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Embedding ESG And Carbon Accounting Into The Financial Ledger: A Sub-Ledger Architecture For CSRD-Aligned Reporting

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Abstract—The Corporate Sustainability Reporting Directive (CSRD, in force from January 2023) and the first set of European Sustainability Reporting Standards (ESRS Set 1, adopted as Commission Delegated Regulation (EU) 2023/2772) subject some 50,000 European preparers to mandatory, externally assured sustainability disclosures. The data that feeds these disclosures, however, is still produced in most organisations from spreadsheets, ad-hoc trackers and isolated sustainability tools, none of which carries the financial-grade controls assumed by ISAE 3000-style assurance or by the March 2023 COSO ICSR framework. This paper proposes an ESG sub-ledger that sits inside SAP S/4HANA as a parallel ledger in the Universal Journal (ledger 2S alongside the leading IFRS ledger 0L) and integrates with the SAP Sustainability Control Tower. Each Scope 1, Scope 2 and Scope 3 emission is captured as a quantity-only posting in tCO_2e, linked to a cost centre, internal order, source document, emission-factor master record and reporting period, and then reconciled, snapshotted and locked at period end. We describe the posting logic, map the controls onto the five components of COSO ICSR, and present a five-stage maturity model for adoption. The result is a reconcilable, period-locked and audit-ready ESG ledger that allows CSRD- and ESRS-bound preparers to extend the discipline of the financial close to sustainability data.

Keywords—ESG accounting; CSRD; carbon accounting; IFRS S1/S2; sub-ledger architecture; SAP S/4HANA; Green Ledger; ICSR.

I. INTRODUCTION

By the close of 2023, sustainability reporting in Europe has shifted from a marketing exercise to a regulated financial-reporting obligation. The CSRD (Directive (EU) 2022/2464, OJ L 322, 16 December 2022) entered into force in early 2023, and the first reporting wave applies to large public-interest entities for FY 2024. In July 2023 the European Commission adopted ESRS Set 1 as Commission Delegated Regulation (EU) 2023/2772, fixing the twelve cross-cutting and topical standards under which CSRD preparers must report; the delegated act was published in the Official Journal on 22 December 2023. In parallel, on 26 June 2023 the International Sustainability Standards Board (ISSB) issued IFRS S1 (general sustainability-related disclosures) and IFRS S2 (climate-related disclosures), effective for annual periods beginning on or after 1 January 2024. In March 2023, the Committee of Sponsoring Organizations of the Treadway Commission (COSO) published "Achieving Effective Internal Control over Sustainability Reporting (ICSR)", which extends the 2013 internal-control framework to sustainability data.

The implication for accounting and information-systems practice is direct: the data that feeds a CSRD disclosure must withstand an external assurance walkthrough under ISAE 3000 and, for greenhouse-gas data, ISAE 3410. Spreadsheets do not survive that walkthrough. In our experience, the typical client environment at end-2023 still relies on a quilt of departmental Excel workbooks, ad-hoc emission trackers and bespoke sustainability tools whose figures are reconciled to the general ledger only on a best-efforts basis. Period locks, segregation of duties (SoD) and source-to-disclosure traceability — the basics of financial accounting — are largely absent.

This paper proposes an alternative: treat carbon and ESG quantities as accounting objects and post them into a parallel ESG sub-ledger inside SAP S/4HANA, alongside the Universal Journal. Building on SAP's announcement of the "Green Ledger" concept at SAP Sapphire in May 2023 and on the general availability

of the SAP Sustainability Control Tower since March 2023, we describe (i) the data model and posting logic for the sub-ledger; (ii) the control framework aligned to COSO ICSR; and (iii) a five-stage maturity model. The contribution is therefore architectural and practical: a concrete posting scheme that brings ESG data inside the same internal-control envelope as the financial close.

Section II reviews the literature on sustainability accounting, digital-ERP enablement and carbon accounting. Section III analyses the regulatory and operational gap that motivates a ledger-based approach. Section IV develops the sub-ledger architecture and its realisation in SAP S/4HANA. Section V maps the control framework to COSO ICSR and presents the maturity model. Section VI concludes and notes limitations.

