

Mapping the E-Waste Recycling Research Landscape (2015–2025): A Bibliometric Analysis of Publication Trends, Thematic Structure, and Leading Contributors

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Abstract - Electronic waste (e-waste) is one of the fastest-growing waste streams in the world, and the research addressing it has grown quickly across several disciplines without ever acquiring a clear account of its own composition. This study maps that research landscape for the period 2015 to 2025. We analysed 925 Scopus-indexed journal articles retrieved through a four-block Boolean string, working through a four-stage design that covers aim definition, data collection, analysis and visualisation, and interpretation. Publication and citation distributions were analysed in Microsoft Excel, and the keyword co-occurrence network was mapped in VOSviewer. All cleaning rules and mapping parameters are reported so that the analysis can be repeated. Annual output rose from 38 articles in 2015 to 143 in 2025. The co-word analysis returned four thematic clusters: sustainability and waste management, behavioural determinants of recycling, environmental exposure and monitoring, and human health and toxicological effects. Behaviour-related keywords occupy a well-connected position in the network but form a comparatively small part of it, and consumer-behaviour studies account for 142 of the 925 records. Output is concentrated by geography, by institution and by publication outlet. What the study maps is the field's conceptual structure; its intellectual structure would require citation-based techniques we did not use.

Key Words: e-waste, WEEE, recycling, bibliometric analysis, co-word analysis, VOSviewer.

1. INTRODUCTION

The rapid proliferation of electrical and electronic equipment, coupled with shortening product life cycles and accelerating rates of technological obsolescence, has made electronic waste (e-waste), or waste electrical and electronic equipment (WEEE), one of the fastest-growing waste streams in the world (Forti et al., 2020). Discarded devices such as mobile phones, laptops, televisions and household appliances contain hazardous substances, including lead, mercury, cadmium and brominated flame retardants, that pose serious risks to human health and the environment when they are improperly disposed of in landfills, incinerated, or handled through informal recycling channels. At the same time, these end-of-life products embody scarce and valuable secondary materials whose recovery is central to the transition toward a circular economy. Effective e-waste management has therefore become a pressing concern for governments, manufacturers, recyclers and researchers worldwide (Islam et al., 2021).

Technological and infrastructural solutions matter, but e-waste management is a multidisciplinary problem in a fairly deep sense. Environmental chemists document contamination pathways. Toxicologists measure human exposure. Operations and supply-chain researchers design reverse-logistics networks, policy analysts assess extended producer responsibility, and behavioural scientists ask why consumers do or do not return their end-of-life devices. These communities publish in different outlets, cite different literatures and use methods that do not readily translate between them. The field has grown quickly without ever developing a shared account of its own structure.

That creates a practical difficulty for anyone entering the field. It is hard to establish which themes dominate, which have matured and which remain peripheral, or to identify the outlets, institutions and geographies that shape the available evidence. Bibliometric analysis is designed for exactly this problem. By treating publications, keywords, authors and citations as countable units, it produces a reproducible description of a field's size, growth, thematic composition and concentration,

and so establishes the context within which narrower syntheses can be positioned (Donthu et al., 2021; Phulwani et al., 2020).

Accordingly, this study maps the research landscape of e-waste recycling published between 2015 and 2025. It is deliberately a study of the field's composition, not of its substantive findings: it establishes what the literature consists of and how it is organised, and identifies which of its components merit dedicated synthesis. A companion study reports a systematic review of the behavioural sub-field identified here. The analysis is guided by five research questions:

One framing point should be stated at the outset, because it bounds every claim that follows. This is a bibliometric, science-mapping study, not a scoping review. It does not chart evidence against protocol-driven eligibility criteria in the manner PRISMA-ScR requires, and it makes no claim to synthesise findings. Equally, the analyses reported here are performance indicators and co-word mapping, which reveal a field's conceptual structure the relationships among the concepts it studies. They do not reveal its intellectual structure, which is established through citation-based techniques such as co-citation analysis and bibliographic coupling and is not attempted here. The title and the claims throughout are scoped accordingly.

