entity-level indicators. Transition risks may arise from regulatory change, technology, markets, carbon prices, and resource substitution; supply-chain risks from labor conditions, critical materials, biodiversity, or geopolitical disruption; and product-related risks from use-phase emissions, safety, reparability, circularity, and end-of-life responsibilities. A stage-based structure is therefore relevant because the location and interaction of these risks can influence their timing, controllability, and potential financial effects.

Life cycle integration can strengthen the informational value of ESG disclosures by making such distributed risks more visible. By mapping impacts across upstream, operational, downstream, and end-of-life stages, LCSA can help companies identify sustainability hotspots and translate them into risk-relevant disclosures. This can improve the ability of investors and other stakeholders to evaluate long-term resilience, exposure to transition pressures, and the credibility of corporate sustainability strategies.

From this perspective, sustainability accounting can be reconceptualized as a boundary-alignment process. The challenge is not merely to disclose more ESG indicators, but to align disclosure boundaries with the actual systems in which sustainability impacts and risks occur. LCSA provides a methodological basis for such alignment, while ESRS provides the regulatory disclosure architecture through which the resulting information can be communicated.

2.6. Research Gap and Theoretical Positioning of the Study

The reviewed literature reveals three interrelated gaps. First, although ESG reporting and sustainability accounting research has extensively examined disclosure quality, legitimacy, materiality, and regulatory development, less attention has been paid to the boundary logic through which ESG information is generated and structured. Existing studies often treat ESG reporting as a disclosure-quality issue, while the present study treats it as a boundary-definition and integration problem.

Second, while LCSA is well developed as a sustainability assessment paradigm, its translation into corporate reporting systems remains underexplored. The literature has not sufficiently examined how life cycle evidence can be embedded within ESRS-based sustainability accounting without creating a parallel reporting regime. This is particularly important because ESRS already requires value chain and double materiality disclosures, but does not prescribe a full LCSA methodology.

Third, the financial implications of insufficient life cycle integration remain insufficiently addressed. If ESG disclosures do not capture systemic sustainability risks across value chains, they may provide incomplete information for sustainable finance decision-making. This affects risk transparency, capital allocation, and the assessment of long-term value creation.

Against this background, the present study positions LCSA as a methodological bridge between ESRS-based reporting and systemic sustainability risk assessment. It argues that integrating life cycle thinking into sustainability accounting can enhance the decision-usefulness of ESG disclosures by improving boundary transparency, stage-based impact identification, cross-dimensional coherence, and risk-relevant interpretation. The study

therefore contributes to sustainability accounting, sustainable finance, and LCSA research by developing an operationalization logic that connects regulatory disclosure requirements with systemic sustainability assessment.

3. Materials and Methods

3.1. Research Design

This study uses a theory-driven qualitative comparative content analysis to address RQ1 and an analytical design synthesis to address RQ2. LCSA provides the benchmark for examining the three 2024 disclosures; the case findings and literature are then used to derive a conceptual model. The two tasks are therefore distinct: the case analysis generates empirical observations about disclosure structure, whereas model development is a normative-conceptual exercise that requires subsequent testing.

The use of a theory-driven qualitative content analysis design is consistent with directed approaches to qualitative content analysis, where existing theory or prior conceptual frameworks guide the development of analytical categories and interpretation of textual evidence (Hsieh & Shannon, 2005). In sustainability and environmental reporting research, content analysis has been widely used to examine corporate disclosure narratives, reporting structures and the informational characteristics of environmental and sustainability-related reports (Beck et al., 2010).

Content analysis is particularly appropriate for this study because sustainability reports represent formalized corporate communication artifacts through which companies disclose material impacts, risks, opportunities, governance mechanisms, and value chain-related information. Unlike purely quantitative disclosure scoring, qualitative content analysis allows for the interpretation of structural patterns, boundary assumptions, methodological references, and the degree of integration between environmental, social, and economic dimensions.

The purpose of the analysis is not to measure ESG disclosure quality in general, but to assess the degree of methodological alignment between ESRS-based reporting logic and LCSA principles. Therefore, the study focuses on the structure, depth, and coherence of disclosures rather than on the frequency of specific keywords. Particular attention is given to how companies define reporting boundaries, whether they disclose upstream and downstream impacts, whether sustainability dimensions are integrated across life cycle stages, and whether disclosures support the identification of systemic sustainability risks.

The study is exploratory and interpretive. The three-case design is appropriate for detailed examination of RQ1, but it is not used to validate the model proposed under RQ2, test causal relationships, estimate prevalence, or support sector-level generalization.

3.2. Sample Selection and Data Sources

The empirical analysis is based on publicly available corporate sustainability disclosures for the 2024 reporting cycle issued by three major European non-financial enterprises: Enel, Unilever, and Siemens AG. These companies were selected because they operate in sectors characterized by complex value chains, substantial sustainability impacts, and relatively advanced sustainability reporting practices. The selected sectors—energy, consumer goods, and industrial manufacturing—are particularly relevant for life cycle-based analysis because they involve upstream resource inputs, operational impacts, downstream use-phase effects, and end-of-life considerations.

The 2024 reporting cycle was selected for three reasons. First, it was the first reporting year for the initial group of undertakings required to prepare sustainability statements under the CSRD/ESRS regime, making it a critical transition point for observing emerging practice (Sauer et al., 2026). Second, it provided the most recent completed and broadly

contemporaneous reports available at the time of data collection. Third, it captured the period in which established ESG systems were being aligned with ESRS value chain and double materiality requirements. The study nevertheless does not assume that the three documents have identical formal regulatory status, as clarified below.

The documentary corpus comprises the Enel Integrated Annual Report 2024 (ENEL S.p.A., 2024), the Unilever Annual Report and Accounts 2024 (Unilever PLC, 2024), and the Siemens Sustainability Report 2024 (SIEMENS AG, 2024). The reports were obtained from the official corporate websites of the respective companies. The use of publicly available documents enhances transparency and allows future researchers to replicate, verify, or extend the analysis.

The companies and reports were selected according to four criteria. First, each company operates in a context with significant environmental, social, and supply-chain implications. Second, each report contains extensive disclosures on sustainability strategy, material impacts, risks and opportunities, value chain relationships, environmental performance, governance, and risk management. Third, the reports are available in English and provide sufficient documentary evidence for qualitative comparison. Fourth, diversity across energy, consumer goods, and industrial manufacturing permits comparison of how three different corporate contexts organize life cycle-related information. Because only one company is included per sector, any observed variation is treated as company-specific and illustrative; no sector-wide pattern is inferred.

The sample is intentionally limited because the objective is analytical depth rather than statistical representativeness. This sampling logic is consistent with qualitative case-based research, in which carefully selected cases can contribute to conceptual development (Flyvbjerg, 2006). The companies are therefore treated as illustrative cases. The analysis seeks analytical transferability, not statistical or sectoral generalization; with one case per sector, it cannot distinguish firm-specific practice from sector effects.

Although the three documents differ in their formal reporting format—an integrated annual report, an annual report containing extensive sustainability disclosures, and a standalone sustainability report—they all provide substantial information on sustainability, value chains, materiality, risks, environmental performance, and corporate governance. To avoid assuming an identical regulatory status for all three reports, they are treated as corporate sustainability disclosures for the 2024 reporting cycle and assessed against a common analytical benchmark derived from ESRS reporting logic and LCSA principles.

The unit of analysis was the disclosure unit, defined as a paragraph, table, metric, methodology note, policy description, or cross-referenced section containing information relevant to at least one of the analytical dimensions. Where several explicitly cross-referenced passages jointly addressed the same sustainability matter, they were treated as a connected disclosure unit. This approach allowed the analysis to capture information distributed across narrative sections, quantitative indicators, methodological explanations, and related report components.

3.3. Analytical Framework

To evaluate the degree of life cycle integration in corporate sustainability disclosures, an LCSA-informed analytical framework was developed. The framework is derived from the conceptual differences between ESRS reporting logic and LCSA, as discussed in the literature review. It operationalizes six analytical dimensions: boundary definition logic, upstream integration, downstream integration, cross-dimensional coherence, explicit methodological reference, and risk relevance and decision-usefulness.

The first five dimensions are grounded primarily in LCSA principles, while the sixth extends the framework toward the assessment of sustainability-related financial risks

and the decision-usefulness of corporate disclosures. The framework therefore connects sustainability accounting with systemic sustainability risk assessment. It enables the analysis to capture not only the presence of life cycle-related information, but also the extent to which such information is structured, integrated, and relevant to investors and other users of sustainability information.

The analytical dimensions, evaluation focus, and guiding questions applied during the coding process are presented in Table 2.

Table 2. Analytical framework for assessing life cycle integration in corporate sustainability disclosures.

Analytical Dimension	Evaluation Focus	Key Guiding Question
Boundary definition logic	Reporting boundaries, value chain scope, product-system orientation, and inclusion or exclusion of life cycle stages	Do the disclosures remain primarily entity-centered, or do they extend toward explicitly defined product-system and cradle-to-grave boundaries?
Upstream integration	Supplier impacts, raw material sourcing, upstream Scope 3 emissions, human rights issues, resource dependencies, and supply chain risks	Are upstream impacts and risks assessed systematically and connected to specific value chain stages, or are they presented mainly through isolated supplier governance and compliance narratives?
Downstream integration	Product use, customer impacts, maintenance, product efficiency, circularity, waste treatment, recycling, and end-of-life management	Are downstream and end-of-life impacts incorporated into the overall reporting structure, or are they presented as separate initiatives, targets, or narratives?
Cross-dimensional coherence	Integration of environmental, social, and economic impacts within and across life cycle stages	Are environmental, social, and economic impacts linked within the same life cycle stages, enabling the identification of interactions, trade-offs, and cumulative effects?
Explicit methodological reference	References to LCA, S-LCA, LCC, LCSA, product footprinting, Environmental Product Declarations, or other life cycle-based methods	Do the reports explicitly refer to or apply recognized life cycle-based methodologies, and are these methods used systematically or only for selected products and environmental issues?
Risk relevance and decision-usefulness	Links to financial risk, transition exposure, resource dependency, liabilities, resilience, long-term value creation, and capital allocation	Do the disclosures enable investors and other users to assess systemic sustainability risks and their potential implications for financial performance and enterprise value?

As shown in Table 2, the analytical framework combines life cycle-based assessment logic with the risk-oriented and decision-usefulness perspective of sustainable finance. It allows the study to move beyond a general assessment of ESG disclosure quantity or completeness and to examine whether corporate sustainability disclosures reflect the systemic logic of LCSA. The framework also enables the identification of methodological gaps between value chain disclosure under ESRS reporting logic and life cycle-based sustainability assessment.

For analytical consistency, the identified disclosure units were first coded according to one or more of the six analytical dimensions. A disclosure unit could therefore receive multiple dimensional codes when it addressed interconnected issues. For example, a passage linking supplier emissions, raw material dependency, and financial exposure could be coded simultaneously under upstream integration, cross-dimensional coherence, and risk relevance and decision-usefulness.

Following the coding of individual disclosure units, the accumulated evidence for each company–dimension combination was classified into one of four qualitative integration categories: not identified, mentioned or fragmented, partially integrated, and systemically integrated.

“Not identified” indicates that no relevant evidence was located for the respective analytical dimension after full-document and section-specific review. This category refers only to the absence of identifiable evidence in the publicly available report and does not imply that the underlying corporate practice does not exist.