II. RELATED WORKS

A. Sustainability Accounting and ESG Reporting

Earlier scholarship documented the gap between traditional bookkeeping and representing the economic costs and environmental issues from emissions [1] and the Green Accounting System (GAS) was proposed to fill this gap. The findings of the following metasyntheses – sustainability accounting [2], management-control linkages [3] and assurance practice [4] – further suggest the same pattern, namely the lack of uniformity in terms, methodology and scope of sustainability reports makes comparison and auditing challenging and also a terminological drift that it is designed to solve. CSRD and ESRS Set 1 are trying to fill these gaps with standardisation.

A parallel study looks at whether disclosure has a beneficial effect. Sehgal et al. conclude that there is a positive long-term relationship between ESG performance and firm value [5] whereas lower information asymmetry due to ESG disclosures results in lower cost of capital according to Kumawat and Patel, and Mulchandani et al. [6] and [7]. Kumar et al. warn that in their absence, disclosure frameworks may be subject to opportunistic behaviour [8] and Desai's evidence of carbon-disclosure determinants of listed firms in India [9] supports the same worry in practice. The common denominator is that it is not the availability of ESG data, but its quality.

B. Digital Technologies, ERP and Automation

Vărzaru's cross-country EU analysis links the digital-transformation index to sustainability-reporting performance [10]. Dumitru et al. trace how automation and intelligent ERP capabilities raise data consistency and reporting timeliness [11]; Akrong et al. update the DeLone–McLean information-systems success model in the ERP context [12]. Empirical work on ERP implementations [13], [14] reports measurable gains in operational sustainability outcomes. At the data-capture layer, Wu et al. propose a blockchain-anchored IoT reporting system (SESRS-B) [15] — a useful precedent for the ingestion layer of the architecture we propose, though blockchain is not central to our design.

C. Carbon Accounting, Controls and Ledger-Based ESG

Bui et al. analyse 1,672 firm-year observations from CDP data and show that mature carbon-accounting systems correlate with stronger emissions-reduction outcomes [16]. Kaur et al. extend the case beyond direct operations and argue for supply-chain-wide carbon accounting integrated with ERP [17] — a direct motivator for the sub-ledger described in Section IV. On the controls side, Krishnan et al. identify a negative association between internal-control material weaknesses and a firm's social-environmental performance [18], suggesting that the architecture which strengthens financial reporting also strengthens sustainability reporting. Ramautar and España's domain analysis of 21 ethical, social and environmental accounting methods [19] reinforces the case for a single, standardised "accounting object" for ESG. Manoj documents the expanding role of management accountants in ESG governance [20].

To this body of work the present paper adds an architectural proposition consistent with the regulatory regime in force at the end of 2023 — CSRD, ESRS Set 1, IFRS S1/S2 and COSO ICSR — and one that maps cleanly onto SAP S/4HANA.

III. ESG ACCOUNTING INTEGRATION

A. The December 2023 Regulatory Stack

Four reference points define the regulatory regime under which the proposed architecture must operate. CSRD [21] extends mandatory sustainability reporting to approximately 50,000 EU undertakings, with the first reporting wave applying to large public-interest entities for FY 2024. ESRS Set 1, adopted as Commission Delegated Regulation (EU) 2023/2772 on 31 July 2023 [22], fixes the disclosure content. IFRS S1 and IFRS S2, issued by the ISSB on 26 June 2023 [23], [24], provide the IFRS-aligned counterpart for non-EU jurisdictions. COSO ICSR [25], published in March 2023, makes explicit that the 2013 internal-control framework applies to sustainability disclosures across all five components — Control Environment, Risk Assessment, Control Activities, Information and Communication, and Monitoring Activities. Together these instruments make ESG reporting an internal-controls problem, not only a data-gathering one.

B. From Quantity to Posting

The data point at the heart of all four instruments is a measured or estimated quantity of an environmental or social variable — most commonly a Scope 1, 2 or 3 emission expressed in tonnes of carbon-dioxide equivalent (tCO_2e). The IPCC Sixth Assessment Report [27] and the GHG Protocol [26] provide the methodological grounding. The emission calculation itself is well known:

$CO_2e = AD \times EF$,

where AD is activity data for the period (kWh of grid electricity, litres of diesel, tonne-kilometres of road transport) and EF is the applicable emission factor sourced from a recognised dataset (DEFRA, IEA, EPA, or supplier-specific). What is missing in current practice is not the formula but the posting logic: which document recorded the activity, which cost centre bears the emission, which approver validated the entry and which period it belongs to. These are the questions an assurance provider asks during an ISAE 3000 walkthrough.

