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MINIMUM DIGITAL TRACEABILITY FOR POST INDUSTRIAL GARMENT WASTE IN INDONESIA

Cornelia Susianti[1], Christian Natalie[2], Rahardrian Prananditya[3]
[12]Magister Management Universitas Sanata Dharma, [3]Reverse Resources OÜ
[1]lia.cornelia@gmail.com, [2]tian.natalie@gmail.com, [3] rahardrian.prananditya@gmail.com
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Abstract
This study develops a minimum digital traceability specification for identifiable post-industrial garment waste, including cutting scraps, roll ends, production samples, yarn waste, and products that fail to meet specifications. The system boundary starts when waste is identified and grouped into a batch at a garment factory and ends when the batch is received at the recycler gate. The study uses an exploratory qualitative design based on document analysis and process mapping. Academic literature was searched in Google Scholar in July 2026 using seven search strings and a 2018-2026 publication window. The search produced 55 record occurrences and 47 unique journal articles. After title and abstract screening, 34 articles moved to full-text assessment plus three additional non-journals. Twenty-two were used in the main synthesis, twelve as supporting literature. The analysis also used Indonesia's Circular Economy Roadmap and National Action Plan 2025-2045 and operational documents from Reverse Resources and Closed Loop Fashion. The study proposes nine material events, twelve minimum data groups, four batch-lineage rules, and a responsibility matrix for five actor groups. These outputs can support waste-generation data for indicator 2.1.c and upstream provenance and feedstock-receipt evidence for 2.3.a. They cannot verify recycled content in a final product because the study stops at the recycler gate. Since the study does not include interviews, field observation, or a system pilot, the specification should be treated as a document-based proposal that needs pilot testing before wider use as guidance or a standard.
Keywords*: Digital traceability; post-industrial garment waste; batch lineage; chain of custody; circular economy; Indonesia*

1. Introduction

Post-industrial garment waste is generated before products are used by consumers and may include cutting scraps, roll ends, production samples, yarn, or products that fail to meet specifications. Compared with post-consumer waste, these materials are generally cleaner and easier to link to production records. Their value nevertheless depends on the ability of actors to preserve information on material origin, fibre composition, colour, condition, and quantity. When waste is mixed or transferred without adequate records, the range of possible recovery options narrows and its value tends to decline (Akter et al., 2022).

Post-industrial garment waste is generated during garment manufacturing before products are used by consumers. It may include cutting scraps, roll ends, production samples, yarn waste, and products that fail to meet specifications. Compared with post-consumer waste, these materials are usually cleaner and can often be linked to production records. Their reuse or recycling value depends on information about origin, category, material composition, condition, the reason for non-conformity when relevant, and quantity. When material moves, mixes, or is processed without adequate records, traceability falls and reuse or recycling options become more limited (Akter et al., 2022).

Indonesia's Circular Economy Roadmap and National Action Plan 2025-2045 lists textiles as a priority sector. Strategy 2 focuses on reducing textile waste through four action plans: zero-waste technology in garment manufacturing, Green Industry Standards, higher recycled content, and textile eco-design. This study focuses on the data needs of indicator 2.1.c and on upstream evidence that is relevant to indicator 2.3.a. For 2.1.c, the roadmap reduces average textile waste from 15% of total production in 2025-2029 to 10%, 5%, and 2% in later periods. For 2.3.a, the average recycled-content milestone rises from 10% to 15%, 20%, and 25% (Kementerian PPN/Bappenas, 2024).

The two indicators need evidence at different points. Indicator 2.1.c needs factory-level waste weight that can be matched with a production denominator for the same period or unit. Upstream support for 2.3.a needs continuous information on material origin, characteristics, quantity, transfers,

and receipt as recycling feedstock. The core issue is therefore not only which digital technology to use. It is also what data must be recorded, when records are created, how batch relationships change, and who is responsible for each record.

The scale of the Indonesian problem is becoming clearer. Nurkomariyah et al. (2026) estimated that about 572 kilo tonnes of post-industrial polyester waste were generated in 2023. The study identified 19 waste types, and 61% were fibre blends that limit textile-to-textile recycling. This work is important for understanding volume, characteristics, and end-of-life routes, but it does not define how a batch identity should be kept when waste is sorted, transferred, split, or merged across several actors.