“Mentioned or fragmented” refers to isolated narratives, policies, targets, metrics, or initiatives that address a relevant sustainability issue but are not connected across life cycle stages, sustainability dimensions, or risk categories.

“Partially integrated” indicates structured disclosure covering more than one life cycle stage or sustainability dimension, but without comprehensive cradle-to-grave coverage, systematic cross-dimensional integration, or a consistent connection to material impacts, risks, opportunities, and financial consequences.

“Systemically integrated” requires explicit or clearly traceable boundary definition, stage-based linkage, multidimensional consideration of environmental, social, and economic effects, and a connection to material impacts, risks, opportunities, or decision-usefulness. This category represents the closest observable alignment between the corporate disclosure structure and the systemic logic of LCSA.

The four categories were used as interpretive classifications rather than numerical scores. Where disclosure evidence within the same company–dimension combination varied in depth, the final classification reflected the highest level of integration that was consistently supported by multiple related disclosure units rather than by a single isolated statement. This aggregation rule reduced the risk that an exceptional example or a general corporate commitment would result in an overstated assessment of life cycle integration.

3.4. Coding Procedure

The coding procedure was conducted in three stages.

In the first stage, each report was reviewed in full to identify sections related to sustainability strategy, materiality assessment, value chain impacts, environmental performance, social impacts, circular economy, supply chain management, product responsibility, and risk management. This initial reading allowed the identification of the main disclosure architecture of each report.

In the second stage, relevant disclosure passages were coded according to the six analytical dimensions presented in Table 2. The coding focused on structural and conceptual features rather than isolated terms. For example, the presence of Scope 3 emissions data was not interpreted as life cycle integration unless it was connected to broader upstream or downstream impact assessment. Similarly, references to circular economy initiatives were not treated as comprehensive downstream integration unless they were linked to product use, end-of-life impacts, or resource recovery.

In the third stage, the coded findings were compared across the three companies in order to identify common patterns, sector-specific differences, and evidence of methodological convergence or divergence between ESG reporting and LCSA principles. The comparative analysis focused on whether the companies disclose sustainability impacts through entity-centered, risk-oriented, or system-oriented logic.

The coding did not assign numerical scores. This decision reflects the exploratory nature of the study and its focus on structural alignment rather than disclosure quantity. Instead, the analysis emphasizes the depth of integration, consistency of reporting bound-

aries, cross-dimensional linkage, and the extent to which disclosures support systemic sustainability risk assessment.

The detailed inclusion, exclusion, and classification rules applied to each analytical dimension are provided in Appendix A. These rules were established before the final comparative interpretation in order to ensure consistent treatment of similar disclosure evidence across the three reports.

To support coding dependability, the complete set of 18 company–dimension classifications was subjected to a structured second-pass audit against the predefined inclusion, exclusion, and aggregation rules and the page-referenced evidence in Supplementary Table S1. Borderline cases were resolved conservatively: the lower category was retained unless multiple mutually supporting disclosure units justified the higher category. Because the study used one primary coder and a small exploratory corpus, no inter-coder coefficient is reported. Instead, transparency is provided through the full evidence matrix, coding rationales, conservative decision rules, and an audit-trail example in Appendix A.

The qualitative coding and the structured second-pass audit were conducted manually, without the use of specialized qualitative data analysis software.

3.5. Interpretation Strategy

The interpretation strategy follows a theory-driven logic. LCSA is used as the benchmark for evaluating whether ESG disclosures reflect life cycle thinking. At the same time, ESRS-based sustainability reporting is interpreted as a disclosure architecture shaped by materiality assessment, value chain transparency, and regulatory accountability.

The analysis therefore does not assume that companies are required to conduct full LCSA under ESRS. Rather, it examines whether existing ESG disclosures contain elements that approximate, support, or fall short of life cycle integration. This distinction is important because the study does not criticize companies for failing to provide mandatory LCSA-based reporting. Instead, it investigates whether current reporting practices generate information that is sufficiently systemic, coherent, and risk-relevant.

Particular attention is paid to the distinction between narrative disclosure and methodological integration. A report may refer extensively to value chain impacts, supplier engagement, or circular economy initiatives without systematically integrating these elements across life cycle stages. Conversely, a disclosure may contain partial life cycle logic even if it does not explicitly use the term LCSA. The analysis therefore evaluates both explicit methodological references and implicit structural alignment with life cycle principles.

3.6. Trustworthiness and Limitations of the Method

Several steps were taken to strengthen trustworthiness. The framework was derived from established LCSA principles; the same predefined dimensions and decision rules were applied to all three reports; the complete set of 18 final classifications was re-audited against the page-referenced evidence; and the full evidence matrix is available in Supplementary Table S1. Prior content-analysis research emphasizes that transparent rules and systematic judgment are central to reliability in corporate reporting studies (Milne & Adler, 1999).

Nevertheless, the method has limitations. The sample includes only three companies, which limits the possibility of generalization. However, the selected companies are large European enterprises with advanced sustainability reporting practices, making them suitable for exploratory analysis. If life cycle integration remains limited even in such advanced cases, this may indicate a broader structural challenge in ESG reporting.

A second limitation concerns the use of public disclosures only. Internal management systems, non-public LCA studies, supplier databases, or assurance documents may

contain more detailed life cycle information than what is disclosed in sustainability reports. Therefore, the study evaluates reporting outputs rather than internal sustainability practices.

A third limitation concerns the interpretive nature of qualitative coding. The analysis relied on a single primary coder and therefore does not claim statistical inter-coder reliability. Dependability was strengthened through ex ante categories, explicit inclusion and exclusion rules, a complete second-pass audit of the 18 final classifications, conservative treatment of borderline evidence, and a publicly available audit trail. Future multi-coder studies should test the framework using formal agreement statistics.

Finally, the study is normative in the sense that LCSA principles are used as an evaluative benchmark. This is consistent with the research objective, which is to examine whether ESG disclosures can be methodologically strengthened through life cycle integration. Future research could build on this design by developing a quantitative scoring index, expanding the sample, or combining content analysis with interviews, assurance data, or investor perception studies.

4. Results

4.1. Persistence of Entity-Centered Boundary Logic

An alternative explanation must also be considered. Some of the observed segmentation may reflect the topical architecture of ESRS itself, which organizes disclosures through separate environmental, social, and governance standards, rather than an absence of life cycle thinking in the companies' internal systems. The analysis therefore interprets fragmentation as a property of the publicly disclosed reporting structure and does not infer that the companies lack internal LCA or integrated management practices.

Across the three examined corporate disclosures, reporting boundaries remain predominantly anchored in the reporting undertaking. Enel, Unilever, and Siemens AG provide extensive sustainability information and refer to value chain impacts, but their public reporting architecture does not consistently organize this information through a complete product-system or cradle-to-grave perspective.

Within these cases, expanded value chain disclosure does not automatically produce life cycle integration. Information is commonly organized around corporate functions, sustainability targets, risk management processes, supplier programs, and topical ESG sections. The resulting boundary is therefore more closely aligned with organizational accountability than with a unified systemic sustainability assessment.

In the case of Enel, sustainability disclosures are strongly connected with decarbonization, energy transition, Scope 3 emissions, supplier engagement, and climate-related targets. However, these disclosures are primarily structured around the company's strategic and operational boundaries. The broader life cycle implications of energy infrastructure, raw material extraction, technology deployment, and end-of-life treatment are not systematically integrated within a cradle-to-grave assessment logic.

Unilever provides extensive disclosures on sustainable sourcing, packaging, product responsibility, and consumer-use impacts. Nevertheless, the reporting logic remains organized around brands, corporate sustainability priorities, and selected value chain initiatives rather than an integrated life cycle sustainability model. Product-related sustainability impacts are visible, but they are not consistently mapped across upstream, operational, downstream, and end-of-life stages.

Siemens discloses significant information on supply chain due diligence, decarbonization, product efficiency, governance systems, and customer-related sustainability impacts. However, these disclosures are mainly framed through corporate risk management, com-

pliance, and technological innovation. The connection between upstream impacts, product use-phase effects, and end-of-life outcomes remains fragmented.

Taken together, the three cases do not fully reconfigure public reporting boundaries toward product-system accountability. They provide case-based evidence of a structural tension between ESRS-oriented value chain disclosure and LCSA-based assessment, consistent with critical research showing that formally advanced reports may still omit or fragment substantive sustainability problems (Boiral, 2013). This is an analytical finding from the selected cases, not a population-level claim about ESG reporting.

4.2. Selective Upstream Integration

The analysis shows that upstream impacts are present in all three reports, but their integration remains selective and predominantly environmental or compliance-oriented. Supplier-related disclosures are generally framed through supplier codes of conduct, procurement policies, due diligence systems, audit mechanisms, Scope 3 emissions, and risk monitoring. These elements are relevant, but they do not amount to systematic life cycle integration.

Enel's upstream disclosures focus strongly on decarbonization pathways, energy supply chains, supplier engagement, and climate-related value chain impacts. This provides useful information for assessing transition risk and supply chain exposure. However, social and economic life cycle dimensions, such as labor conditions in raw material extraction, community impacts linked to infrastructure development, or cost implications across the supply chain, are less systematically integrated.

Unilever demonstrates more visible upstream sustainability logic through sustainable agriculture, traceability, responsible sourcing, and supplier requirements. These disclosures are valuable from the perspective of value chain transparency. Yet, the integration remains fragmented because environmental sourcing impacts, supplier labor issues, product cost implications, and circularity considerations are not consistently analyzed within a unified life cycle framework.

Siemens presents detailed information on supplier risk management, human rights due diligence, environmental compliance, and responsible sourcing. These disclosures indicate a mature governance system. However, the reporting remains focused on procedural control and compliance, rather than cumulative upstream impact assessment. In other words, supplier governance is relatively advanced, but life cycle impact integration remains limited.

Across the three companies, upstream integration is therefore better characterized as risk-oriented and governance-oriented, rather than system-oriented. This distinction is important for sustainable finance. While supplier risk disclosures may help investors understand exposure to operational or reputational risks, they do not necessarily provide a comprehensive view of sustainability impacts across the upstream life cycle. This result is also consistent with prior research on Scope 3 greenhouse gas emissions, which shows that upstream and value chain emissions assessment is methodologically complex and may depend on estimation approaches, emission factors and the availability of supplier-related data (Downie & Stubbs, 2013).

4.3. Fragmented Downstream and End-of-Life Disclosure

Downstream and end-of-life impacts are less systematically disclosed than upstream impacts. Although all three companies refer to product use, circular economy, customer solutions, efficiency, recyclability, waste reduction, or end-of-life initiatives, these disclosures are usually presented as separate sustainability initiatives rather than as integrated stages of a life cycle model.

In Enel's case, downstream impacts are closely related to energy use, infrastructure, electrification, and decarbonization pathways. However, the disclosures are mainly framed through climate strategy and transition objectives. End-of-life considerations related to infrastructure components, technology replacement, and circular resource flows are not systematically developed as part of a full life cycle sustainability assessment.

Unilever provides comparatively more visible downstream disclosure due to the nature of the consumer goods sector. Product use, packaging waste, water consumption, consumer behavior, and circularity initiatives are discussed in several sections. However, these disclosures remain partly narrative and target-driven. They do not fully integrate environmental, social, and economic impacts across the product life cycle.