C. Why Spreadsheets Fail the Walkthrough

There are three points that a walkthrough does not pass for a spreadsheet-based ESG model. First, traceability: The value of a cell at time of disclosure is not repeatable 6 months later. Secondly, segregation of duties: preparation, review and approval are all in the same workbook and audit logs (if they exist) are in opaque local files. Third: locking the period; the workbook is able to be reopened and edited after disclosure. All of these are deficiencies in the textbooks for SOX testing and each is a COSO ICSR finding.

Table I contrasts the two operating models.

TABLE I Traditional ESG Reporting vs. Ledger-Based ESG Reporting

Feature	Traditional ESG Reporting	Ledger-Based ESG Reporting
Auditability	Limited	Strong, line-item evidence
Traceability	Manual tracking	Automated source-doc linkage
Period locking	Generally absent	Enforced at period end
Reporting cadence	Delayed, batch	Near real-time

Feature	Traditional ESG Reporting	Ledger-Based ESG Reporting
GL integration	Weak	Native parallel ledger
Internal controls	Minimal	COSO ICSR-aligned
Data consistency	Variable	Standardised master data
ISAE 3000/3410 readiness	Low	High

The remainder of the paper develops the ledger-based alternative.

D. Regulatory Pressure, 2015–2023

The reach of mandatory sustainability frameworks has expanded steadily since 2015 — the EU Non-Financial Reporting Directive (NFRD, 2014), the TCFD recommendations (2017), the SFDR (2019/2021), the CSRD (2022), ESRS Set 1 (2023) and IFRS S1/S2 (2023) — and external assurance requirements have followed the same trajectory. Fig. 1 plots three rough indices of adoption; the trend, not the absolute calibration, is the relevant signal.

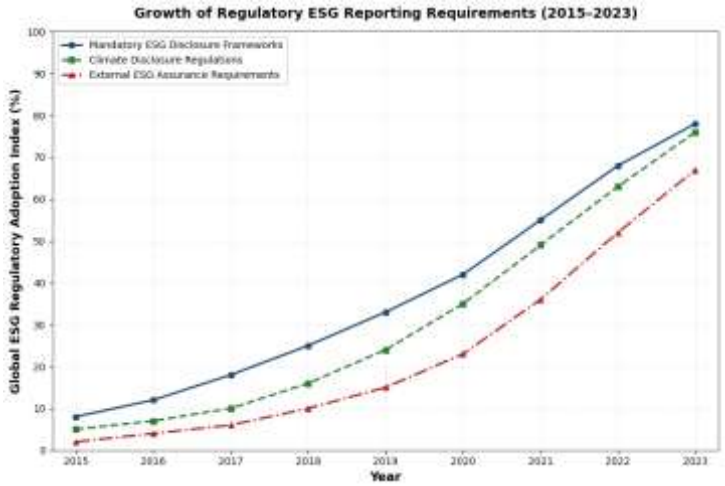

Fig. 1. Growth of regulatory ESG reporting requirements, 2015–2023. The series reflect, respectively, mandatory disclosure frameworks, climate-specific disclosure regulations and external assurance requirements.

IV. ESG SUB-LEDGER ARCHITECTURE AND SAP S/4HANA

A. The Sub-Ledger as an Accounting Object

The proposed sub-ledger treats each ESG entry as a journal posting in the accounting sense: a uniquely identified record that references a cost object (cost centre or internal order), a source document so that any line item can be traced back to the originating business event, an emission-factor master record so that the underlying calculation can be re-performed, a reporting period that can be opened, closed or locked, and an approval record that evidences segregation of duties. Fig. 2 makes the data model explicit.