Textile traceability studies show that physical material can be connected to digital records through identifiers, tags, batch records, activity records, or traceability platforms (Agrawal et al., 2018; Alves et al., 2022, 2024). Reverse-supply-chain studies also show that factories, collectors, waste handlers, sorters, logistics providers, and recyclers perform different physical functions (Akter et al., 2025; Sandberg & Pal, 2024; Do & Stevenson, 2026). However, these two groups of literature do not directly provide a minimum specification that links material events, minimum data, batch relationships, and recording responsibilities for post-industrial garment waste in Indonesia.

The start of this study is the point where waste is formed into a batch, given an identity, and weighed/recorded at a garment factory. The end is the point where the batch is received, inspected, weighed, and accepted or rejected at the recycler gate. Recycling after receipt is outside the study. The study can therefore support evidence of origin and feedstock receipt, but it cannot verify recycled content in a final product.

Based on this boundary, the study asks two research questions:

1. Which material events and minimum data need to be kept from batch creation at a garment factory to receipt at the recycler gate?
2. What batch-lineage rules and actor responsibilities are needed to keep records consistent and support measurement under Strategy 2?

2. Literature Review

The theoretical foundation of this study draws on Indonesia’s Circular Economy Roadmap and National Action Plan, Green Industry Standards, studies on material flows and digitalization in Indonesia, and published textile-waste mapping reports.

2.1 Strategy 2 of Indonesia’s Textile Circular Economy Roadmap as the policy basis for data needs

Indonesia's Circular Economy Roadmap and National Action Plan 2025-2045 is the main policy reference because it provides indicators, baselines, milestones, and responsible agencies for the textile sector. Of the four action plans in Strategy 2, this study focuses on the data needs of 2.1.c and upstream support for 2.3.a. Action 2.2 on the Green Industry Standard and Action 2.4 on eco-design remain part of the policy context, but they are not measured because they need company- and product-level data beyond a waste-batch unit.

For 2.1.c, traceability can help build a consistent waste numerator by facility and period. The indicator still needs a comparable production denominator. For 2.3.a, this study only provides evidence up to the recycler gate. Origin, composition, weight, transfer, lineage, and receipt can be traced, but final-product recycled content needs additional data on recycling processes, yield, losses, blending, and later manufacturing.

This position is consistent with the roadmap's wider data-management direction, which stresses resource tracking, supply-chain transparency, data integration, and verification/validation. Traceability is therefore treated as an information function, not as a reason to require one specific technology.

2.2 Manufacturing waste and material flows

Manufacturing studies show that pre-consumer or post-industrial textile waste is created at several production stages and has different characteristics. Dissanayake and Weerasinghe (2021), Li et al. (2021), Haslinger et al. (2019), and Määttänen et al. (2021) show that waste type, quantity, condition,

and treatment route affect later recovery options. Akter et al. (2022) add a material-flow and waste-trading perspective across textile and apparel manufacturing.

For Indonesia, Nurkomariyah et al. (2026) provide the most direct material-flow evidence. Because this study covers several identifiable forms of post-industrial garment waste, the unit of analysis is a batch: a quantity of waste managed as one unit because its origin, category, and characteristics are similar enough to be recorded together. A batch can be a container, bag, bale, or lot, including a grouped set of production samples or products that fail to meet specifications. Individual pieces or products do not need separate identities as long as the batch relationship is preserved.

Reverse-flow literature shows that material can be sorted, stored, repacked, consolidated, transferred, and processed by more than one actor (Akter et al., 2025; John & Rahman, 2025; Do & Stevenson, 2026). Traceability must therefore be able to reconstruct relationships when one batch stays intact, is split into child batches, or is merged into an aggregate batch.

2.3 Material traceability and continuity of batch identity

Material traceability needs a stable link between physical material and digital records. Agrawal et al. (2018) demonstrate a secured tag for identification in the textile and clothing supply chain. Alves et al. (2022) review blockchain and Internet of Things functions for recording activities on traceable items and linking them to digital representations. Alves et al. (2024) present a platform that traces product batches and related activities at batch level.

This study takes the functional idea but does not require those technology architectures. A structured spreadsheet, mobile form, company database, QR code, or digital platform can be used if it can keep batch identity, event sequence, custody transfers, batch relationships, and correction history. This technology-neutral position is also consistent with literature that treats digitalization as an enabler of visibility and coordination rather than an end in itself (Antikainen et al., 2018).