Siemens emphasizes product efficiency, customer solutions, digital technologies, and industrial transformation. These disclosures are relevant for assessing how Siemens products may reduce downstream environmental impacts for customers. Nevertheless, downstream impacts are often framed as client benefits or technological contributions rather than as cumulative system-level effects across the life cycle.

This fragmentation limits the ability of ESG disclosures to capture deferred or distributed sustainability risks. Downstream impacts often become financially relevant over longer time horizons, especially where product use, energy consumption, maintenance, circularity, or end-of-life obligations influence future costs, liabilities, market expectations, and regulatory exposure. Therefore, the weak integration of downstream and end-of-life impacts reduces the decision-usefulness of ESG reporting for sustainable finance. The fragmented treatment of end-of-life impacts is particularly important in light of circular economy research, which emphasizes closed-loop resource flows, waste reduction and the need to consider product systems beyond production and immediate operational boundaries (Ghisellini et al., 2016; Kirchherr et al., 2017).

4.4. Dimensional Segmentation of Environmental, Social, and Economic Information

A central finding across the three cases is the persistence of dimensional segmentation. Environmental, social, and governance information is generally presented in separate sections or thematic blocks. Environmental indicators are the most developed, particularly for emissions, energy, climate strategy, resource efficiency, and circularity, whereas social and economic dimensions are rarely integrated with environmental impacts at specific life cycle stages.

This is visible across all three companies. Environmental information is often quantified and linked to targets, whereas social information is more frequently presented through policies, commitments, due diligence mechanisms, workforce indicators, or stakeholder engagement. Economic and cost-related implications are usually implicit, dispersed, or connected to strategic narratives rather than explicitly integrated into life cycle stages.

From the perspective of LCSA, this segmentation is problematic because sustainability performance is not only the sum of separate environmental, social, and economic indicators. A life cycle perspective requires the joint consideration of these dimensions within each stage of the product system. For example, upstream raw material sourcing may involve carbon impacts, labor risks, supplier cost volatility, and community consequences. Similarly, downstream product use may involve energy efficiency, consumer safety, affordability, and long-term cost implications.

The analyzed reports rarely provide such integrated stage-based interpretation. This suggests that ESG reporting remains closer to an indicator architecture than to a systemic sustainability assessment architecture. Consequently, the ability of reports to reveal trade-offs, interdependencies, and systemic risks remains limited. This finding also reflects a broader limitation in sustainability practice, since the environmental, social and economic

pillars of sustainability are often discussed together conceptually but remain difficult to integrate empirically and operationally in reporting systems (Purvis et al., 2019).

4.5. Limited Explicit Operationalization of LCSA

The analysis also shows that explicit references to life cycle-based methods are uneven and partial. Life cycle thinking appears most often in relation to environmental assessment, product footprinting, circularity, or selected environmental performance initiatives. However, comprehensive Life Cycle Sustainability Assessment, understood as the integration of environmental LCA, social LCA, and life cycle costing, is not systematically operationalized in the examined reports.

This indicates a methodological asymmetry. Environmental life cycle elements are more visible than social and economic life cycle dimensions. Companies may refer to product footprints, emissions across the value chain, resource efficiency, or circular economy, but these elements are not consistently connected to social impacts or economic life cycle costs. As a result, reporting practices remain closer to partial environmental life cycle thinking than to full LCSA.

The absence of comprehensive LCSA operationalization does not mean that the analyzed companies lack sustainability management practices. Rather, it indicates that such practices are not translated into sustainability disclosures in a way that allows external users to assess systemic life cycle impacts. This distinction is crucial. The study evaluates disclosure outputs, not internal management systems. It is possible that companies use more sophisticated internal tools than those visible in public reports. However, from the perspective of investors and other external stakeholders, only disclosed information can support decision-making.

4.6. Risk Relevance and Decision-Usefulness of ESG Disclosures

The results suggest that the current structure of ESG reporting provides useful but incomplete information for assessing systemic sustainability risks. The reports offer valuable insights into climate strategy, governance mechanisms, supplier management, circular economy initiatives, and sustainability targets. These disclosures are relevant for investors and other stakeholders. However, their risk relevance is constrained by the absence of systematic life cycle integration.

The main limitation concerns the fragmented representation of risks across the value chain. Transition risks, resource dependencies, supplier vulnerabilities, product-use impacts, circularity constraints, and end-of-life responsibilities are often disclosed separately. This makes it difficult for users to understand how these risks accumulate, interact, or shift across life cycle stages.

For sustainable finance, this limitation is significant. Investors need ESG information that supports the assessment of long-term value creation, risk pricing, and capital allocation. If sustainability disclosures remain entity-centered and indicator-based, they may underestimate systemic risks that originate outside the reporting undertaking but ultimately affect financial performance, resilience, or strategic positioning.

Life cycle integration could therefore enhance the decision-usefulness of ESG disclosures in three ways. First, it could improve boundary transparency by clarifying where impacts occur across the value chain. Second, it could strengthen risk interpretation by connecting environmental, social, and economic impacts across life cycle stages. Third, it could support comparability by providing a more consistent structure for organizing value chain information. This is relevant for sustainable finance because institutional investors increasingly perceive climate-related and sustainability-related risks as financially material for portfolio companies and investment decision-making (Krueger et al., 2020).

4.7. Comparative Synthesis of Results

Table 3 presents selected representative evidence supporting the company-level coding. The examples illustrate how the analytical categories were assigned on the basis of identifiable report sections and page references. The complete evidence base, including all eighteen company–dimension observations and the corresponding coding rationales, is provided in Supplementary Table S1.

Table 3. Representative disclosure evidence supporting the comparative coding.

Company	Analytical Dimension	Representative Evidence	Page(s)	Interpretation
Unilever	Boundary definition logic	The double materiality assessment covers own operations and any stage of the upstream and downstream value chain, including product use and disposal.	226	Broad value-chain coverage is evident, but the disclosure does not establish a fully specified cradle-to-grave product-system boundary across all LCSA dimensions.
Enel	Upstream integration	The report links the procurement of critical raw materials, including lithium, cobalt, and nickel, with human rights concerns, geopolitical concentration, supply-chain disruption, and price volatility.	364–365	Specific upstream materials and interconnected environmental, social, and economic risks are identified, but they are not integrated with downstream and end-of-life impacts in a complete LCSA framework.
Siemens AG	Downstream integration	Siemens quantifies Scope 3 emissions from the use of sold products over their expected lifetime and reports that products sold in fiscal 2024 are expected to generate 398 million metric tons of CO ₂ e during their anticipated use phase.	70	The disclosure quantitatively addresses the downstream use phase, but it remains focused on greenhouse gas emissions and does not integrate social, economic, or end-of-life effects across the complete product life cycle.
Unilever	Cross-dimensional coherence	Unilever links plastic packaging and extended producer responsibility schemes with environmental pressures and quantified economic consequences, including estimated effects of EPR costs and plastic taxes on net profit and net revenue under different scenarios and time horizons.	262	The disclosure connects environmental and economic effects within the downstream and end-of-life stages, but it does not incorporate the social dimension or provide an integrated assessment of trade-offs across the complete life cycle.
Siemens AG	Explicit methodological reference	Siemens explicitly applies Life Cycle Assessments and Environmental Product Declarations within its Robust Eco Design approach and calculates an LCA for representative products within Homogeneous Product Families.	80–83	The disclosure demonstrates a structured application of LCA across several product life cycle phases, but the methodology remains predominantly environmental and does not integrate Social LCA and Life Cycle Costing into a comprehensive LCSA framework.

Table 3. *Cont.*

Company	Analytical Dimension	Representative Evidence	Page(s)	Interpretation
Enel	Risk relevance and decision-usefulness	Enel links the sourcing of critical raw materials with geopolitical concentration, possible supply-chain disruption, and increases or volatility in material prices, indicating potential operational and economic consequences.	364–365	The disclosure provides decision-relevant information by connecting identifiable upstream dependencies with operational and economic risks. However, the potential financial effects are not systematically quantified or traced across the complete life cycle.

The comparative findings are summarized in Table 4. The table shows that all three companies demonstrate advanced ESG disclosure practices, but none fully operationalizes LCSA within its reporting architecture.

Table 4. Comparative synthesis of life cycle integration in ESG disclosures.

Analytical Dimension	Enel	Unilever	Siemens AG	Overall Finding
Boundary definition logic	Mainly entity-centered, with strong climate and transition focus	Entity-centered, with visible product and sourcing elements	Entity-centered, with governance and technology focus	Reporting boundaries remain predominantly organizational
Upstream integration	Strong supplier and Scope 3 disclosure, mainly environmental	Strong sourcing and traceability disclosure	Strong supplier governance and due diligence	Upstream integration is present but not fully life cycle-based
Downstream integration	Focus on energy transition and infrastructure impacts	Product use, packaging, water, and consumer impacts visible	Product efficiency and customer solutions emphasized	Downstream impacts remain fragmented and partly narrative
Cross-dimensional coherence	Environmental dimension dominates	Environmental and consumer-related issues visible, but fragmented	Governance and environmental compliance dominate	Environmental, social, and economic dimensions are not systematically integrated
Explicit LCSA reference	Partial life cycle/environmental logic	Partial product and circularity logic	Partial product efficiency and environmental logic	Full LCSA is not operationalized
Risk relevance	Strong transition-risk relevance	Strong value chain and consumer-risk relevance	Strong supply chain and technology-risk relevance	Risk-relevant information exists, but systemic risk representation remains incomplete

The comparative synthesis confirms that the analyzed companies are not weak reporters. On the contrary, they represent relatively advanced examples of ESG disclosure. However, their reporting structures remain insufficiently aligned with life cycle sustainability assessment. This supports the central argument of the study: ESRS-based ESG reporting

can improve value chain transparency, but without explicit life cycle integration it may still fail to capture systemic sustainability risks comprehensively.

Across the 18 company–dimension observations documented in Supplementary Table S1, all were classified as partially integrated and none met the predefined threshold for systemically integrated disclosure. These classifications summarize the three cases only and should not be interpreted as sector-level or population-level estimates.

The findings therefore justify the need for an operationalization model that can translate LCSA principles into ESRS-based sustainability accounting. Such a model should not replace ESRS requirements, but should provide a methodological layer for improving boundary definition, stage-based indicator mapping, cross-dimensional coherence, and risk-relevant interpretation.

5. The LCSA–ESRS Operationalization Model

The empirical findings reveal a structural misalignment between entity-centered ESG reporting and system-based life cycle sustainability assessment. Although ESRS-based disclosures increasingly include value chain information, Scope 3 emissions, circular economy initiatives, and supplier due diligence, the analyzed reports do not fully operationalize a cradle-to-grave sustainability perspective. Sustainability information remains predominantly organized around the reporting undertaking, thematic ESG categories, and corporate risk management processes rather than around product-system boundaries and life cycle stages.

To address the diagnosed gap, this study proposes the LCSA–ESRS Operationalization Model as a conceptual, theory-informed design. It is not an empirically validated or piloted reporting instrument. The three cases diagnose the disclosure problem and inform the model's components, but future studies must test its feasibility, reliability, reporting burden, and effects on users' decisions. The model does not replace ESRS requirements or create a parallel reporting regime; it introduces a methodological integration layer for translating life cycle evidence into ESRS-based sustainability accounting.