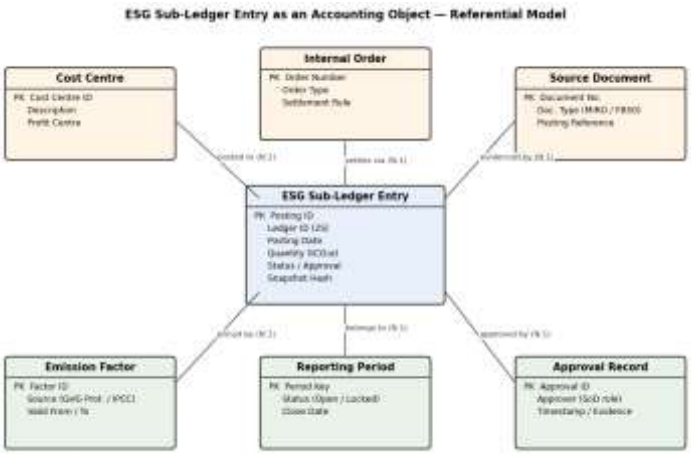

Fig. 2. ESG sub-ledger entry as an accounting object. Each posting references the five surrounding entities (cost centre, internal order, source document, emission factor, reporting period and approval record), making it traceable and reproducible.

A practical question is where the sub-ledger physically resides. Two designs are viable inside S/4HANA.

The first treats the ESG sub-ledger as a parallel ledger in the Universal Journal (ACDOCA), assigning it a dedicated ledger ID — by convention we use 2S alongside the leading IFRS ledger 0L. Each ESG posting is then a standard ACDOCA row, but with the monetary fields WSL, HSL and KSL left null and the quantity field MSL populated in tCO_2e. The advantage is inherited infrastructure: parallel-ledger reporting, document number ranges, document types and period control via the standard `OB52`-style tables all come for free. The disadvantage is that ACDOCA was not designed for high-cardinality quantity-only postings, and customer enhancements are required to suppress monetary aggregation in CDS views.

The second design uses a separate extension table (a Z-table, or, in newer terminology, an extension ledger) that holds ESG postings and references ACDOCA only by document number. This is lighter on the core, but loses the native period-control and reporting infrastructure of the Universal Journal and re-introduces a reconciliation surface between the two stores. In our experience, the parallel-ledger design is preferable wherever the deployment already runs on S/4HANA with the Universal Journal in use; the extension-table approach makes more sense in side-by-side architectures where S/4HANA is one of several data sources for a broader sustainability platform.

A subtle point of accounting-object hygiene applies in both designs. ESG postings record quantities (tCO_2e, kWh, m^3 of water), not monetary amounts. They must therefore not be aggregated against financial KPIs without an explicit conversion — an internal carbon price, for example — applied at the reporting layer, not at the posting layer. Mixing the two at posting time is the most common implementation pitfall.

B. A Worked Posting Example

Let's take a hypothetical case of a manufacturing facility in the UK using 10,000 kWh of grid electricity in a month. The end-to-end flow is as below.

1) Source event. A bill is received from the utility for the electricity use for the month. The invoice is received in MM and posted through 'MIRO' and an ACDOCA line is created on ledger 0L: Dr Utilities Expense / Cr Vendor.
2) Trigger. A BAdI which is implemented in the invoice posting interface (or an event-driven extension in the API layer) is triggered on document type RE and a utility-account assignment.
3) Activity data capture. The kWh value is obtained from a structured field on the invoice, to which the supplier enters it, or from a meter reading that has already been inputted into the system. The plant code expands to be cost centre 4711 - Manufacturing.

4) Emission-factor lookup. The applicable factor for UK grid electricity is taken from a master data table, which is controlled by the validity period. A location based factor of ~0.233 kgCO_2e/kWh is applicable for 2023.
5) Sub-ledger posting. An ACDOCA line is recorded on ledger 2S with MSL = 2.33 tCO_2e (scope 2 attribute), with cost centre 4711, a source-document reference to the original MIRO document, and with a reference to the emission-factor master record in force.
6) Reconciliation. A periodic CDS-view based control ensures that there is one posting per 2S and one 0L utility-invoice line that satisfies a condition. The ESG controller is notified of differences for investigation prior to lock.
7) Period close. The standard parallel-ledger close is used to close ledger 2S at the end of the month. The posting that occurred during the period, and the versions of the emission factors for the period which were in effect at the time, are recorded in an immutable archive along with a snapshot of the closing balance. The status of the period changes from Open to Locked.