The harder problem appears when material change structure or is mixed. Carlsson and Nevzorova (2025) explain how traceability can be lost when materials mix in warehouses or industrial processes. Cross-sector mass-balance and chain-of-custody studies help explain the need for input-output reconciliation when physical identity can no longer be fully maintained (Schumacher & Beers, 2024; Caraceni et al., 2024; Krueger et al., 2026). In this study, these cross-sector sources only support the reconciliation logic. They are not used as evidence that the same practices already operate in Indonesian garment waste flows.

2.4 Intermediary functions and operational documents

A textile reverse supply chain includes more than factories and recyclers. Sandberg and Pal (2024) separate capabilities in collection, sorting, and recycling. John and Rahman (2025) describe acquisition, collection, inspection and sorting, and disposition. Do and Stevenson (2026) show that digital platforms can change intermediation without removing the need for actors who collect, inspect, sort, store, consolidate, and move material. Teixeira et al. (2026) also show the diversity of actors and relationships in textile reverse supply chains.

Reverse Resources is used as an operational comparator, not as independent evidence of industry-wide practice. Its platform describes tracking by waste type, composition, colour, location, origin, volume, and chain-of-custody documentation. Closed Loop Fashion is used in a limited way as an industry source describing waste-mapping work in Bangladesh, Indonesia, and Sri Lanka with Reverse Resources. These sources help show how academic functions can appear in operations, but they are not used to claim platform effectiveness or national adoption (Reverse Resources, n.d.; Closed Loop Fashion, n.d.).

2.5 Study system boundary

The system boundary as in Table 1 is set so that the proposed specification stays within evidence that can be built from documents. The focus is the flow of identifiable post-industrial garment-waste batches from batch creation at a garment factory to receipt at the recycler gate.

In this study, yarn waste means yarn or thread waste generated during garment manufacturing. Waste from yarn production at a spinning mill is outside the system boundary. Production samples and products that fail to meet specifications may contain trims or accessories; these components should be recorded when they affect sorting, acceptance, or recycling options.

To maintain analytical clarity and avoid claims beyond the available evidence, this study defines specific boundaries for the materials, process stages, actors, digital functions, and policy relevance as summarized in Table 1.

Table 1. System boundary and scope decisions

Dimension	Included	Excluded
Material	Identifiable post-industrial garment waste generated during garment manufacturing, including cutting scraps, roll ends, production samples, yarn waste, and products that fail to meet specifications.	Post-consumer waste, wastewater, sludge, chemicals, packaging waste, and waste generated upstream during fibre, yarn, fabric, dyeing, or finishing production before garment manufacturing.
Start boundary	Material is formed into a batch, given an ID, and weighed/recorded at the garment factory.	Fibre, yarn, and fabric production and upstream process details before the material becomes waste.
End boundary	The batch is received, inspected, weighed, and accepted or rejected at the recycler gate.	Recycling operations, production of new fibre/fabric, and recycled-content claims in final products.
Core actors	Garment factory, collector/waste handler, logistics provider, recycler, and digital system operator.	Consumers, retailers, post-consumer facilities, and regulators as transaction operators.
Information functions	Batch identity, material events, transfers, batch relationships, weighing/handover evidence, and correction history.	A specific technology choice, blockchain architecture, complex IoT, or a national dashboard.
Policy link	Direct support for data needs under 2.1.c and upstream provenance/feedstock evidence for 2.3.a.	Assessment of Green Industry Standard compliance, CAD/zero-waste effectiveness, or final-product recycled-content verification.

Sources: Research boundaries established by the author based on Kementerian PPN/Bappenas (2024), Akter et al. (2022), and Nurkomariyah et al. (2026).

3. Research Method

This study uses an exploratory qualitative approach based on document analysis and process mapping. Document analysis supports a systematic review of document content, context, and relationships that can be checked again (Bowen, 2009). The study does not test causal relationships, assess company compliance, or evaluate the effectiveness of a specific platform.

The research process has five stages: (1) identify literature with seven search strings; (2) screen titles and abstracts; (3) assess full text against four research functions; (4) assign each source as main synthesis, supporting literature, or pending; and (5) extract evidence and triangulate across document types.

In this paper, minimum means the smallest proposed group of information needed to reconstruct identity, movement, batch relationships, and material receipt within the system boundary. It does not mean a legal minimum or an approved national standard.