- RQ1. How has scholarly output on e-waste recycling evolved between 2015 and 2025?
- RQ2. What are the predominant research themes, and how are they related within the keyword co-occurrence network?
- RQ3. Which authors, institutions and countries are the most prolific and the most cited contributors to the field's output?
- RQ4. Which journals serve as the primary outlets for this research?
- RQ5. Which documents are the most cited, and what contributions have they made?

The remainder of the paper is organised as follows. Section 2 justifies the choice of bibliometric analysis over the alternative review methodologies, sets out the seven-step protocol

followed, and describes corpus construction, cleaning and the indicators applied. Section 3 reports the results for each research question in turn. Section 4 discusses the structural picture that emerges, Sec. 5 draws conclusions and implications, and Sec. 6 sets out the limitations of the analysis across coverage, tooling and quantification.

2. MATERIALS AND METHODS

2.1 Choice of review methodology

Three established approaches were available for synthesising this literature, and the choice among them is determined by the

scope of the question, the size of the retrievable corpus and the type of inference sought (Passas, 2024). Meta-analysis pools effect sizes across studies to estimate the magnitude and direction of a relationship, and requires methodological and contextual homogeneity across the pooled studies. Systematic literature review synthesises findings qualitatively and is best suited to a narrowly bounded question and a small, manageable set of studies. Bibliometric analysis summarises large volumes of records quantitatively to reveal a field's structure, trends and constituents, and is appropriate where the review question is broad and the corpus large (Donthu et al., 2021; Snyder, 2019). Table 1 sets out the comparison.

Table -1: Comparison of review methodologies and the rationale for the present design.

Criterion	Bibliometric analysis	Meta-analysis	Systematic literature review
Primary goal	Summarise large volumes of records to reveal a field's trends, structure and constituents	Pool empirical effect sizes to estimate the strength and direction of relationships	Synthesise and interpret the substantive findings of a defined set of studies
Appropriate when	The review question is broad and the retrievable corpus is large	Studies are homogeneous in design, population and measurement	The question is narrow and the eligible set is small and manageable
Inappropriate when	The question is specific and the dataset small	Studies are heterogeneous, or few high-quality studies exist	The review is broad and the dataset large
Scope	Broad	Broad or specific	Specific
Dataset size	Large (hundreds to thousands of records)	Large or adequate	Small (tens of studies)
Mode of analysis	Quantitative, with qualitative interpretation of clusters and themes	Quantitative only	Qualitative synthesis
Fit to the present study	Selected. The question how the e-waste recycling field is structured is broad, and the retrievable corpus (925 records) is large and heterogeneous in discipline and design	Not applicable. The corpus spans toxicological, engineering, operations-research and behavioural designs with no common effect size	Applied separately. The behavioural sub-field identified here is narrow and small enough for qualitative synthesis, and is treated in a companion systematic review

Note: Comparison adapted from Passas (2024) and Donthu et al. (2021). The three approaches are complementary rather than competing; the present study and its companion systematic review apply the first and third respectively to the same domain at different levels of resolution.

This reasoning also explains why the present study and its companion review are reported separately rather than combined. A single hybrid design would require one corpus to serve two incompatible purposes: a large, deliberately inclusive set for structural mapping, and a small, tightly bounded set for substantive synthesis. Reporting them separately allows each to use the corpus its method requires, and allows the boundary between them to be stated explicitly rather than blurred.

2.2 Research design and analytical protocol

The study applies bibliometric analysis, a quantitative technique that uses the bibliographic attributes of publications year, keywords, authorship, affiliation, source and citation counts to describe the structure and evolution of a research domain (Donthu et al., 2021; Zupic and Čater, 2015). Bibliometric analysis measures the scientific output of a field and examines how its intellectual, social and conceptual structures have evolved through the relationships among its constituent items papers, authors, keywords, journals, institutions and countries (Öztürk et al., 2024). The design is informed by prior bibliometric treatments of recycling and e-waste research (Phulwani et al., 2020; Islam et al., 2021).