Table II illustrates the resulting structure for a small set of postings drawn from a Q3 2023 close.

TABLE II ESG Ledger Posting Structure in SAP S/4HANA (Q3 2023)

Posting ID	Cost Centre	Activity	Scope	tCO_2e	Source Doc
ESG-0001	Manufacturing	Electricity	Sc. 2	12.50	INV-45821
ESG-0002	Logistics	Diesel	Sc. 1	8.30	FUEL-8821
ESG-0003	Procurement	Supplier transport	Sc. 3	15.10	SCM-7720
ESG-0004	Administration	Office energy	Sc. 2	3.40	UTIL-5512

C. Architecture and Integration

Fig. 3 shows the end-to-end flow. IoT devices and operational systems feed activity data into S/4HANA transaction processing; the ESG sub-ledger captures the resulting emission postings; the Sustainability Control Tower acts as the analytics and disclosure layer, mapping ledger balances onto ESRS and IFRS S1/S2 datapoints; and the bottom band of the diagram — internal controls, audit trail, period locking, approval workflow and data traceability — is what makes the chain auditable.

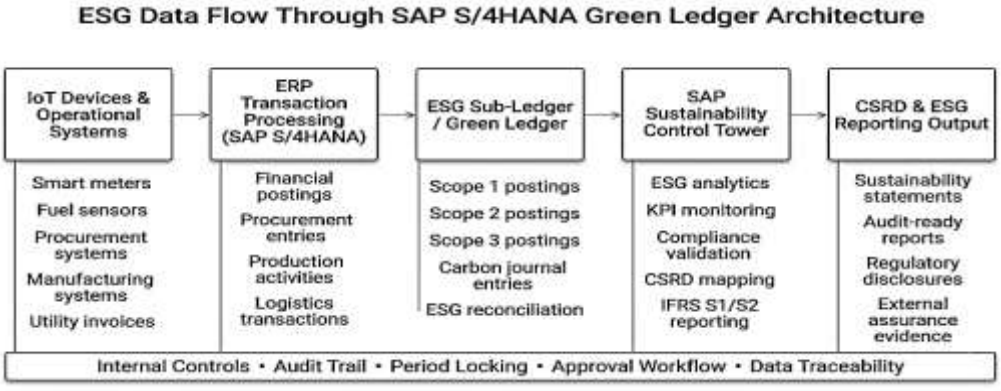

Fig. 3. ESG data flow through the SAP S/4HANA Green Ledger architecture. Activity capture, posting, analytics and disclosure are connected by a single control band.

Master-data discipline is the often underestimated prerequisite. The cost-centre and profit-centre hierarchies, the chart of accounts, the emission-factor catalogue, the plant and facility master and the source-document type catalogue must all be governed centrally. Where this is not the case, the same operational event posts differently across two periods and the period-over-period comparability required by CSRD breaks down.

D. Carbon Allocation

Direct postings address Scope 1 and Scope 2 completely. Scope 3 is less likely to be directly visible at posting time, and is normally assigned from operational drivers. The rule to allocate is:

$E_i = (D_i / \Sigma_j D_j) \times E\_total$,

where the activity driver is the driver of the activity that can be attributed to cost object i (such as machine-hours, energy used, transport distance, procurement spent), and E_total is the total of the emissions. The natural S/4HANA implementation is an assessment or distribution cycle extended to the ESG ledger or for parallel-ledger design – an internal-order settlement that posts to ledger 2S.

At the end of each period, reconciliation is carried out using the same identity as for any other ledger:

$B\_close = B\_open + P - A$,

With P as postings, and A as adjustments. If the closing balance doesn't match underlying activity data, the difference is examined prior to locking. The four cost-centre allocation shown in Table IV is from a Q3 2023 close.

TABLE IV Emission Allocation Across Cost Centres

Cost Centre	Energy (kWh)	Alloc. %	tCO_2e	Scope
Manufacturing Unit A	45,000	45%	22.50	Scope 2
Manufacturing Unit B	30,000	30%	15.00	Scope 2
Logistics Division	15,000	15%	7.50	Scope 1
Administration Office	10,000	10%	5.00	Scope 2

V. CONTROLS, PERIOD CLOSE AND MATURITY

A. COSO ICSR Mapping

COSO ICSR organises controls under the same five components as the 2013 framework. Table III identifies each component with the proposed sub-ledger and a typical ICFR control type (preventive, detective, IT general control (ITGC) or application control).