3.1 Academic literature search

The search was conducted in July 2026 using Google Scholar as the only academic search engine. The substantive publication window was 2018-2026. Method references such as Bowen (2009) were not limited by this window. Google Scholar was used to build a corpus that could be checked through

titles and DOIs, but this study does not claim to be a systematic review that captures every relevant publication.

Seven search strings were designed around the information needs of RQ1 and RQ2. The source string for each article was retained so that search provenance could be audited.

Table 2. Google Scholar academic search strategy

ID	RQ	Search purpose	Search string	Information sought
S1	RQ1	Material events in manufacturing	("textile waste" OR "garment waste" OR "apparel waste") AND ("manufacturing waste" OR "post-industrial waste" OR "pre-consumer waste")	Waste activities and material changes at the manufacturing stage.
S2	RQ1	Indonesian post-industrial waste flows	("post-industrial textile waste" OR "garment manufacturing waste") AND Indonesia AND ("material flow" OR "waste flow" OR recycling)	Material flows, transfer points, changes, and actors.
S3	RQ1	Traceability information needs	("material traceability" OR "textile traceability") AND ("data requirements" OR "data elements" OR "minimum data" OR "information requirements")	Information needed to identify, reconcile, and trace material.
S4	RQ1/ RQ2	Handover and information continuity	("material traceability" OR "chain of custody") AND (handover OR transfer OR transaction OR custody) AND (waste OR recycling)	Transfer, confirmation, and handover evidence.
S5	RQ2	Batch identity continuity	("chain of custody" OR "material lineage" OR "batch tracking" OR "batch traceability") AND (textile OR recycling OR "recycled material")	Batch relationships and continuity of material identity.
S6	RQ2	Batch structure change and reconciliation	(traceability OR "chain of custody") AND (splitting OR merging OR aggregation OR segregation OR reconciliation) AND (material OR recycling)	Split, merge, aggregation, segregation, and reconciliation.
S7	RQ2	Actor functions in reverse supply chains	("reverse supply chain" OR "reverse logistics") AND (textile OR garment OR apparel) AND (collector OR aggregator OR intermediary OR recycler)	Collection, transfer, consolidation, receipt, and processing functions.

In Stage 1, all S1-S7 results were collected and deduplicated using DOI as the main identifier. The search produced 55 record occurrences and 47 unique journal articles after deduplication. The original search string was kept for each article.

3.2 Title, abstract, and full-text screening

In Stage 2, the title and abstract of all 47 unique articles were read. An article was retained when the abstract contained extractable information for the purpose of the relevant search string. This step retained 34 articles and excluded 13. To keep the protocol sequential, articles that failed abstract screening were not brought back at the full-text stage.

In Stage 3, the 34 retained articles were assessed using full text or an available full-text version against four research functions: C1 covers material waste in textile/apparel manufacturing; C2 provides evidence on post-industrial waste flows in Indonesia; C3 explains traceability or digitalization functions relevant to material flow; and C4 covers intermediary functions in textile reverse supply chains. One article could meet more than one function.

In Stage 4, direct evidence that could be separated within the system boundary was assigned to the main synthesis. Relevant cross-sector, post-consumer, or broader lifecycle evidence was kept as supporting literature. One early-access article remained pending because full text could not be confirmed.

Table 3. Summary of literature selection

Stage	Result	Main decision
Stage 1	55 record occurrences; 47 unique journal articles after DOI deduplication.	All unique articles moved to title and abstract screening.
Stage 2	47 articles screened; 34 substantive journal articles retained; 13 excluded.	Only retained articles moved to full-text assessment.
Stage 3	34 articles assessed against C1-C4	Assessment used research function and system-boundary relevance.
Stage 4	22 main-synthesis journal articles; 12 supporting articles.	The main synthesis formed the primary evidence base.

3.3 Academic evidence extraction

Structured extraction was carried out for the 22 main-synthesis articles. The unit of extraction was not an article summary. It was the evidence needed to answer RQ1 and RQ2. The extraction categories were material event/process, material-state change, actor, data or information element, transfer/custody mechanism, batch relationship, traceability function, and relevance to Strategy 2.

Supporting literature was used to clarify transferable concepts, especially material mixing, reconciliation, digitalization, and chain of custody. It was not used as the main evidence for claims about actual post-industrial garment-waste flows in Indonesia.

3.4 Policy and operational-document extraction

Indonesia's Circular Economy Roadmap and National Action Plan 2025-2045 was purposively selected as the primary policy source. Extraction focused on textile Strategy 2, especially 2.1.c and 2.3.a, and on data-management themes related to resource tracking, supply-chain transparency, data integration, and verification/validation.