Two considerations govern the design. The first is the fit between the research aim, the research questions and the analyses performed. Where that fit is absent, a study risks conducting technically competent analyses that are disconnected from its stated objective (Öztürk et al., 2024). Each research question stated in Sec. 1 is therefore matched in Table 6 to the specific indicator or technique that answers it. The second is the requirement that the procedure be replicable: every decision affecting which records enter the corpus and how they are analysed is reported explicitly, so that another researcher executing the same steps would obtain the same dataset.

Execution followed the four-stage design proposed by Öztürk et al. (2024) defining the research aim, collecting the data, analysing and visualising it, and interpreting the findings with the operational steps within each stage drawn from Passas (2024). Adopting an explicit, published protocol makes each decision point visible and the procedure reproducible. Table 2 maps the stages and steps to the decisions taken in this study, the tools used and the section in which the outcome is reported.

Table -2: The four-stage bibliometric research design and its constituent steps, as applied in this study.

Stage	Step	Decisions taken in this study	Tools	Reported in
1. Defining the aim of the research	1.1 Aim, expected results and research questions	Aim fixed as mapping the research landscape of e-waste recycling 2015–2025; five research questions specified; unit of analysis fixed as the bibliographic record	-	Section 1
	1.2 Scope and focus of the analysis	Focus set on presenting the field's overall structure; performance analysis and co-word science mapping selected as the scope	-	Sections 1, 2.5
2. Collecting data on the relevant literature	2.1 Selecting the database	Scopus selected and assessed against six database-selection criteria; single-database design adopted deliberately rather than by default	Scopus	Section 2.3; Table 3
	2.2 Identifying search terms	Topic-based four-block Boolean string executed against title, abstract and keyword fields; truncation and phrase operators applied within blocks	Scopus	Section 2.3; Table 4

Stage	Step	Decisions taken in this study	Tools	Reported in
	2.3 Filtering	Language, document-type and publication-year criteria applied; titles and abstracts of retained records screened for domain relevance	Scopus	Section 2.4; Table 5
	2.4 Downloading the dataset	Full record and cited references exported in CSV and RIS formats compatible with the analysis software	Scopus export	Section 2.4
3. Analysis and visualisation	3.1 Preprocessing and cleaning	Duplicates removed; author names, affiliation strings and keyword variants standardised through a thesaurus file	Microsoft Excel; VOSviewer thesaurus	Section 2.4; Fig. 1
	3.2 Identifying the techniques	Performance analysis selected for RQ1 and RQ3–RQ5; co-word analysis selected for RQ2; co-citation, bibliographic coupling and co-authorship considered and not applied	-	Section 2.5; Fig. 2; Table 6
	3.3 Analysing and visualising	Annual output, author, institution, country, source and citation distributions computed; co-occurrence network constructed on the 20 keywords with the highest total link strength	VOSviewer 1.6.20; Microsoft Excel; iipmaps	Section 3; Figs. 3–8
4. Interpreting the findings and results	4.1 Sensemaking and interpretation	Findings interpreted through the scanning–sensing–substantiating sequence rather than described; cluster labels assigned by inspection of constituent keywords	-	Section 4
	4.2 Implications and research agenda	Structural findings related to the field's gaps; limitations of coverage, tooling and quantification stated; future bibliometric directions specified	-	Sections 5, 6

Note: Stage structure follows Öztürk et al. (2024); step detail follows Passas (2024). The right-hand column records where each step's output appears, so that every reported result can be traced to the procedural decision that produced it.

2.3 Database selection and search strategy

Database selection is consequential rather than administrative: indexing policies differ across sources, and the choice

determines which literature can enter the corpus at all. Scopus was therefore assessed against the six criteria Öztürk et al. (2024) propose for database selection in bibliometric research, reported in Table 3.