The logic of the model is consistent with prior research emphasizing the need to integrate corporate sustainability assessment, management accounting, management control and reporting, rather than treating them as isolated organizational systems (Maas et al., 2016). It also aligns with evidence that sustainability key performance indicators become more useful when they are embedded in internal planning, decision-making and performance management processes (Adams & Frost, 2008).

The proposed model is based on four interrelated pillars:

1. Boundary reconfiguration—from entity-centered reporting toward product-system and value chain logic;
2. Stage-based indicator mapping—alignment of ESG indicators with life cycle stages;
3. Dimensional harmonization—integration of environmental, social, and economic dimensions across each stage;
4. Accounting translation layer—connection between life cycle impacts, double materiality, risk relevance, and ESRS disclosure logic.

Together, these pillars provide a structured pathway for embedding LCSA logic into sustainability reporting without extending beyond the regulatory architecture of ESRS.

5.1. Pillar 1: Boundary Reconfiguration from Entity to Product-System Logic

The first pillar addresses the central limitation identified in the results: the persistence of entity-centered reporting boundaries. Traditional corporate reporting is grounded in organizational accountability, legal consolidation, and financial control. ESRS expands this logic by requiring value chain information where material, but the reporting undertaking

remains the primary unit of disclosure. By contrast, LCSA is organized around product systems, functional units, and explicitly defined life cycle boundaries.

Boundary reconfiguration therefore requires companies to supplement entity-based reporting with product-system mapping. This does not mean abandoning corporate reporting boundaries. Rather, it means extending sustainability analysis to identify where material impacts occur across upstream, operational, downstream, and end-of-life stages.

In practical terms, companies could begin by identifying key product groups, services, or business activities with significant sustainability impacts. For each of these, the reporting process could map the relevant life cycle stages: raw material extraction, supplier production, own operations, distribution, product use, maintenance, waste treatment, recycling, or disposal. Such mapping would help clarify whether sustainability impacts are concentrated within the company's own operations or distributed across the wider value chain.

This boundary extension is also consistent with value chain accounting logic, where companies are encouraged to understand their full value chain emissions impact in order to identify major reduction opportunities, data gaps and sustainability-related risks across upstream and downstream activities ([World Resources Institute & World Business Council for Sustainable Development, 2011](#)).

This pillar strengthens ESG reporting in two ways. First, it increases boundary transparency by making explicit which life cycle stages are included or excluded from disclosure. Second, it enhances systemic risk identification by revealing sustainability-related exposures that may originate outside the reporting entity but still affect long-term value creation, transition risk, supply chain resilience, or regulatory exposure.

5.2. Pillar 2: Stage-Based Indicator Mapping

The second pillar introduces a structured alignment between ESG indicators and life cycle stages. Current ESG reporting commonly presents information by topical categories such as climate change, pollution, resource use, workforce, value chain workers, consumers, governance, or business conduct. While this structure supports regulatory compliance, it may obscure how impacts accumulate across the life cycle.

Stage-based indicator mapping reorganizes sustainability information according to the sequence of value creation and impact generation. Instead of presenting environmental, social, and economic information only in separate thematic blocks, companies could map relevant ESG indicators to life cycle stages. Stage-based indicator mapping can also be linked to sustainability performance measurement systems, which aim to connect financial and non-financial, short-term and long-term, as well as environmental, social and economic indicators within strategy implementation and management control processes ([Hansen & Schaltegger, 2016](#)).

For example, the upstream stage may include indicators related to supplier emissions, raw material sourcing, biodiversity impacts, value chain workers, human rights due diligence, supplier cost volatility, and exposure to critical materials. The own-operations stage may include energy use, operational emissions, workforce safety, water consumption, pollution control, and production costs. The downstream stage may include product-use emissions, customer health and safety, energy efficiency, accessibility, affordability, and maintenance impacts. The end-of-life stage may include recyclability, waste generation, recovery value, take-back systems, and circularity performance.

This pillar improves the interpretability of ESG disclosures because users can see not only what the company reports, but also where in the life cycle the reported impacts occur. It also supports more meaningful comparison between companies and sectors because it separates operational impacts from upstream and downstream impacts. For sustainable finance, this distinction is important because different life cycle stages may generate differ-

ent types of risks: upstream supply risks, operational transition risks, downstream market risks, or end-of-life liability risks.

5.3. Pillar 3: Dimensional Harmonization Across Environmental, Social, and Economic Impacts

The third pillar addresses the segmentation of ESG reporting. The results show that environmental information is generally more developed and more frequently quantified than social and economic life cycle information. However, LCSA requires the integration of environmental, social, and economic dimensions within each life cycle stage.

Dimensional harmonization means that companies should not treat environmental, social, and economic impacts as isolated reporting categories. Instead, each life cycle stage should be analyzed through an integrated sustainability lens. The need for dimensional harmonization is also supported by research linking sustainable entrepreneurship, income, and sustainable consumption, which demonstrates that economic, social, and behavioural factors interact with environmental sustainability outcomes (S. Petrova et al., 2023). Related evidence from the European bioeconomy identifies significant interdependencies among intellectual capital, circular economy development, and economic growth, further supporting the need to assess sustainability outcomes through interconnected rather than isolated dimensions (Nedelea et al., 2018). For instance, upstream raw material sourcing may involve greenhouse gas emissions, biodiversity impacts, labor risks, community effects, supply continuity, and price volatility. Product use may involve energy consumption, user safety, affordability, accessibility, and customer-related risks. End-of-life management may involve waste reduction, recycling infrastructure, informal labor risks, community impacts, and recovery value.

This pillar is important because sustainability risks often arise from interactions between dimensions. A product may reduce operational emissions but increase upstream critical material dependency. A circular economy initiative may improve resource efficiency but generate social risks in informal recycling networks. A supplier transition may reduce carbon intensity but increase costs or expose the company to labor-related risks. These trade-offs are difficult to identify when ESG disclosures remain dimensionally segmented.

By integrating environmental, social, and economic information across life cycle stages, dimensional harmonization can improve the quality of sustainability-related risk analysis. It also supports more balanced decision-making by preventing overreliance on single-dimensional indicators such as carbon emissions alone.

5.4. Pillar 4: Accounting Translation Layer

The fourth pillar connects life cycle impacts with ESRS-based materiality assessment and financial decision-usefulness. One of the main barriers to integrating LCSA into sustainability reporting is that LCSA outputs are often technical, product-specific, and assessment-oriented, whereas ESRS disclosures are regulatory, entity-oriented, and materiality-based. The accounting translation layer is designed to bridge this difference.

The accounting translation layer is consistent with research on integrated reporting and internal mechanisms of change, which shows that new reporting frameworks may require changes in internal information systems, management processes and organizational routines in order to make sustainability information more integrated and decision-useful (Stubbs & Higgins, 2014).

This layer translates life cycle impacts into accounting-recognizable disclosure categories. Environmental, social, and economic life cycle impacts can be linked to ESRS material impacts, risks, and opportunities. For example, upstream resource depletion may be translated into supply chain risk, resource dependency, or transition exposure. Use-phase emissions may be translated into product-related climate risk or market transition

risk. End-of-life waste impacts may be translated into circular economy risk, regulatory exposure, or future liability. Social impacts in the value chain may be translated into human rights risk, reputational risk, or due diligence requirements.

The translation layer is also relevant to professional judgment and managerial discretion. ESRS implementation requires companies to make judgments about materiality, value chain boundaries, time horizons, assumptions, and data limitations. Without a structured methodology, these judgments may remain opaque or inconsistent. LCSA can support professional judgment by providing a more disciplined basis for identifying where impacts occur and how they relate to sustainability-related risks.

From a sustainable finance perspective, the accounting translation layer improves the decision-usefulness of ESG disclosures. Investors and other users do not need only technical impact data; they need information that helps them assess risk exposure, resilience, capital allocation implications, and long-term value creation. By linking life cycle impacts with materiality and risk categories, the model makes sustainability information more relevant for financial decision-making.

5.5. Operational Logic of the Model

The operational logic of the proposed model can be summarized as a sequence of five steps.

First, the company identifies the most relevant products, services, or activities for life cycle assessment based on materiality, risk exposure, and stakeholder relevance. Second, it maps the life cycle stages associated with these products or activities. Third, it identifies environmental, social, and economic impacts within each stage. Fourth, it links these impacts to ESRS disclosure topics and double materiality assessment. Fifth, it translates the resulting information into risk-relevant and decision-useful disclosure.

This process is not intended to transform every sustainability report into a full technical LCSA report. Rather, it provides a structured method for using life cycle thinking within ESRS-based sustainability accounting. The purpose is to improve the coherence of disclosures, not to overload reports with excessive technical detail.

The operational logic is presented in Table 5.

Table 5. Operational logic of the LCSA–ESRS integration model.

Step	Purpose	Practical Application	Expected Reporting Improvement
1. Identify material products, services, or activities	Select the most relevant objects of assessment	Identify business activities with significant sustainability impacts or financial risk exposure	More focused and material sustainability reporting
2. Map life cycle stages	Extend reporting beyond own operations	Distinguish upstream, own operations, downstream use, and end-of-life stages	Greater boundary transparency
3. Identify E/S/economic impacts	Integrate sustainability dimensions	Map environmental, social, and economic impacts at each stage	Reduced dimensional fragmentation
4. Link impacts to ESRS materiality	Translate life cycle impacts into reporting logic	Connect impacts with ESRS topics, IROs, and double materiality assessment	Stronger regulatory alignment

Table 5. Cont.

Step	Purpose	Practical Application	Expected Reporting Improvement
5. Communicate risk-relevant information	Improve decision-usefulness	Explain how life cycle impacts affect transition risk, supply chain risk, circularity risk, and long-term value	More useful information for investors and stakeholders

5.6. Application of the LCSA–ESRS Operationalization Model

To demonstrate how the model can be applied, Table 6 presents an illustrative mapping of life cycle stages, sustainability dimensions, and ESRS integration logic. The table does not propose new mandatory disclosures. Instead, it shows how existing ESRS-based sustainability information could be organized more systematically through life cycle thinking.

Table 6. Illustrative LCSA–ESRS mapping logic.

Life Cycle Stage	Environmental Focus	Social Focus	Economic/LCC Focus	ESRS Integration Logic
Upstream	Supplier emissions, raw material extraction, biodiversity impacts, upstream transport	Value chain workers, human rights due diligence, community impacts	Supplier cost volatility, resource dependency, critical material exposure	Use value chain IRO identification to justify stage materiality and connect to material ESRS topics
Own operations	Operational emissions, energy use, pollution, water use, resource consumption	Own workforce safety, working conditions, governance controls	Operational costs, energy cost exposure, compliance costs	Align operational data with material topical metrics and assurance-ready internal control systems
Downstream use	Use-phase emissions, energy efficiency, water consumption, product-related environmental impacts	Consumer health and safety, accessibility, user impacts	Cost-to-use, affordability, maintenance costs	Make use-phase impacts explicit within materiality narratives and clarify assumptions
End-of-life	Waste treatment, recyclability, circularity outcomes, recovery rates	Community impacts, informal-sector risks, end-user responsibility	Recovery value, end-of-life costs, future liabilities	Link circular economy initiatives to stage-based KPIs and explain whether data are quantified or narrative

This mapping illustrates how LCSA can support ESRS-based reporting by improving the structure and interpretability of value chain information. It also demonstrates how companies can connect sustainability impacts with financial risk categories without creating a separate reporting framework.