Reverse Resources and Closed Loop Fashion were purposively selected as operational/industry documents. Their information was used as a comparator for data categories and operational functions stated explicitly by these organizations. It was not used to claim system effectiveness or adoption across all actors in Indonesia.

3.5 Triangulation and specification development

Triangulation in this study is limited to triangulation across document sources. Academic evidence, policy needs, and operational documents were compared for convergence and difference. Candidate requirements then received three analytic labels: E1 for requirements stated explicitly in one or more sources; E2 for requirements synthesized from relationships across sources; and E3 for proposed rules or indicators needed for consistent lineage and reconciliation but not yet stated as explicit requirements or tested in practice.

E1, E2, and E3 are labels created for this study, not an external evidence-grading system. The triangulation produced four main outputs: a material-event map, minimum data groups, batch-lineage rules, and actor responsibilities.

3.6 Method limitations and position of the results

The study does not include interviews, field observation, or a system pilot. The term validation is therefore not used to mean empirical validation. The result is a document-based minimum specification that can support a future pilot; it is not a validated national standard.

Using only one academic search engine also limits corpus coverage. In addition, abstract screening was deliberately strict and sequential. Some papers that might have become relevant after full-text review were not reintroduced after failing Stage 2. This choice improves protocol consistency but may reduce literature recall.

The recycler-gate boundary also limits policy claims. The study can support waste-generation records for 2.1.c and provide provenance and feedstock-receipt evidence relevant to upstream support for 2.3.a. It does not verify that the material was recycled or became recycled content in a final textile product.

4. Research Findings and Discussion

4.1 Position of the results and evidence level

Evidence strength is different across the four research functions. C1 has many sources on waste type, generation point, management, and material transformation. C3 also has several sources on identification, batch/activity records, material identity, and digital traceability. C4 is supported by work on collection, sorting, transfer, recycling, brokerage, and actor roles. C2 has less direct empirical evidence; Nurkomariyah et al. (2026) is the main source for Indonesian post-industrial waste flows.

For this reason, evidence from Bangladesh, India, Europe, Sri Lanka, and other settings is only used to understand functions that may be transferable. The paper does not state that the same practices are already used by all actors in Indonesia.

Table 4. Evidence position of result components

Result component	Main basis	Dominant status	Meaning
Basic material attributes and actor functions	Category, weight, composition, origin, condition, batch/activity records, and collection/sorting/recycling functions are stated in sources.	E1	Explicit evidence forms the base of the specification.
Nine-event material map	Built from evidence on waste generation, sorting, collection, storage, transfer, receipt, and batch/activity records.	E2	The event sequence is a synthesis for this system boundary.
Twelve minimum data groups	Combines explicit attributes with identification, reconciliation, and handover needs.	E2	The minimum set is a synthesis; several components have E1 support.
Transfer, split, merge, correction, and tolerance rules	Derived from continuity, mixing, and reconciliation needs.	E3	Proposed for pilot testing and not validated as a standard.
Actor responsibility matrix	Actor functions are supported by C4; data assignments are based on each actor's position in an event.	E1 for functions; E2 for assignment	Actor functions have direct support; field assignment is a synthesis.

Result component	Main basis	Dominant status	Meaning
Link to 2.1.c and 2.3.a	Derived from policy data needs and the boundary of data that can be produced.	E2	Shows possible support and claim limits.
Pilot indicators	Proposed to test feasibility and data quality.	E3	Not implementation results.

E1 = explicit evidence; E2 = cross-source synthesis; E3 = proposed rule/indicator that has not been tested.

Table 5. Research-function crosswalk and main sources

Function	Use in synthesis	Main sources
C1 - Manufacturing waste & transformation	Waste types, generation points, management, and material transformation.	Li et al. (2021); Akter et al. (2022); Nurkomariyah et al. (2026); Haslinger et al. (2019); Määttänen et al. (2021); Simonetti et al. (2024); de Lima et al. (2025); and Ramzan et al. (2025).
C2 - Indonesian waste flow	Direct empirical evidence on Indonesian post-industrial textile waste volumes and flows.	Nurkomariyah et al. (2026) is the main and most direct source.
C3 - Traceability/digitalization	Identification, batch/activity records, material identity, traceability, and data continuity.	Agrawal et al. (2018); Alves et al. (2022, 2024); Moora et al. (2026); Do & Stevenson (2026).
C4 - Intermediary functions	Collection, sorting, transfer, processing, brokerage, and reverse-chain actor roles.	Akter et al. (2022, 2025); Sandberg & Pal (2024); John & Rahman (2025); Do & Stevenson (2026); Teixeira et al. (2026).