TABLE III Mapping of the ESG Sub-Ledger to COSO ICSR (March 2023)

COSO ICSR Component	Implementation in the ESG Sub-Ledger	Typical Control Type
Control Environment	Sustainability function owns the ESG ledger; ESG controller role separated from data owners.	Manual; entity-level

COSO ICSR Component	Implementation in the ESG Sub-Ledger	Typical Control Type
Risk Assessment	Annual scoping of in-scope ESRS datapoints; risk-rated emission-factor sources.	Manual; preventive
Control Activities	Three-way match between activity data, emission factor and `2S` posting; period lock; SoD via SAP auth groups.	Automated; application & detective controls
Information & Communication	Snapshot package delivered to audit committee; reconciliation reports to disclosure layer.	Automated; reporting
Monitoring Activities	Continuous control monitoring on the `2S` ledger; exception reporting on broken reconciliations.	Automated; detective ITGC

Two observations follow. First, most of the controls in the control set are automated application controls and ITGCs, which are typical of more mature financial-reporting environments and what drives the assurability of ESG data at scale. Secondly, separation of duties is not replicated in an SAP sustainability tool, but rather the ESG sub-ledger resides in its own authorisation group, independent of the financial close.

A convenient summary statistic is the compliance ratio,

$CR = V / T$,

where V is the number of validated controls for a period, and T is the number of controls in scope for the period. This ratio is provided to audit committee in the same manner as the close package.

B. Period Close, Locking and Restatement

An ESG close cannot take the stance of a financial close and assume that emission factors and supplier data will remain unchanged. It is done in the architecture using immutable snapshots and explicit restatement entries. If an emission factor is updated retroactively, the old posting will not be changed, but a new corrective 2S posting will be created referencing the old line and the new emission factor in the factor master record, and the old period's snapshot will not be modified. The disclosure layer can then disclose the restated comparatives transparently — as in IFRS restatement disclosure.

In practice, the period-close cadence we recommend mirrors the financial calendar: a soft close on working day +3 with management review of exceptions, a hard close on working day +5 with the period locked and snapshot written, and a sealed package delivered to the assurance provider. Where this cadence is impractical — for example, because Scope 3 supplier data only arrives quarterly — the sub-ledger accepts late postings into a clearly tagged restatement period rather than reopening the closed period.