An illustrative, non-validating application can be made to Unilever’s packaging disclosures. Under Pillar 1, packaging would be defined as a product-system boundary spanning material sourcing, manufacturing, consumer use, collection, and end-of-life treatment. Under Pillar 2, existing Scope 3, packaging, extended producer responsibility, and plastic-tax information would be mapped to these stages. Under Pillar 3, environmental waste and emissions data would be considered together with consumer, worker or community, affordability, and cost effects. Under Pillar 4, the disclosed extended producer responsibility

and plastic-tax scenarios would be translated into material impacts, risks and opportunities, time horizons, and potential financial effects. This exercise shows how the model can reorganize information already present in the report, but it does not validate the model or demonstrate that all required data are currently available.

5.7. Contribution of the Model to Sustainable Finance and Risk Transparency

The proposed LCSA–ESRS Operationalization Model contributes to sustainable finance by improving the quality of ESG information available for risk assessment. Current ESG disclosures often provide extensive information, but such information may remain fragmented across topics, sections, and indicators. Consequently, investors may encounter difficulties in assessing how sustainability impacts accumulate across value chains and how they may affect long-term financial performance. In this context, the transition toward a green economy also depends on financing mechanisms capable of supporting energy-efficient, resource-saving, and environmentally oriented investment projects (Krastev et al., 2023).

However, recent evidence from seven EU Member States and the EU-27 does not establish a robust direct relationship between environmental taxes and sectoral eco-investments, indicating that environmental fiscal instruments should not be assumed to stimulate green investment automatically (Georgieva, 2026). This finding reinforces the need for sustainability disclosures to provide transparent information on companies' actual environmental investment responses, financing commitments, resource allocation decisions, and implementation capacity.

By introducing life cycle integration, the model helps identify systemic sustainability risks that may remain insufficiently visible under entity-centered reporting. These include transition risks associated with upstream inputs, physical and environmental risks related to resource use, reputational risks across the value chain, downstream market risks, and circularity-related risks connected with end-of-life obligations. Such risks are increasingly relevant to capital allocation, credit assessment, insurance, investment analysis, and corporate valuation.

The model also supports long-term value creation by encouraging companies to disclose not only the sustainability targets they have adopted, but also where material impacts, risks, and financial consequences arise across the life cycle. This may strengthen the credibility of corporate sustainability strategies and improve investors' ability to distinguish between substantive sustainability transformation and symbolic disclosure.

This risk-translation logic is also consistent with the recommendations of the Task Force on Climate-Related Financial Disclosures, which emphasize the interconnections among climate-related risks and opportunities, governance, strategy, risk management, metrics, and targets (Task Force on Climate-Related Financial Disclosures, 2017).

5.8. Summary of the Model

The proposed model reframes ESG reporting as a boundary-alignment and risk-translation process. Its central argument is that ESRS-based reporting and LCSA are not competing frameworks. Rather, they can be integrated through a structured methodological layer that connects product-system sustainability impacts with corporate disclosure requirements.

The overall logic of the proposed model is summarized in Figure 1, which presents the connection between LCSA logic, ESRS disclosure requirements, the four operational pillars of integration, and the expected improvement in systemic coherence, risk transparency and decision-usefulness.

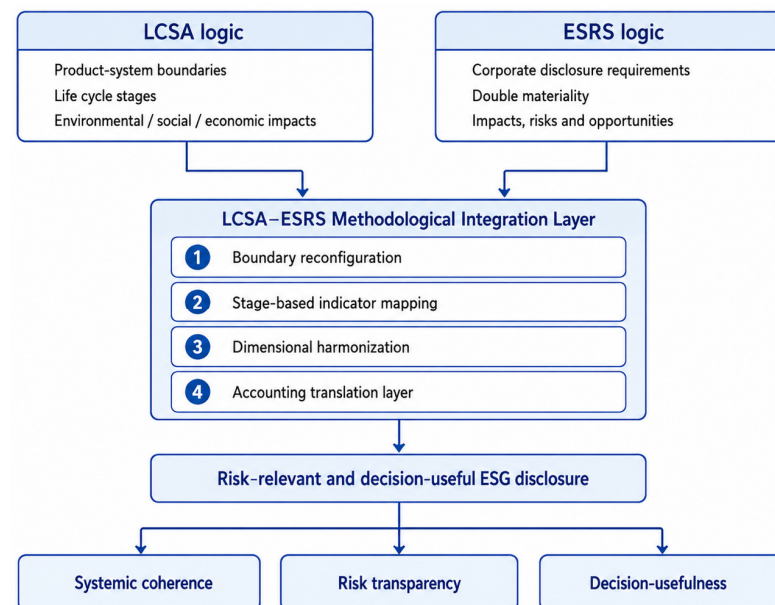


Figure 1. The LCSA-ESRS Operationalization Model for risk-relevant sustainability disclosure.

The model has three key implications. First, it enhances systemic coherence by aligning ESG disclosures with life cycle stages. Second, it improves risk transparency by identifying sustainability-related risks across upstream, operational, downstream, and end-of-life stages. Third, it strengthens decision-usefulness by translating life cycle impacts into materiality, governance, and financial risk categories.

In this way, the LCSA-ESRS Operationalization Model provides a practical and conceptual bridge between sustainability assessment and sustainability accounting. It supports the development of ESG disclosures that are not only compliant with regulatory expectations but also more meaningful for investors, regulators, companies, and other stakeholders concerned with sustainable finance and corporate responsibility.

6. Discussion

6.1. Reframing ESG Reporting as a Boundary-Definition Problem

Across the three cases, the most consequential issue is not disclosure volume but the alignment between the boundaries of reporting and the systems in which impacts occur. Corporate and topical ESRS structures organize accountability effectively, yet they can leave upstream, downstream, and end-of-life effects distributed across separate sections. The analytical question is therefore how those dispersed disclosures can be connected without displacing the entity-based reporting architecture.

The results therefore support earlier critical accounting literature which argues that sustainability reporting may reproduce organizational narratives without fully capturing the relationship between corporate activity and broader socio-ecological systems (Bebington & Larrinaga, 2014; Gray, 2010). Even under more advanced regulatory frameworks, the architecture of disclosure may remain entity-centered unless it is complemented by methodologies capable of identifying systemic impacts across value chains.

From this perspective, the contribution of the present study is to shift the analytical focus from “how much ESG information is disclosed” to “how sustainability impacts are bounded, connected, and interpreted.” This reframing is important because extensive ESG reporting does not automatically produce systemic sustainability accountability. Reports may become longer, more standardized, and more detailed, while still failing to integrate upstream, downstream, and end-of-life impacts into a coherent life cycle structure.

This interpretation is also consistent with evidence that the relationship between sustainability performance and sustainability disclosure is not always straightforward, since disclosure may serve both informational and legitimacy-oriented purposes (Hummel & Schlick, 2016). Therefore, the expansion of ESG disclosure should be assessed not only by volume or formal compliance, but also by the extent to which it improves the substantive visibility of sustainability impacts across organizational and value chain boundaries.

6.2. ESRS, Double Materiality, and the Challenge of Operationalization

The European Sustainability Reporting Standards represent a significant regulatory advancement because they require companies to consider both impact materiality and financial materiality. In principle, double materiality creates a bridge between corporate impacts on society and the environment, on the one hand, and sustainability-related financial risks and opportunities, on the other. This dual perspective is highly relevant for strengthening corporate accountability and improving the usefulness of sustainability disclosures for investors and other stakeholders.

The segmentation observed in the reports may partly result from the ESRS topical architecture rather than from a lack of internal life cycle management. This distinction limits the inference: the study evaluates the organization and connectivity of public disclosures, not undisclosed corporate practices. Even so, if users must reconstruct life cycle relationships across separate topical statements, the decision-usefulness problem remains.

This finding is consistent with Baumüller and Sopp (2022), who emphasize that the shift from non-financial reporting to European sustainability reporting creates new opportunities but also implementation challenges. Double materiality can become transformative only if it is supported by robust processes for identifying, assessing, and connecting impacts, risks, and opportunities. Without such methodological support, it risks becoming a procedural exercise driven by compliance rather than a substantive mechanism for sustainability accountability (Baumüller & Sopp, 2022).

The present study argues that LCSA can strengthen the practical implementation of double materiality. LCSA does not replace materiality assessment, but it can support it by providing a systematic basis for identifying where impacts occur across the life cycle. This is particularly important for value chain assessment, where companies must exercise professional judgment regarding data availability, time horizons, boundaries, and the significance of upstream and downstream impacts. By introducing explicit life cycle boundaries and stage-based mapping, LCSA can make these judgments more transparent and more consistent.

This argument is consistent with prior research showing that different approaches to materiality may create tensions for users of sustainability information, especially when impact-oriented and financial materiality perspectives are not clearly connected (Jørgensen et al., 2022). A life cycle-based interpretation of materiality can therefore help reduce ambiguity by clarifying where impacts occur, how they relate to value chain stages, and whether they may become financially relevant over time.

6.3. Implications for Sustainable Finance and Systemic Risk Assessment

The findings have important implications for sustainable finance. ESG disclosures are increasingly used by investors, lenders, analysts, rating agencies, and regulators to assess long-term risks, corporate resilience, transition exposure, and value creation potential. However, the decision-usefulness of ESG information depends on whether disclosures capture the systemic conditions that may affect future financial performance.

The analyzed reports provide valuable information on sustainability strategies, governance systems, climate commitments, supplier monitoring, and circular economy initiatives.

Nevertheless, the fragmented structure of these disclosures may limit their usefulness for assessing systemic sustainability risks. Transition risks, supply chain vulnerabilities, resource dependencies, product-use impacts, and end-of-life responsibilities are frequently disclosed in separate sections, making it difficult to understand how they interact across the value chain.

This limitation is particularly relevant because many sustainability-related financial risks are not confined to the reporting entity's own operations. For example, upstream raw material dependency may affect cost volatility and production resilience; supplier labor issues may create reputational and compliance risks; product-use emissions may influence market demand and regulatory exposure; and end-of-life obligations may generate future liabilities or circularity-related costs. These risks are life cycle-based in nature, even when they are reported through entity-based disclosure structures.

Empirical evidence from European Union companies also indicates a long-term relationship between corporate ESG performance and financial performance, while suggesting that the financial effects of sustainability initiatives depend on resource allocation, managerial capacity, and their implications for corporate cash flows (Ivascu et al., 2022). This evidence reinforces the importance of transforming fragmented sustainability information into a more systematic basis for financial risk assessment.

By embedding LCSA principles into ESRS-based sustainability accounting, companies could improve the risk relevance of ESG disclosures. Life cycle integration can help identify where sustainability risks originate, how they accumulate, and how they may affect long-term enterprise value. This could improve the informational value of ESG reporting for sustainable finance by supporting more accurate risk pricing, capital allocation, and assessment of corporate transition strategies.

Material sustainability information has also been shown to improve stock price informativeness when it is relevant to the firm's industry and risk profile (Grewal et al., 2021). From this perspective, life cycle integration may increase the usefulness of ESG disclosures by transforming dispersed sustainability information into more material, comparable, and risk-relevant signals for capital market participants.

6.4. Methodological Contribution: Connecting LCSA and Sustainability Accounting

The study also contributes methodologically by positioning LCSA as a bridge between sustainability assessment and sustainability accounting. Traditionally, LCSA has been developed within industrial ecology, environmental management, and sustainability assessment research. It provides a robust framework for evaluating environmental, social, and economic impacts across product systems. However, its integration into corporate reporting and accounting systems has remained limited.