4.2 Material-event map from garment factory to recycler gate

Process mapping produced nine types of material event that should be recordable when they occur. The map is an E2 synthesis based on evidence about waste generation, weighing, sorting, collection, storage, transport, batch/activity records, and recycler/intermediary functions (Akter et al., 2022, 2025; Alves et al., 2022, 2024; Sandberg & Pal, 2024; John & Rahman, 2025; Do & Stevenson, 2026; Nurkomariyah et al., 2026).

Table 6. Nine material events and minimum records

No	Event	Main change	Minimum record	Evidence basis
1	Batch creation	Waste is identified and grouped as one traceable unit.	Batch ID, source facility, date, category, composition, color when relevant, container, and reason for becoming waste when relevant.	Identity/attributes E1; sequence and classification reason E2
2	Initial weighing	The starting quantity of the batch is set.	Gross, tare, net weight, unit, weighing method/equipment, evidence when available.	Weight E1; metadata E2

No	Event	Main change	Minimum record	Evidence basis
3	Source sorting/inspection	Material is kept together or sorted by category, characteristics, condition, or conformity.	Sorting criteria, condition/contamination, reason for non-conformity when relevant; if batch structure changes, use the split/merge event.	Sorting E1; ID rule and non-conformity reason E2
4	Outbound handover	Custody moves from the factory to the next actor.	Sender, receiver, time, location, dispatch weight, handover evidence.	Transfer E1; record structure E2
5	Receipt by collector/waste handler	Weight, condition, and conformity are checked again.	Receipt weight, condition, discrepancy, accepted/conditional/rejected status.	Receipt/inspection E1; status E2
6	Split or merge	The relationship between batches changes.	Parent/source IDs, child/aggregate IDs, source/result weights, reason for change.	Lineage E2; rule E3
7	Storage or repackaging	Location, container, or packaging changes without necessarily changing the material.	Location, time, new container, unchanged/linked ID.	Storage E1; linkage E2
8	Dispatch to recycler	Custody and location move toward the recycler.	Batch list, sender, receiver, time, dispatch weight, transport/handover document.	Transport/transfer E1; structure E2
9	Recycler-gate receipt	The final weight within the study boundary and feedstock conformity are confirmed.	Receipt weight, inspection/test result if available, acceptance/rejection, discrepancy.	Recycler/inspection E1; structure E2

The nine events are not nine compulsory steps for every batch. A batch sent directly from a factory to a recycler may pass through fewer events. The rule is simpler: any change in identity, quantity, characteristics, location, custody, or receipt status should be recordable.

Dispatch and receipt are separate events so that a sender's weight does not automatically replace the receiver's measured weight. Weight differences should be kept as reconciliation information. They should not automatically be treated as non-compliance because scales, moisture, packaging, or transport conditions can affect the result.

4.3 Twelve minimum data groups

The event needs were combined into twelve minimum data groups. Several attributes are explicit in the literature or operational documents, but grouping them into exactly twelve categories is a study synthesis. The full minimum data set is therefore treated as E2.

Table 7. Twelve minimum data groups

No	Data group	Use status	Short definition	Evidence basis
1	Unique batch ID	Required	A unique code that is not reused and stays linked to the physical label or identifier.	E1
2	Event ID, time, and location	Required	Event identity, date/time, and the location where the event occurred.	E2
3	Source facility and production link	Required	The facility that created the batch plus a period, order, material, or product reference that can link the waste to production data.	Origin E1; production link E2
4	Material category	Required	Cutting scraps, roll ends, production samples, yarn waste, products that fail to meet specifications, or another agreed subcategory.	E1
5	Material composition and information basis	Required	Main fibre type/percentage plus components or accessories that matter for sorting or recycling; the information source may be a declaration, checked document, or test result when available.	Composition E1; component detail and evidence basis E2
6	Colour or colour group	Conditional	Dominant colour or colour group when it affects sorting, value, or recycler acceptance.	E1
7	Net weight and measurement basis	Required	Gross, tare, net weight, unit, and weighing method/equipment.	Weight E1; metadata E2
8	Actor and custody	Required	Who creates the record, holds the material, sends it, and receives it.	Actor function E1; custody structure E2
9	Event type	Required	Creation, weighing, sorting, transfer, receipt, split, merge, storage/repackaging, rejection, correction.	E2
10	Batch relationship	Conditional	Parent-child IDs or source IDs when batch structure changes.	E2
11	Condition/contamination	Conditional	Wet/dry condition, contaminants, accessories or trims, and relevant quality deviations or reasons for failing specifications.	Condition E1; non-conformity detail E2
12	Evidence, discrepancy, and correction history	Event-based	Handover photo/document, inspection result, discrepancy note, and correction/reversal record without deleting the original record.	Evidence E1/E2; correction trail E3