Table -3: Assessment of Scopus against the database-selection criteria for bibliometric research.

Selection criterion	Assessment for the present study
Number of journals covered for the research field	E-waste research spans environmental science, engineering, public health, operations management and consumer behaviour. Scopus indexes all of these, which a discipline-specific database would not. Coverage breadth is the decisive criterion for an interdisciplinary field.
Accessibility of the database	Full institutional access available throughout the retrieval period, permitting complete record export rather than sampled access.
Journal impact factors and field-leading potential	Scopus supplies CiteScore and subject-category quartile data at source level, which are used to characterise publication outlets in Sec. 3.4.
Ability to download data in a compatible format	Records exported in CSV and RIS with full record and cited references, both directly readable by VOSviewer and Microsoft Excel.
Ability to filter data in line with the research questions	Native filters for publication year, document type and language allowed the inclusion criteria in Table 5 to be applied within the database rather than manually after export.
Number of records exportable	The full corpus of 925 records was exportable in a single operation, avoiding the batching and re-merging that introduces error.

Note: Criteria from Öztürk et al. (2024), after Öztürk (2021).

We used a single database by choice, not by default. Reviewers of bibliometric work often ask for more than one, but multi-database designs are not automatically better. Coverage of business, management and environmental journals overlaps heavily between Scopus and Web of Science, so the same search terms return largely the same records. The exported files also differ in field structure and sequence, which makes integration awkward and duplication hard to resolve cleanly (Öztürk et al., 2024). Where de-duplication across sources is imperfect it inflates counts and distorts the co-occurrence weights the thematic analysis depends on. We judged metadata consistency within one source more valuable here than a marginal gain in coverage. Section 6.1 addresses the coverage risk that decision leaves behind.

The search was topic-based rather than author- or journal-based, since the object of study is a research field and not the output of any particular producer. Four conceptual blocks were combined with the AND operator: (i) e-waste terminology and its synonyms; (ii) recycling, take-back and disposal terms; (iii) consumer, household and population terms; and (iv) determinant, outcome and behavioural terms. Within each block, synonyms and truncated variants were combined with OR to maximise recall. Small changes to a string of this kind, such as adding a term or removing a truncation, can alter the retrieved set substantially and with it how well the corpus represents the field (Öztürk et al., 2024). Table 4 therefore reports the string in full so that it can be reproduced exactly. It was run against the title, abstract and keyword fields (TITLE-ABS-KEY) on a single date, so that the retrieved set would not drift during the search.

Table -4: Search strategy used to construct the bibliometric corpus.

Element	Specification
Search database	Scopus (Elsevier)
Search fields	TITLE-ABS-KEY article title, abstract, author keywords and index keywords
Search query	TITLE-ABS-KEY (("electronic waste" OR "e-waste" OR ewaste OR WEEE OR "waste electrical and electronic equipment" OR "end-of-life electronic*" OR "electronic scrap" OR "e-scrap") AND (recycl* OR "take-back" OR takeback OR "collection system*" OR "collection scheme*" OR dispo* OR return*) AND (consumer* OR household* OR resident* OR citizen* OR individual* OR user* OR public) AND (intention* OR "behavioral intention*" OR "recycling intention*" OR determinant* OR antecedent* OR predictor* OR factor* OR driver* OR