The proposed LCSA–ESRS Operationalization Model addresses this gap by translating life cycle logic into a reporting-compatible structure. Instead of treating LCSA as a separate technical assessment tool, the model positions life cycle thinking as a methodological layer that can enhance ESRS-based reporting. Its four pillars—boundary reconfiguration, stage-based indicator mapping, dimensional harmonization, and accounting translation—offer a structured pathway for embedding systemic assessment into sustainability disclosure architecture.

This methodological contribution is important because it avoids two extremes. On the one hand, it does not suggest that ESRS should be replaced by LCSA or that companies should transform sustainability reports into technical life cycle assessment documents. On the other hand, it does not accept value chain disclosure as sufficient merely because upstream or downstream impacts are mentioned. Instead, it proposes a middle path:

using life cycle thinking to organize, interpret, and translate sustainability information into materiality, risk, and decision-useful disclosure categories.

In this sense, the model contributes to the broader agenda of integrating sustainability assessment methodologies with corporate reporting systems. It shows how LCSA can become relevant not only for product assessment and environmental management, but also for accounting, assurance, governance, and sustainable finance.

This methodological contribution is also consistent with research on integrated and sustainability reporting, which shows that materiality is not merely a technical reporting filter but a process through which organizations define, prioritize and communicate the issues considered relevant for value creation and accountability (Mio et al., 2020). The LCSA–ESRS model extends this logic by adding a structured life cycle perspective to the construction of material sustainability information.

6.5. Practical Implications for Companies, Investors, and Regulators

The study has several practical implications. For companies, the proposed model provides a pathway for improving the coherence of ESG disclosures without creating an additional reporting regime. Companies can use life cycle mapping to identify material sustainability impacts across upstream, operational, downstream, and end-of-life stages. They can then connect these impacts to ESRS topics, materiality assessment, internal controls, risk management, and disclosure narratives.

For investors and other users of sustainability information, life cycle-based disclosure can improve the interpretation of systemic risks. Rather than reading ESG information as separate thematic indicators, users could assess how risks and impacts are distributed across the value chain. This would support better evaluation of long-term resilience, exposure to transition pressures, circular economy readiness, and sustainability-related value creation.

This implication is supported by experimental evidence showing that the format and assurance of sustainability information can affect professional investors' information processing and investment-related judgments (Reimsbach et al., 2018). Therefore, more structured life cycle-based disclosure may strengthen investor interpretation by making the location, interaction and financial relevance of sustainability risks more explicit.

For regulators and standard setters, the findings suggest that the future development of sustainability reporting should not focus only on additional indicators. Greater attention is needed to methodological guidance on boundary definition, value chain assessment, and cross-dimensional integration. ESRS already provides a strong regulatory architecture, but its implementation could be strengthened by clearer links between value chain disclosure, double materiality, and life cycle-based assessment logic. National evidence also suggests that implementation challenges extend beyond formal compliance to differences in reporting scope, quality, methodological maturity, and organizational preparedness (Dimitrova, 2020; Nikolov, 2023; Papradanova et al., 2025; P. Petrova, 2024). Evidence from European-funded investment programmes similarly reveals that sustainability may be strongly emphasized at the programmatic level, while environmental and social criteria receive comparatively limited operational weight in project selection, implementation, and post-completion performance (Manolescu et al., 2019). Environmental impact assessment experience also shows that the existence of a legal framework does not by itself guarantee effective implementation, emphasizing the need for continuous methodological improvement and the systematic integration of environmental considerations into decision-making processes (Diaconu, 2024). Taken together, this evidence reinforces the need to translate formal sustainability requirements into clear operational criteria, assessment procedures, and monitoring mechanisms.

This recommendation is also aligned with the broader EU regulatory direction toward value chain accountability. The Corporate Sustainability Due Diligence Directive requires companies to address actual and potential adverse human rights and environmental impacts in their own operations, subsidiaries, and chains of activities ([European Parliament and Council of the European Union, 2024](#)). This reinforces the need to connect sustainability reporting, due diligence, value chain assessment, and life cycle-based risk interpretation.

For assurance providers, the model may also be useful because life cycle mapping can clarify the assumptions, boundaries, and data sources underlying ESG disclosures. This is particularly relevant as sustainability assurance becomes more important under the European reporting regime. A more structured life cycle approach may improve auditability, internal control, and the credibility of sustainability information.

The relevance of assurance is further supported by evidence that audit committees and assurance mechanisms can strengthen the credibility of sustainability reporting ([Al-Shaer & Zaman, 2018](#)). In addition, the development of International Standard on Sustainability Assurance 5000 confirms the growing need for consistent, high-quality assurance engagements over sustainability information ([International Auditing and Assurance Standards Board, 2024](#)). The transition also has professional and educational implications, because accountants and assurance providers require broader sustainability-reporting competences and stronger familiarity with digital and interdisciplinary information systems ([Pavlova & Petrova, 2023](#); [Stancheva-Todorova & Nikolova, 2024](#); [Stefanov et al., 2026](#)).

6.6. Theoretical Implications for Sustainability Accounting Research

The findings contribute to sustainability accounting theory by advancing the concept of boundary alignment. Existing research has often examined sustainability reporting through the lenses of legitimacy, accountability, disclosure quality, materiality, or institutional pressure. This study adds that the systemic usefulness of ESG reporting depends on the alignment between accounting boundaries and sustainability impact boundaries.

The concept of boundary alignment helps explain why ESG reports may be formally advanced but still methodologically incomplete. A company may disclose extensive environmental, social, and governance information, yet the information may remain insufficiently systemic if it is not organized across the stages where impacts occur. Therefore, sustainability accounting research should pay greater attention to how reporting boundaries are constructed, justified, and operationalized.

This perspective also opens new research directions. Future studies could examine whether different sectors show different levels of life cycle integration, whether LCSA-based reporting improves investor interpretation of ESG risks, or whether assurance processes become more robust when sustainability disclosures are organized through life cycle stages. Quantitative research could also develop scoring models to measure the degree of LCSA integration in ESG reports.

In summary, the cases contain meaningful life cycle elements, but the public reporting architecture does not connect them consistently across stages and sustainability dimensions. The LCSA-ESRS model is offered as a conceptual method for improving that connectivity; its empirical effectiveness remains to be tested.

7. Conclusions

This study addressed two distinct questions: the empirical extent of life cycle integration in the 2024 corporate sustainability disclosures of Enel, Unilever, and Siemens AG, and the conceptual design of an ESRS-compatible LCSA translation model. The qualitative comparison provides analytical evidence from three purposively selected cases; it does not support general claims about ESG reporting as a whole or sector-wide patterns.

Across all 18 company–dimension assessments, the evidence was classified as partially integrated and none met the threshold for systemic integration. The cases disclose substantial upstream, Scope 3, product-use, circularity, and risk information, but cross-stage boundary transparency, social and economic LCSA dimensions, and end-of-life linkages remain incomplete. These findings concern public reporting outputs and may partly reflect the topical organization of ESRS rather than an absence of internal life cycle practices.

The proposed LCSA–ESRS Operationalization Model is therefore a conceptual contribution, not a validated instrument. Its four pillars—boundary reconfiguration, stage-based indicator mapping, dimensional harmonization, and accounting translation—show how existing life cycle evidence could be connected to double materiality, systemic sustainability risks, and decision-useful disclosure. The illustrative application to Unilever’s packaging information demonstrates feasibility at the level of disclosure organization, while leaving empirical validation for future research.

The policy implication is not that ESRS should add another layer of mandatory datapoints. Rather, EFRAG, regulators, and standard setters could provide non-mandatory stage-based boundary maps and interoperability guidance linking product or organizational LCA outputs to ESRS impacts, risks and opportunities. Companies should disclose which life cycle stages are included or excluded, the assumptions and data gaps used in value chain estimates, and how distributed impacts are translated into risk and financial-effect narratives. Assurance guidance could correspondingly emphasize the traceability and consistency of these boundary choices.

The principal limitations are the three-case purposive sample, the inclusion of only one company per sector, variation in the formal reporting formats, reliance on public disclosures, use of a single primary coder, and the absence of empirical validation of the model. These limitations mean that company-specific practices cannot be separated from sector effects and that internal LCA systems may be more advanced than the public reports reveal.

Future research should concentrate on three priorities: multi-coder validation and larger cross-company samples; sector-specific pilots that test the model’s data requirements and reporting burden; and experimental or market-based studies examining whether life cycle-organized disclosures improve investor, lender, and assurance judgments. This focused agenda would establish whether the conceptual gains identified here translate into measurable improvements in decision-usefulness.

Overall, the study concludes that the next development of sustainability accounting depends not only on the quantity of disclosure but on transparent alignment between corporate reporting boundaries and the value-chain systems in which impacts and risks arise. LCSA can inform that alignment, but its integration with ESRS must be tested, proportionate, and compatible with the regulatory reporting architecture.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/jrfm19070521/s1>, Table S1: Evidence Matrix for the Comparative Assessment of Life Cycle Integration in Corporate Sustainability Disclosures.

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Data Availability Statement: The corporate reports analyzed in this study are publicly available through the official websites of Enel S.p.A., Unilever PLC, and Siemens AG and are cited in the References section. The coded evidence matrix supporting the qualitative comparative analysis, including the report sections, page references, analytical dimensions, integration categories, and coding rationales, is provided in Supplementary Table S1.

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Appendix A. Coding Manual for the Assessment of Life Cycle Integration

Appendix A.1. General Coding Principles

The coding manual was developed to support the consistent application of the six analytical dimensions presented in Table 2. The coding process focused on identifiable disclosure evidence rather than on the frequency of individual keywords. A disclosure unit was coded only when its content provided an explicit or clearly traceable connection to one or more analytical dimensions.

Disclosure units could receive multiple codes where the same passage addressed several interconnected aspects. For example, a disclosure linking critical raw material sourcing, supplier-related environmental impacts, and cost exposure could be coded under upstream integration, cross-dimensional coherence, and risk relevance and decision-usefulness.

A keyword or general corporate commitment was not considered sufficient evidence of integration. Terms such as “value chain”, “circular economy”, “sustainability risk”, or “life cycle” were interpreted in relation to the surrounding disclosure context, the relevant life cycle stage, the reported impact or risk, and the degree of methodological or financial linkage.

Where relevant evidence was distributed across explicitly cross-referenced paragraphs, tables, metrics, methodology notes, or policy descriptions, the related passages were assessed jointly as a connected disclosure unit. Evidence not identified after full-document review and targeted review of relevant report sections was classified as “not identified in the public report”. This classification does not imply that the corresponding internal corporate practice does not exist.

Audit-trail example. Siemens AG’s Robust Eco Design disclosure (pp. 80–83) was coded under explicit methodological reference because it names Life Cycle Assessment and Environmental Product Declarations and describes repeated application to representative products within homogeneous product families. It was classified as partially integrated, rather than systemically integrated, because the evidence remains predominantly environmental and does not combine Social LCA and Life Cycle Costing across multiple stages. This example illustrates the link between the disclosed evidence, the inclusion rule, and the conservative category decision.

Appendix A.2. Dimension-Specific Coding Rules

Table A1. Dimension-specific coding rules.