Two points need clarification. First, composition data should show the basis of the information. A supplier declaration, a checked document, and a laboratory test do not have the same level of certainty.

The specification does not require laboratory testing for every batch, but it should show where the composition value came from. For production samples and products that fail to meet specifications, relevant trims or non-textile components should also be recorded when they may affect recycling.

Second, commercial data such as price, final buyer identity, or production formulas do not need to be part of the shared minimum data set. For 2.1.c, the factory only needs to keep a link between the waste batch and a period/order/material/product reference that lets the waste numerator be matched with a production denominator without exposing all commercial data to every actor.

4.4 Batch relationships and reconciliation rules

Traceability is easiest when a batch moves without changing. Risk increases when material is split, merged, or corrected. Material-traceability and mass-balance literature shows the importance of keeping input-output relationships and preventing double counting after mixing (Schumacher & Beers, 2024; Caraceni et al., 2024; Carlsson & Nevzorova, 2025; Krueger et al., 2026).

The study therefore proposes four minimum rules. All rules in this subsection are E3. The study does not set a universal weight-difference tolerance because the evidence base does not support one value for all cases. A tolerance should be set in a pilot and should consider scale type, batch size, moisture, packaging, and transport conditions.

Table 8. Proposed batch-lineage and reconciliation rules

Situation	Proposed rule	Reconciliation	Status
One-to-one transfer	Keep the same batch ID when physical identity stays intact; create a new event ID for the transfer.	Store dispatch and receipt weights separately. Record the difference and review it when it exceeds the pilot tolerance.	E3
Splitting	Close the parent batch as an active unit; give each part a child ID linked to the parent.	Compare total child weight with parent weight; record any loss/gain as a discrepancy.	E3
Merging	Create a new aggregate ID that lists all source IDs; close source batches as active units to prevent double counting.	Store each source weight and the aggregate total and reconcile them.	E3
Rejection/correction	Do not delete the old record. Create a new rejection, reversal, or correction event.	Keep the original and corrected values with reason, time, and the actor who made/confirmed the correction.	E3

4.5 Responsibilities across actors

C4 literature supports different functions across the reverse supply chain. The responsibility principle used here is simple: create data as close as possible to the physical event, and let the receiving party confirm handover data. The digital system operator manages ID structure, access rights, format validation, and audit trails, but it does not replace the physical actor's responsibility for material weight, condition, or composition.

Actor functions have E1 support from the literature. Assigning specific data fields to particular actors is E2 because the study maps the fields to each actor's position in an event.

Table 9. Recording and confirmation responsibilities

Actor	Data created	Data confirmed	Main use
Garment factory	Initial batch ID, category, composition, color when relevant, initial weight, sorting, outbound handover.	Corrections to source data and resolution of issues linked to production data.	Measure waste generation and provide origin evidence.
Collector/waste handler	Receipt, inspection, split/merge, storage/repackaging, shipment.	Weight/condition at receipt and the next handover data.	Keep lineage and match material with recycler needs.
Logistics provider	Transport time, sender, receiver, transport document, pickup/delivery evidence when relevant.	Physical pickup and delivery.	Show continuity of custody during transport.
Recycler	Receipt weight, inspection/test when available, acceptance/rejection.	Batch conformity with feedstock specification.	Supply planning, quality control, and feedstock receipt evidence.
Digital system operator	ID structure, actor registration, access rights, format validation, audit trail, and data export.	Technical record consistency, not the physical truth of the material.	Maintain information integrity and support reporting.