Element	Specification
	motivat* OR influenc* OR barri* OR facilit* OR attitude* OR "subjective norm*" OR "social norm*" OR "perceived behavioral control" OR PBC OR awareness OR knowledge OR "environmental concern" OR trust OR habit* OR convenience OR incentive* OR "policy effectiveness" OR perception* OR belief* OR willingness))
Block 1 domain	e-waste terminology and synonyms
Block 2 activity	recycling, take-back, collection and disposal terms
Block 3 population	consumer, household, resident, citizen, individual, user, public
Block 4 focus	determinant, antecedent, driver, barrier, attitude, norm, awareness, perception and willingness terms
Publication year	2015–2025
Document type	Journal articles only LIMIT-TO (DOCTYPE , "ar")
Language	English only LIMIT-TO (LANGUAGE , "English")
Rationale for Block 1	Defines the waste stream. Synonyms and orthographic variants are required because no single term is standard across the environmental, engineering and management literatures
Rationale for Block 2	Defines the activity of interest and excludes records concerned with e-waste generation or composition alone
Rationale for Block 3	Locates the record at the level of individuals and populations, excluding purely firm-level or municipal-system studies
Rationale for Block 4	Requires a determinant, outcome or perception term, ensuring retrieved records examine causes, correlates or consequences rather than reporting descriptive statistics alone
Records retrieved	2,063 before database limits; 925 unique records after limits and de-duplication

Note: The four blocks are combined with AND; terms within each block are combined with OR. Asterisks denote right-hand truncation. Because Block 4 admits general terms such as factor*, influenc*, awareness and perception*, the string retrieves not only consumer-behaviour studies but also environmental-exposure and health studies examining factors affecting populations near e-waste sites. This behaviour of the string is intentional for a field-mapping exercise and is reflected in the thematic structure reported in Sec. 3.2.

2.4 Database limits, corpus construction and preprocessing

Even a carefully specified string returns records outside the intended scope, and those records affect both the validity of the analysis and its results. We therefore set inclusion and exclusion criteria in advance and applied them to the retrieved

set. Each criterion rests on either a practical justification, such as database or language, or a methodological one, such as document type or time window. Saying which applies to each criterion is what allows a reader to judge whether the resulting corpus represents the field (Öztürk et al., 2024). Table 5 reports the criteria.

Table -5: Inclusion and exclusion criteria applied in constructing the corpus.

Criterion	Applied in this study	Justification
Publication years	2015–2025 inclusive; earlier records excluded	Methodological the window captures the period in which e-waste became a distinct research field and keeps the growth analysis in RQ1 interpretable
Document types	Journal articles only; conference papers, book chapters, editorials, notes and review articles excluded	Methodological articles carry a consistent peer-review threshold; proceedings duplicate content later issued as articles; review articles attract atypically high citation counts that would distort the impact analysis in RQ5
Language	English only	Practical required for the keyword harmonisation on which the co-word analysis in RQ2 depends; the resulting language bias is stated in Sec. 6.1
Research fields	No subject-area restriction applied	Methodological restricting to a subject category would have pre-imposed a disciplinary boundary on a field whose interdisciplinarity is itself a finding (Section 3.2)
Affiliations, countries and sources	No restriction applied	Methodological institutional, geographic and source distributions are results to be reported under RQ3 and RQ4, not filters to be imposed
Duplicate records	Three duplicate records identified and removed	Practical duplicates inflate output counts and distort keyword co-occurrence weights
Content and scope	Titles, abstracts and keywords screened; records outside the e-waste domain excluded	Methodological databases cannot fully exclude off-topic records through filters alone, so manual screening is required to secure domain relevance

Note: Criteria structure follows Öztürk et al. (2024). Note that this study deliberately applies no subject-area, affiliation or country restriction: those dimensions are treated as findings rather than filters.

Bibliometric corpus construction followed a transparent identification, database-refinement, relevance-screening and preprocessing procedure, illustrated in Fig. 1. One distinction runs through the account and is worth stating at the outset. Applying database limits is not the same operation as screening records for relevance. The first is an automated restriction that Scopus executes against structured metadata fields. The second is a judgement made by the analyst about whether a record falls within the e-waste domain. Separating the two ensures that each stage of corpus construction is documented explicitly and can be reproduced, and it is why the 1,135 records dropped by the language, document-type and publication-year limits are recorded as removed by those limits rather than excluded by screening.

