A data science framework for sustainable decommissioning: auditable inventories, material traceability and evidence-based decision-making

From inventory to decarbonization

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Introduction. The sustainability of offshore asset decommissioning depends on an often overlooked condition: the quality of information on materials removed, recovered and returned to the industrial supply chain. In current Brazilian practice, inventories of recoverable steel are estimated from LDT (lightweight displacement tonnage) or manufacturers' specifications, and are rarely measured. Since traceability, the circular economy and end-of-life decisions rely on these inventories, poor inventory quality affects every subsequent stage. The Hong Kong International Convention (IMO, 2009), in force since 2025, makes this requirement pressing by requiring material inventories, chain of custody and auditing of the physical destination of steel; in parallel, digital measurement, reporting and verification (MRV) is discussed as an audit layer for circularity chains (WORLD BANK, 2022). The decommissioning literature focuses on options and impacts (BULL; LOVE, 2019; SOMMER et al., 2019) and multicriteria analysis of strategies (MARTINS et al., 2020); however, inventory production is rarely treated as a methodological data science problem, although operational records have already proved to be a source of robust evidence for decision-making (DANTAS et al., 2021).

This paper proposes a data science framework for sustainable decommissioning, organized around the data science lifecycle (WIRTH; HIPP, 2000; PROVOST; FAWCETT, 2013), that converts dispersed operational records into auditable inventories, material traceability and evidence-based decision support. The research question is: how can a data science framework be structured to support sustainable decommissioning through auditable inventories, material traceability and evidence-based decision support? The contribution is methodological: a framework whose feasibility is demonstrated through a proof of concept in an actual operation.

Objective. To propose a data science framework for sustainable decommissioning that connects auditable inventories, material traceability and evidence-based decision-making, and to demonstrate its feasibility through a proof of concept in the dismantling of a steel structure.

Framework and methodological approach. The framework uses the data science lifecycle as its methodological approach, comprising six iterative stages (Figure 1); Table 1 maps each stage to its empirical implementation in the proof of concept and its corresponding contribution to sustainability. Business Understanding formulates the underlying problem: the estimated inventory and its uncertainty. Data Acquisition collects primary data through officially certified weighing and operational documents (weighbridge ticket, manifest and invoice). Data Preparation classifies materials into controlled categories, consolidates them and derives physical and operational variables (cumulative weight and revenue, and an operational efficiency index). Data Modeling develops the central artifact: a load-level physical and financial measurement protocol (MRV-P) that structures measurement, reporting and verification. The same load-level records are also used to develop predictive

models of recoverable steel, which are subsequently evaluated. Evaluation reconciles the cumulative physical and financial curve (closure error), assesses predictive model accuracy (RMSE and R^2), and compares auditability with current practice (LDT/nameplate) against four criteria: granularity, traceability, independent auditability and replicability. Deployment uses auditable information to support governance, the circular economy and end-of-life decisions. The framework's specific contribution is distinct from the MRV-P artifact: while the latter performs measurement, the framework organizes the entire process and prescribes, in the modeling and evaluation stages, an auditable physical and financial inventory and an interpretation of circularity that a generic application of the data science lifecycle does not specify.

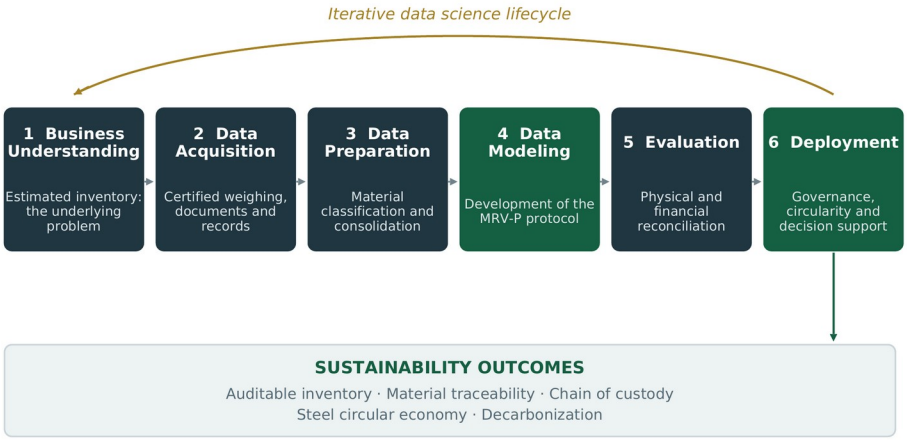

Figure 1 — Framework: the data science lifecycle applied to sustainable decommissioning, from the problem of estimated inventories to sustainability outputs (auditable inventory, traceability, circularity and decarbonization).

Stage (data science lifecycle)	Implementation in the proof of concept (STS)	Contribution to sustainability
1. Business Understanding	LDT/nameplate inventory; pre-operation uncertainty	Makes the underlying information problem explicit
2. Data Acquisition	Certified weighing by load; ticket, manifest, invoice	Traceability and chain of custody
3. Data Preparation	Material classification by category and consolidation	Resource recovery; scrap qualification
4. Data Modeling	MRV-P protocol (measurement, reporting, verification)	Auditable and replicable inventory
5. Evaluation	Curve reconciliation; four auditability criteria	Reduced uncertainty; third-party verification
6. Deployment	Evidence-based support for end-of-life decisions	Circular economy, governance and decarbonization

Table 1 — Mapping the framework stages to their empirical implementation (proof of concept) and contribution to sustainability.

Results (empirical demonstration). The framework's feasibility is demonstrated, as a proof of concept, in an actual, completed dismantling operation involving a port steel structure (a Ship-to-Shore crane) at a Brazilian terminal in 2021. A total of 808 t was recovered, recorded in 107 dispatch entries, checked against gate and buyer weighing records, and classified into four material categories (instrumental case study; YIN, 2018). Consistent with the distinction between evidence for decision-making and technical validation, two types of results are reported.