Analytical Dimension	Inclusion Rule	Evidence Not Sufficient on Its Own	Indicators of Stronger Integration
Boundary definition logic	A disclosure was coded under this dimension when it identified the organizational, product-system, value chain, geographical, or life cycle boundaries applied to the reported sustainability matter. Evidence could include the explicit inclusion or exclusion of upstream, own-operation, downstream, use-phase, or end-of-life stages.	A general reference to the “value chain”, suppliers, customers, or Scope 3 emissions without clarification of the assessed boundary was not sufficient to demonstrate integrated boundary logic.	Stronger integration required an explicit or clearly traceable description of included and excluded stages, the product or system boundary, and the relevant scope of the value chain. Systemic integration required the boundary to extend beyond the reporting entity and to connect multiple life cycle stages within a coherent assessment structure.
Upstream integration	A disclosure was coded as upstream integration when it connected suppliers, raw materials, resource extraction, purchased goods and services, upstream transportation, supplier labor conditions, biodiversity impacts, or upstream Scope 3 emissions with a specific impact, risk, material, resource, supplier group, or sourcing stage.	A supplier code of conduct, general procurement policy, supplier audit programme, or aggregated Scope 3 indicator was not sufficient on its own. Such evidence was classified as fragmented unless it was connected to identifiable upstream impacts, dependencies, risks, or value chain stages.	Stronger integration required a structured connection between upstream activities, environmental or social impacts, resource dependencies, risk exposure, and management responses. Systemic integration required upstream evidence to be connected with other life cycle stages and with materiality or financial consequences.
Downstream integration	A disclosure was coded as downstream integration when it addressed product distribution, product use, customer impacts, maintenance, durability, repairability, take-back systems, reuse, recycling, waste treatment, disposal, or end-of-life responsibility.	A general commitment to circular economy, recycling, waste reduction, or sustainable products was not sufficient unless the disclosure identified a downstream or end-of-life stage and explained the associated impact, responsibility, target, or management mechanism.	Stronger integration required links between products or services and their use-phase or end-of-life effects. Systemic integration required the downstream evidence to connect environmental, social, or economic consequences with product-system boundaries, materiality, risk, or long-term value implications.

Table A1. Cont.

Analytical Dimension	Inclusion Rule	Evidence Not Sufficient on Its Own	Indicators of Stronger Integration
Cross-dimensional coherence	A disclosure was coded under this dimension when it explicitly connected at least two sustainability dimensions—environmental, social, or economic—within the same life cycle stage, product system, value chain activity, or sustainability issue.	The presentation of environmental, social, and economic information in separate sections or adjacent paragraphs was not considered cross-dimensional integration unless the report explained the relationship between the dimensions.	Stronger integration required an identifiable interaction, dependency, trade-off, or cumulative effect. Examples include the connection of emissions reduction with labor conditions, resource efficiency with production costs, circularity with affordability, or environmental compliance with future liabilities. Systemic integration required multidimensional linkage across more than one life cycle stage.
Explicit methodological reference	A disclosure was coded under this dimension when it explicitly referred to or applied LCA, LCSA, S-LCA, LCC, life cycle assessment, life cycle thinking, product environmental footprinting, product carbon footprinting, Environmental Product Declarations, or another identifiable life cycle-based methodology.	General references to product sustainability, environmental performance, value chain analysis, or circularity were not coded as explicit methodological evidence unless a recognized life cycle term, tool, framework, or assessment procedure was identified.	A simple methodological mention was classified as fragmented. Partial integration required evidence that the method was applied to selected products, activities, or impacts. Systemic integration required regular or structured methodological application across environmental, social, and economic dimensions or across multiple life cycle stages.
Risk relevance and decision-usefulness	A disclosure was coded under this dimension when sustainability information was explicitly connected to financial effects, costs, revenues, liabilities, capital expenditure, operating expenditure, access to finance, enterprise value, resilience, risk exposure, time horizons, strategic decisions, or capital allocation.	A general statement that sustainability is important for risk management or long-term success was not sufficient unless the report identified the nature of the risk, the affected business activity, the relevant time horizon, or a possible financial or strategic implication.	Stronger integration required a clear connection between a sustainability impact or dependency and its potential financial, operational, strategic, or valuation consequences. Systemic integration required the risk to be traced across life cycle stages and linked to materiality, enterprise value, resilience, or investment decision-making.

Appendix A.3. Classification Rules

After individual disclosure units were coded according to the six analytical dimensions, the accumulated evidence for each company–dimension combination was classified using the following four qualitative integration categories.

Not identified. No relevant evidence was located for the respective analytical dimension after full-document review and targeted review of the relevant sections. The classification refers only to the publicly available report.

Mentioned or fragmented. Relevant information was present, but it consisted primarily of isolated narratives, policies, targets, indicators, or initiatives. The evidence was not systematically connected across life cycle stages, sustainability dimensions, methodological procedures, or risk categories.

Partially integrated. The report provided structured evidence covering more than one life cycle stage, sustainability dimension, or analytical component. However, the disclosure did not demonstrate comprehensive cradle-to-grave coverage, consistent cross-dimensional integration, or a systematic connection to material impacts, risks, opportunities, and financial consequences.

Systemically integrated. The evidence demonstrated explicit or clearly traceable boundary definition, stage-based linkage, multidimensional sustainability consideration, and a connection to material impacts, risks, opportunities, or decision-usefulness. The classification required multiple mutually supporting disclosure units rather than a single isolated statement.

Appendix A.4. Aggregation and Decision Rules

Where a company disclosed evidence at different levels of depth within the same analytical dimension, the final classification was based on the level of integration consistently supported by the overall disclosure pattern. A single advanced example was not sufficient to classify the entire company–dimension combination as systemically integrated.

Where evidence supported two adjacent categories, the lower category was assigned unless the higher level was confirmed by multiple related disclosure units. This conservative decision rule was applied to reduce the risk of overstating the degree of life cycle integration.

The absence of a direct reference to LCSA did not automatically result in a “not identified” classification for the other dimensions. Reports could demonstrate implicit alignment with life cycle principles through structured upstream, downstream, boundary, multidimensional, or risk-related disclosure. However, the dimension “explicit methodological reference” required an identifiable life cycle-based term, method, tool, or assessment procedure.

The coding classifications evaluate the structure and content of publicly available corporate disclosures. They do not constitute an assessment of the companies’ overall sustainability performance, nor do they establish whether more advanced internal life cycle assessment or management practices exist outside the published reports.

References

- Adams, C. A., & Frost, G. R. (2008). Integrating sustainability reporting into management practices. *Accounting Forum*, 32(4), 288–302. [\[CrossRef\]](#)
- Al-Shaer, H., & Zaman, M. (2018). Credibility of sustainability reports: The contribution of audit committees. *Business Strategy and the Environment*, 27(7), 973–986. [\[CrossRef\]](#)
- Baumüller, J., & Sopp, K. (2022). Double materiality and the shift from non-financial to European sustainability reporting: Review, outlook and implications. *Journal of Applied Accounting Research*, 23(1), 8–28. [\[CrossRef\]](#)
- Bebbington, J., & Larrinaga, C. (2014). Accounting and sustainable development: An exploration. *Accounting, Organizations and Society*, 39(6), 395–413. [\[CrossRef\]](#)
- Beck, C., Campbell, D. J., & Shrives, P. (2010). Content analysis in environmental reporting research: Enrichment and rehearsal of the method in a British-German context. *The British Accounting Review*, 42(3), 207–222. [\[CrossRef\]](#)

- Ben Ismail, N., Alcouffe, S., Galy, N., & Ceulemans, K. (2021). The impact of international sustainability initiatives on Life Cycle Assessment voluntary disclosures: The case of France's CAC40 listed companies. *Journal of Cleaner Production*, 282, 124456. [CrossRef]
- Boiral, O. (2013). Sustainability reports as simulacra? A counter-account of A and A+ GRI reports. *Accounting, Auditing & Accountability Journal*, 26(7), 1036–1071. [CrossRef]
- Burritt, R. L., & Schaltegger, S. (2010). Sustainability accounting and reporting: Fad or trend? *Accounting, Auditing & Accountability Journal*, 23(7), 829–846. [CrossRef]
- Cho, C. H., Laine, M., Roberts, R. W., & Rodrigue, M. (2015). Organized hypocrisy, organizational façades, and sustainability reporting. *Accounting, Organizations and Society*, 40, 78–94. [CrossRef]
- Christensen, H. B., Hail, L., & Leuz, C. (2021). Mandatory CSR and sustainability reporting: Economic analysis and literature review. *Review of Accounting Studies*, 26, 1176–1248. [CrossRef]
- de Salles, A. C. N., & Brantsch, P. (2025). How life cycle assessment supports sustainability reporting: Example from clean aviation. *Engineering Proceedings*, 90(1), 56. [CrossRef]
- Diaconu, L. (2024). Ecological expertise and environmental impact assessment: Reflections on challenges, approaches, and cross-country differences. *The Scientific Journal of Cahul State University "B. P. Hasdeu": Social Sciences*, 18(2), 85–103. [CrossRef]
- Dimitrova, P. (2020). Publicity of non-financial information regarding the environmental policy of public interest enterprises in Bulgaria. In *Sustainable development and competitiveness of regions, book 3*. Academic Publishing House "Talent", University of Agribusiness and Rural Development. Available online: <https://science.uard.bg/index.php/sustdev/article/view/821> (accessed on 10 June 2026).
- Downie, J., & Stubbs, W. (2013). Evaluation of Australian companies' Scope 3 greenhouse gas emissions assessments. *Journal of Cleaner Production*, 56, 156–163. [CrossRef]
- ENEL S.p.A. (2024). *Integrated annual report 2024*. Available online: https://www.enel.com/content/dam/enel-com/documenti/investitori/informazioni-finanziarie/2024/annuali/en/integrated-annual-report_2024.pdf (accessed on 10 June 2026).
- European Commission. (2023). *Commission delegated regulation (EU) 2023/2772 of 31 July 2023 supplementing directive 2013/34/EU of the European parliament and of the Council as regards sustainability reporting standards*. Official Journal of the European Union. Available online: https://eur-lex.europa.eu/eli/reg_del/2023/2772/oj (accessed on 10 June 2026).
- European Financial Reporting Advisory Group. (2024a). *EFRAG IG 1: Materiality assessment implementation guidance*. EFRAG.
- European Financial Reporting Advisory Group. (2024b). *EFRAG IG 2: Value chain implementation guidance*. EFRAG.
- European Parliament and Council of the European Union. (2019). *Regulation (EU) 2019/2088 of 27 November 2019 on sustainability-related disclosures in the financial services sector*. Official Journal of the European Union. Available online: <https://eur-lex.europa.eu/eli/reg/2019/2088/oj> (accessed on 10 June 2026).
- European Parliament and Council of the European Union. (2020). *Regulation (EU) 2020/852 of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending regulation (EU) 2019/2088*. Official Journal of the European Union. Available online: <https://eur-lex.europa.eu/eli/reg/2020/852/oj> (accessed on 10 June 2026).
- European Parliament and Council of the European Union. (2022). *Directive (EU) 2022/2464 of 14 December 2022 amending regulation (EU) No 537/2014, directive 2004/109/EC, directive 2006/43/EC and directive 2013/34/EU, as regards corporate sustainability reporting*. Official Journal of the European Union. Available online: <https://eur-lex.europa.eu/eli/dir/2022/2464/oj> (accessed on 10 June 2026).
- European Parliament and Council of the European Union. (2024). *Directive (EU) 2024/1760 of 13 June 2024 on corporate sustainability due diligence and amending directive (EU) 2019/1937 and regulation (EU) 2023/2859*. Official Journal of the European Union. Available online: <https://eur-lex.europa.eu/eli/dir/2024/1760/oj> (accessed on 10 June 2026).
- Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, 12(2), 219–245. [CrossRef]
- Georgieva, V. (2026). Do environmental taxes stimulate eco-investments? Evidence from seven EU Member States and the EU-27. *Journal of Risk and Financial Management*, 19(4), 256. [CrossRef]
- Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114, 11–32. [CrossRef]
- Gray, R. (2010). Is accounting for sustainability actually accounting for sustainability... and how would we know? An exploration of narratives of organisations and the planet. *Accounting, Organizations and Society*, 35(1), 47–62. [CrossRef]
- Grewal, J., Hauptmann, C., & Serafeim, G. (2021). Material sustainability information and stock price informativeness. *Journal of Business Ethics*, 171, 513–544. [CrossRef]
- Grozeva, N. (2023). The double materiality analysis of sustainable reports' information. In *Challenges for finance and economic accounting in conditions of multiple crises* (pp. 305–309). D. A. Tsenov Academy of Economics.
- Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., & Rydberg, T. (2011). Life cycle assessment: Past, present, and future. *Environmental Science & Technology*, 45(1), 90–96. [CrossRef] [PubMed]