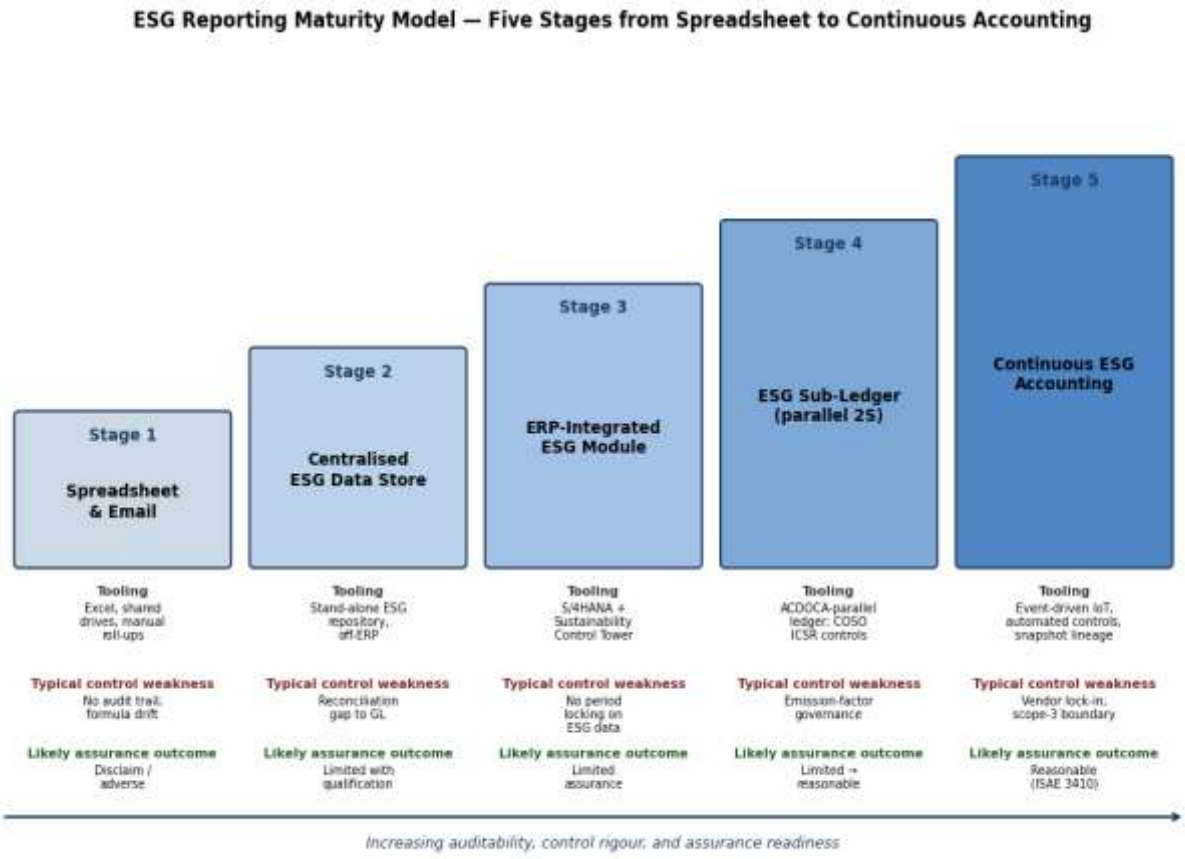

Fig. 4. ESG reporting maturity model. Stages 1 to 5 from spreadsheet-based ESG reporting to continuous, event-driven ESG accounting. The architecture proposed in this paper sits at Stage 4.

C. Maturity Model

Fig. 4 summarises a five-stage maturity model and, for each stage, the typical tooling, the dominant control weakness and the likely assurance outcome. The architecture proposed in this paper sits at Stage 4.

Two short remarks. The transition that creates the most value, in our experience, is the move from Stage 2 (a centralised but off-ERP sustainability data store) to Stage 3 (ERP-integrated capture). Stage 4 — the full sub-ledger with COSO ICSR-aligned controls — is the point at which reasonable assurance becomes a realistic objective. Stage 5 is technically achievable on the same architecture but, at end-2023, is uncommon outside a handful of large preparers with prior investment in event-driven enterprise architecture.

VI. CONCLUSION

The regulatory stack that became effective in 2023 — CSRD, ESRS Set 1, IFRS S1/S2 and COSO ICSR — turns sustainability reporting into a controlled, externally assured discipline. The data architecture that most organisations rely on at the end of 2023 does not yet meet that bar. We have proposed an ESG sub-ledger that lives inside SAP S/4HANA as a parallel ledger in the Universal Journal, captures Scope 1, 2 and 3 emissions as quantity-only postings against the same cost-object hierarchy as the financial ledger, and is closed, locked and snapshotted on the same rhythm. The controls map onto the five COSO ICSR components, and the resulting outputs are recognisable as evidence under ISAE 3000 and ISAE 3410.

First, there are some inherent issues. Even if a sub-ledger always matches its inputs perfectly, errors in those factors still accumulate; Scope 3 has assumptions and supplier disclosures that cannot be guaranteed by the ledger design. Second, this proposal is focused on SAP; preparers on Oracle, Workday or other ERP systems will need to reproduce the parallel-ledger approach with their own engines, and the design

trade-offs are not identical. Third, the boundary of Scope 3 is a methodological issue and not technical one, and there is no architecture to resolve that issue.

Two directions are discussed in December 2023. One, the economics of parallel versus extension ledger design, needs to be determined as the first CSRD reporters begin to report on the data. The other is that as ESRS Set 1 datapoint definitions become easier to define, the mapping between sub-ledger balances and disclosure tables can be uniformised — possibly as a templated content package — so that CSRD producers don't have to worry about translating and focus on quality. Both options can be implemented with the architecture described here.

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