(i) Operational results and evidence-based decision-making (insights). The Acquisition stage reduced pre-operation uncertainty: the measured weight (808 t) contrasts with the

manufacturer's specification (850 t, +5.2%) and the field estimate (680 t, -15.8%), a gap equivalent to 25% of the lower value. This provides a direct information gain for end-of-life decisions. The Deployment stage demonstrated the decision-making value of a traceable inventory: load-level material segregation was associated with a revenue gain of approximately +46% over unsegregated sales, stable across different reference prices and largely concentrated in the structural category. These operational insights support decisions based on evidence rather than aggregate estimates.

As a methodological exploration, models were compared using data that combined empirical parameters and controlled simulations. The metrics from this exercise do not constitute empirical predictive validation. The defensible operational evidence is the P2 reconciliation: 680 t estimated in the field versus 808 t weighed (-15.8%), and 850 t in the manufacturer's reference versus 808 t weighed (+5.2%).

(iii) Sustainability results and information governance. Within this framing, sustainability emerges from information quality and material management. Auditable inventories reduce pre-operation uncertainty and qualify scrap for industrial reintegration at a level compatible with steelworks requirements. Since steel produced through the secondary route (scrap in an electric arc furnace) avoids approximately 1.5 to 1.9 tCO_2e per tonne relative to the primary route (IEA, 2023), the documented recovery of 808 t corresponds to an order of magnitude of 1.2 to 1.5 thousand tCO_2e avoided in the proof of concept. The circularity of the material mix can be summarized using an index such as the Material Circularity Indicator (ELLEN MACARTHUR FOUNDATION; GRANTA DESIGN, 2015), in accordance with the vocabulary and principles of ISO 59004:2024. Load-level traceability and documentary verification constitute the chain of custody required by the Hong Kong Convention, shifting governance from aggregate declarations to evidence verifiable by third parties. Resource recovery, circularity and decarbonization thus become measurable properties of the information process, subject to audit.

Conclusions. This paper reframes sustainable decommissioning as a data science and information governance problem: auditable inventory quality enables traceability, the circular economy and evidence-based decision-making. The proof of concept involving a steel structure indicates the framework's feasibility, although it remains limited to a single case and one item of port equipment. Its transfer to offshore assets (topsides, jackets, FPSOs and subsea systems) requires adapting Acquisition to contaminants, NORM and underwater cutting, and Modeling to more heterogeneous inventories. Consolidating the framework defines the research agenda: replication across multiple cases using actual, anonymized offshore components; quantification of circularity and decarbonization through formal indicators; operational formalization of the domain ontology; and incorporation of decision-making under uncertainty and process mining. The framework therefore provides a replicable methodological basis for applying data science rigor to the information that supports sustainable decommissioning.

Keywords: Sustainable decommissioning. Data science. Material traceability. Circular economy. Evidence-based decision-making.

References

BULL, A. S.; LOVE, M. S. Worldwide oil and gas platform decommissioning: a review of practices and reefing options. Ocean & Coastal Management, vol. 168, pp. 274–306, 2019.

DANTAS, L. F. et al. App-based symptom tracking to optimize SARS-CoV-2 testing strategy using machine learning. PLOS ONE, vol. 16, no. 3, e0248920, 2021.

ELLEN MACARTHUR FOUNDATION; GRANTA DESIGN. Circularity indicators: an approach to measuring circularity — methodology. Cowes: Ellen MacArthur Foundation, 2015.

FRANÇA, J. B. S. et al. KIPO: the knowledge-intensive process ontology. Software and Systems Modeling, vol. 14, no. 3, pp. 1127–1157, 2015.

INTERNATIONAL ENERGY AGENCY (IEA). Iron and steel technology roadmap: towards more sustainable steelmaking. Paris: IEA, 2023.

INTERNATIONAL MARITIME ORGANIZATION (IMO). Hong Kong international convention for the safe and environmentally sound recycling of ships. London: IMO, 2009.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO). ISO 59004:2024: circular economy — vocabulary, principles and guidance for implementation. Geneva: ISO, 2024.

MARTINS, I. D. et al. A review of the multicriteria decision analysis applied to oil and gas decommissioning problems. Ocean & Coastal Management, vol. 184, art. 105000, 2020.

PROVOST, F.; FAWCETT, T. Data science for business: what you need to know about data mining and data-analytic thinking. Sebastopol: O'Reilly, 2013.

RICHETTI, P. H. P.; BAIÃO, F. A.; CAMPOS, M. L. M. Decision-making in knowledge-intensive processes: the case of value ascription and goal processing. In: CONCEPTUAL MODELING (ER 2019), 38th, 2019, Salvador. Proceedings [...]. Cham: Springer, 2019. pp. 363–377. (Lecture Notes in Computer Science, vol. 11788).

SOMMER, B. et al. Decommissioning of offshore oil and gas structures: environmental opportunities and challenges. Science of the Total Environment, vol. 658, pp. 973–981, 2019.

WIRTH, R.; HIPP, J. CRISP-DM: towards a standard process model for data mining. In: INTERNATIONAL CONFERENCE ON THE PRACTICAL APPLICATIONS OF KNOWLEDGE DISCOVERY AND DATA MINING, 4th, 2000, Manchester. Proceedings [...]. 2000. pp. 29–40.

WORLD BANK. Digital measurement, reporting and verification (D-MRV): concepts, architecture and use cases. Washington, DC: World Bank, 2022.

YIN, R. K. Case study research and applications: design and methods. 6th ed. Thousand Oaks: Sage, 2018.