- Hahn, R., & Kühnen, M. (2013). Determinants of sustainability reporting: A review of results, trends, theory, and opportunities in an expanding field of research. *Journal of Cleaner Production*, 59, 5–21. [CrossRef]
- Hansen, E. G., & Schaltegger, S. (2016). The sustainability balanced scorecard: A systematic review of architectures. *Journal of Business Ethics*, 133, 193–221. [CrossRef]
- Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, 15(9), 1277–1288. [CrossRef] [PubMed]
- Huian, M. C., Curea, M., & Mironiuc, M. (2025). Sustainability reporting and credit risk management in the Romanian banking landscape. *Amfiteatru Economic*, 27(70), 1011–1031. [CrossRef]
- Hummel, K., & Schlick, C. (2016). The relationship between sustainability performance and sustainability disclosure: Reconciling voluntary disclosure theory and legitimacy theory. *Journal of Accounting and Public Policy*, 35(5), 455–476. [CrossRef]
- IFRS Foundation. (2023). *IFRS S1: General requirements for disclosure of sustainability-related financial information*. International Sustainability Standards Board.
- International Auditing and Assurance Standards Board. (2024). *International standard on sustainability assurance 5000: General requirements for sustainability assurance engagements*. IAASB. Available online: <https://www.iaasb.org/publications/international-standard-sustainability-assurance-5000-general-requirements-sustainability-assurance> (accessed on 10 June 2026).
- International Organization for Standardization. (2006a). *ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework*. ISO.
- International Organization for Standardization. (2006b). *ISO 14044:2006 Environmental management—Life cycle assessment—Requirements and guidelines*. ISO.
- Ivascu, L., Domil, A., Sarfraz, M., Bogdan, O., Burca, V., & Pavel, C. (2022). New insights into corporate sustainability, environmental management and corporate financial performance in European Union: An application of VAR and Granger causality approach. *Environmental Science and Pollution Research*, 29, 82827–82843. [CrossRef] [PubMed]
- Jørgensen, S., Mjøs, A., & Pedersen, L. J. T. (2022). Sustainability reporting and approaches to materiality: Tensions and potential resolutions. *Sustainability Accounting, Management and Policy Journal*, 13(2), 341–361. [CrossRef]
- Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127, 221–232. [CrossRef]
- Kloepffer, W. (2008). Life cycle sustainability assessment of products. *The International Journal of Life Cycle Assessment*, 13, 89–95. [CrossRef]
- Kostova, S., Kulchev, K., & Ivanova, D. (2022). Analytical models for assessing the financial sustainability of enterprises. *Scientific Research Almanac*, 30, 214–244.
- Krastev, B., Petkov, P., Angelova, V., Angelov, S., & Nechev, T. (2023). The role of project financing for sustainable development of the green economy. *UARD Yearbook 2023*, 11, 1–30.
- Krasteva-Hristova, R., & Moneva, I. (2026). Digitalization, ESG reporting, and circular economy: Accounting challenges for women-led SMEs. *World*, 7(6), 91. [CrossRef]
- Krueger, P., Sautner, Z., & Starks, L. T. (2020). The importance of climate risks for institutional investors. *The Review of Financial Studies*, 33(3), 1067–1111. [CrossRef]
- Maas, K., Schaltegger, S., & Crutzen, N. (2016). Integrating corporate sustainability assessment, management accounting, control, and reporting. *Journal of Cleaner Production*, 136, 237–248. [CrossRef]
- Manes-Rossi, F., Tiron-Tudor, A., Nicolò, G., & Zanellato, G. (2018). Ensuring more sustainable reporting in Europe using non-financial disclosure—De facto and de jure evidence. *Sustainability*, 10(4), 1162. [CrossRef]
- Manolescu, I. T., Percic, S., & Talmaciu, M. (2019). Declarative vs. operational in the orientation of the non-reimbursable financing programs of investments towards sustainability. *CES Working Papers*, 11(4), 365–384.
- Miller, P. (1998). The margins of accounting. *European Accounting Review*, 7(4), 605–621. [CrossRef]
- Milne, M. J., & Adler, R. W. (1999). Exploring the reliability of social and environmental disclosures content analysis. *Accounting, Auditing & Accountability Journal*, 12(2), 237–256. [CrossRef]
- Mio, C., Fasan, M., & Costantini, A. (2020). Materiality in integrated and sustainability reporting: A paradigm shift? *Business Strategy and the Environment*, 29(1), 306–320. [CrossRef]
- Moneva, I. (2025). The European Union sustainability reporting framework. In *Business transformations in the global world: Proceedings of the international scientific conference, 20–21 June 2025* (pp. 196–204). Varna Free University “Chernorizets Hrabar”.
- Nedelea, A.-M., Mironiuc, M., Huian, M. C., Bîrsan, M., & Bedrule-Grigoruță, M. V. (2018). Modeled interdependencies between intellectual capital, circular economy and economic growth in the context of bioeconomy. *Amfiteatru Economic*, 20(49), 616–630. [CrossRef]
- Nikolov, E. (2023). Assessing the quality of sustainability reporting: A case study of Bulgarian SOFIX companies. In *Economic and social development: Book of proceedings of the 100th international scientific conference* (pp. 27–36). Varazdin Development and Entrepreneurship Agency.

- Papradanova, D., Kostova, S., & Vechev, V. (2025). Sustainability reporting in Bulgaria: An overview of reporting practices in Bulgarian companies. In *Corporate sustainability reporting in central and eastern European companies* (pp. 21–39). Routledge. [CrossRef]
- Pavlova, M., & Petrova, R. (2023). The emerging changes in the accounting profession and the accounting practice under the influence of technology. *Economic Archive*, 1, 24–40. [CrossRef]
- Petrova, P. (2024). Accounting for impacts: Exploring sustainability reporting in Bulgarian companies under the CSRD. *Proceedings of the International Conference on Business Excellence*, 18(1), 2172–2182. [CrossRef]
- Petrova, S., Marinov, I., Ivanova, Z., & Akhmedyarov, Y. (2023). Impacts of sustainable entrepreneurship and income on sustainable food consumption. In V. Koval, Y. Kazancoglu, & E.-S. Lakatos (Eds.), *Circular business management in sustainability* (pp. 65–78). Springer. [CrossRef]
- Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: In search of conceptual origins. *Sustainability Science*, 14, 681–695. [CrossRef]
- Reimsbach, D., Hahn, R., & Gürtürk, A. (2018). Integrated reporting and assurance of sustainability information: An experimental study on professional investors' information processing. *European Accounting Review*, 27(3), 559–581. [CrossRef]
- Sala, S., Ciuffo, B., & Nijkamp, P. (2015). A systemic framework for sustainability assessment. *Ecological Economics*, 119, 314–325. [CrossRef]
- Santos, F. M., & Eisenhardt, K. M. (2005). Organizational boundaries and theories of organization. *Organization Science*, 16(5), 491–508. [CrossRef]
- Sauer, S., Di Cecca, C., Kastenhofer, V., Nipper, M., & Hanenkamp, N. (2026). Using organizational life cycle assessment to meet ESRS data requirements: Evidence from a case study. *Journal of Industrial Ecology*, 30, 1069–1083. [CrossRef]
- Schaltegger, S., & Burritt, R. (2018). Business cases and corporate engagement with sustainability: Differentiating ethical motivations. *Journal of Business Ethics*, 147(2), 241–259. [CrossRef]
- Schneider, D., Woerle, M., Kagermeier, J., Zaeh, M. F., & Reinhart, G. (2024). Sustainability risk assessment in manufacturing: A life cycle assessment-based failure mode and effects analysis approach. *Sustainable Production and Consumption*, 47, 617–631. [CrossRef]
- SIEMENS AG. (2024). *Sustainability report 2024*. Available online: <https://assets.new.siemens.com/siemens/assets/api/uuid:32a7154d-edba-47bc-8e9b-9761617ba774/sustainability-report.pdf> (accessed on 10 June 2026).
- Stancheva-Todorova, E., & Nikolova, M. (2024). The impact of sustainability on accountancy profession. In *Proceedings of the 24th international multidisciplinary scientific GeoConference SGEM 2024*. STEF92 Technology. [CrossRef]
- Stefanov, S., Georgieva, D., & Popova-Yosifova, N. (2026). The role of accounting profession in sustainability reporting and the need for changes in accounting education. In M. Busu (Ed.), *Leading change in disruptive times* (pp. 592–614). Springer. [CrossRef]
- Stubbs, W., & Higgins, C. (2014). Integrated reporting and internal mechanisms of change. *Accounting, Auditing & Accountability Journal*, 27(7), 1068–1089. [CrossRef]
- Task Force on Climate-Related Financial Disclosures. (2017). *Recommendations of the task force on climate-related financial disclosures*. Financial Stability Board. Available online: <https://www.fsb-tcfd.org/recommendations/> (accessed on 10 June 2026).
- Teodosiu, C., Barjoveanu, G., Sluser, B. R., Popa, S. A. E., & Trofin, O. (2016). Environmental assessment of municipal wastewater discharges: A comparative study of evaluation methods. *The International Journal of Life Cycle Assessment*, 21(3), 395–411. [CrossRef]
- Unilever PLC. (2024). *Annual report and accounts 2024*. Available online: <https://www.unilever.com/files/unilever-annual-report-and-accounts-2024.pdf> (accessed on 10 June 2026).
- World Resources Institute & World Business Council for Sustainable Development. (2011). *Corporate value chain (Scope 3) accounting and reporting standard. Greenhouse gas protocol*. Available online: <https://ghgprotocol.org/corporate-value-chain-scope-3-standard> (accessed on 10 June 2026).
- Zamagni, A., Pesonen, H. L., & Swarr, T. (2013). From LCA to life cycle sustainability assessment: Concept, practice and future directions. *The International Journal of Life Cycle Assessment*, 18, 1637–1641. [CrossRef]
- Zhelev, Z., & Kostova, S. (2024). Investigating the application of digital tools for information management in financial control: Evidence from Bulgaria. *Journal of Risk and Financial Management*, 17(4), 165. [CrossRef]

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