Government does not need to operate every transaction. A more proportionate policy role is to define material categories, units, minimum rules, indicator definitions, audit mechanisms, and formats for aggregated data export. Commercial data can remain protected, while third-party verification can be used for claims linked to certification, incentives, or market access.

4.6 Link to indicator 2.1.c and upstream support for 2.3.a

For 2.1.c, batch data can provide a waste numerator by facility, category, and period. The waste-generation percentage still needs a production denominator using the same period or measurement unit. Traceability can therefore improve the consistency of waste records, but it cannot calculate the complete indicator without factory production data.

For 2.3.a, the study ends at the recycler gate. The records can show material origin, composition, weight, transfer, lineage, and receipt as feedstock. This is not enough to claim recycled content in a final product. Final verification needs additional information on recycling processes, yield, losses, blending, and later manufacturing.

Table 10. How the traceability outputs relate to Strategy 2

Indicator/need	Data that can be produced	Support provided	Claim limit
2.1.c - Waste-generation percentage	Waste weight by facility, category, period, and production/order/material/product reference.	Provides the waste numerator and trend data; can be matched with a consistent production denominator.	Does not directly assess CAD/zero-waste technology and cannot calculate the ratio without production data.

Indicator/need	Data that can be produced	Support provided	Claim limit
Upstream support for 2.3.a	Origin, composition, weight, transfer, lineage, and recycler-gate receipt.	Traceable feedstock volume, provenance, and weight reconciliation up to the recycler gate.	Does not verify that the feedstock was recycled or became recycled content in a final product.

4.7 Implications for a pilot

Because the study is document-based, the next step should be a limited pilot. The simplest pilot could include one garment factory, one collector or waste handler, and one recycler that already have material transactions. The first system does not need to be complex. A structured spreadsheet, mobile form, simple database, or QR label can be used if it keeps batch IDs, event records, batch relationships, handover evidence, access control, and correction history.

The pilot indicators below are E3 proposals. Their purpose is to test feasibility, data quality, and operational burden before wider use. The pilot should also examine protection of commercial information, willingness to share data, cost allocation, and benefits for each actor.

Table 11. Proposed pilot indicators

Pilot indicator	Purpose
Completeness of required data fields	Test whether the minimum fields can be completed consistently.
Share of batches traceable to the source facility	Test lineage continuity.
Dispatch-receipt weight difference	Identify discrepancy patterns and a basis for tolerance.
Recording time per event	Measure administrative burden.
Completeness of parent-child/source relationships	Test split and merge mechanisms.
Number of correction/dispute records	Find the data points that create the most problems.
Recycler-gate acceptance/rejection rate	Test the link between batch information and feedstock specification.
Share of batches whose composition has an evidence basis	Assess composition-data quality.
Share of labels/identifiers still readable at receipt	Test physical-identity durability during storage and transport.

Notes: All indicators in Table 11 are E3 proposals for future research/piloting and are not current implementation results.

5. Conclusion

This study develops a minimum digital traceability specification for identifiable post-industrial garment waste, including cutting scraps, roll ends, production samples, yarn waste, and products that fail to meet specifications, from batch creation at a garment factory to receipt at the recycler gate. The specification connects policy needs, literature evidence, material events, minimum data groups, batch-lineage rules, and actor responsibilities in one consistent framework.

The main outputs are nine material events, twelve minimum data groups, four batch-lineage rules, and a responsibility matrix for five actor groups. The evidence level is not the same for all outputs. Basic attributes and actor functions have explicit support. The event sequence and field assignments are cross-source syntheses. Detailed split, merge, correction, and tolerance rules remain E3 proposals that need testing.

For indicator 2.1.c, the specification can support more structured waste-generation data when waste batches are linked to a matching production denominator. For 2.3.a, it can provide upstream evidence on provenance, characteristics, quantity, lineage, and feedstock receipt up to the recycler gate. It does not verify recycled content in a final product.

The main limitations are the absence of interviews, field observation, and system testing; the use of Google Scholar as the only academic search engine; and the limited direct Indonesian empirical evidence, which relies heavily on one national-level material-flow study. The results should therefore not be treated as a description of practice across the whole Indonesian supply chain or as a validated standard.

Future research should test the specification in a pilot and assess data completeness, traceability back to origin, weight differences, composition-data quality, label durability, recording time, actor acceptance, commercial-data protection, and costs and benefits. Pilot results can then be used to refine the data groups, set operational tolerances, and assess whether the specification is ready to become broader guidance or a standard.

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