The initial retrieval returned 2,063 records. Applying the Scopus limits for language, document type and publication year

automatically removed 1,135 records before screening, leaving 928. De-duplication, performed in Scopus and confirmed by manual check, removed three records, leaving 925. Those 925 records were then assessed for eligibility by screening their titles, abstracts and keywords for relevance to the e-waste domain. No record was excluded at this stage: all 925 satisfied the domain criterion and were retained, yielding a final bibliometric corpus of 925 records. The arithmetic reconciles at each step: $2,063 - 1,135 = 928$; $928 - 3 = 925$; and $925 - 0 = 925$.

A nil exclusion at the relevance-screening stage deserves an explanation. It follows from the precision of the four-block string, which requires an e-waste term, a recycling or disposal term, a population term and a determinant or outcome term all at once. A record that satisfies all four is, by construction, within the e-waste domain. The zero does not mean the

screening step was skipped, and it does not mean the corpus was narrowed to consumer-behaviour research. The criterion applied was domain relevance, not topical focus, so

environmental-exposure and toxicological records that satisfied the string were retained. Section 2.7 examines what that implies for the results.

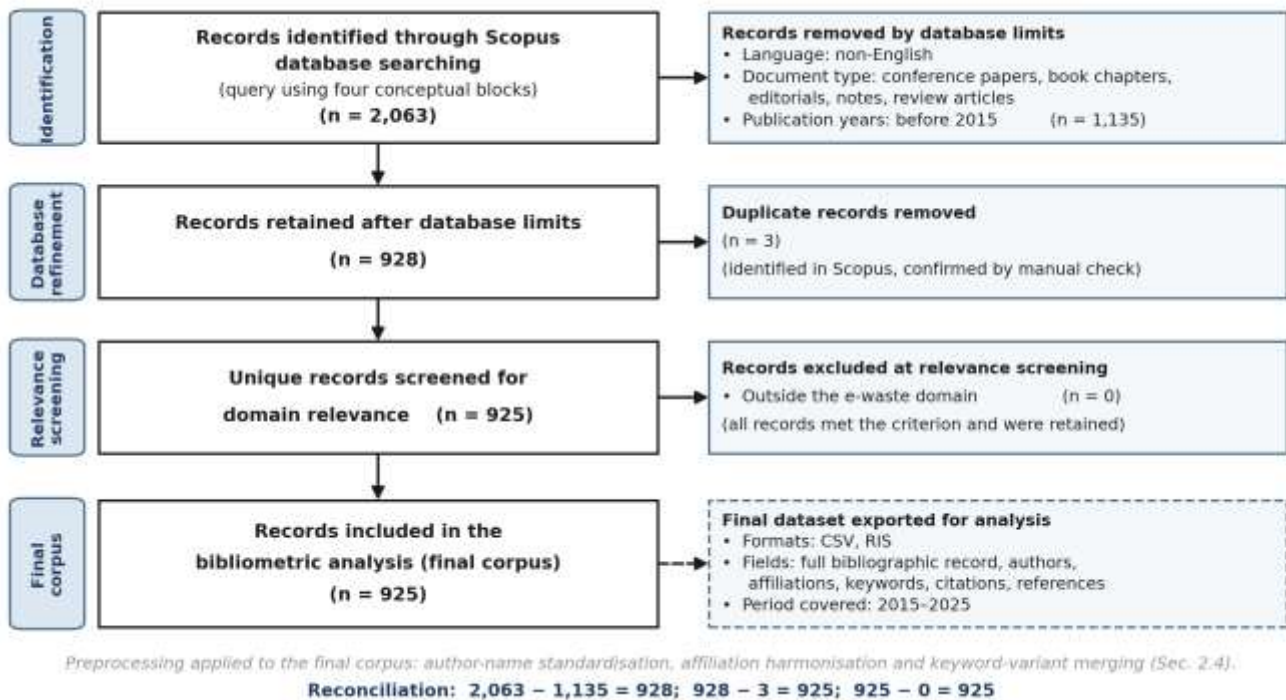


Fig -1: Bibliometric corpus identification and refinement flow diagram, from initial Scopus retrieval to the final corpus of 925 records.

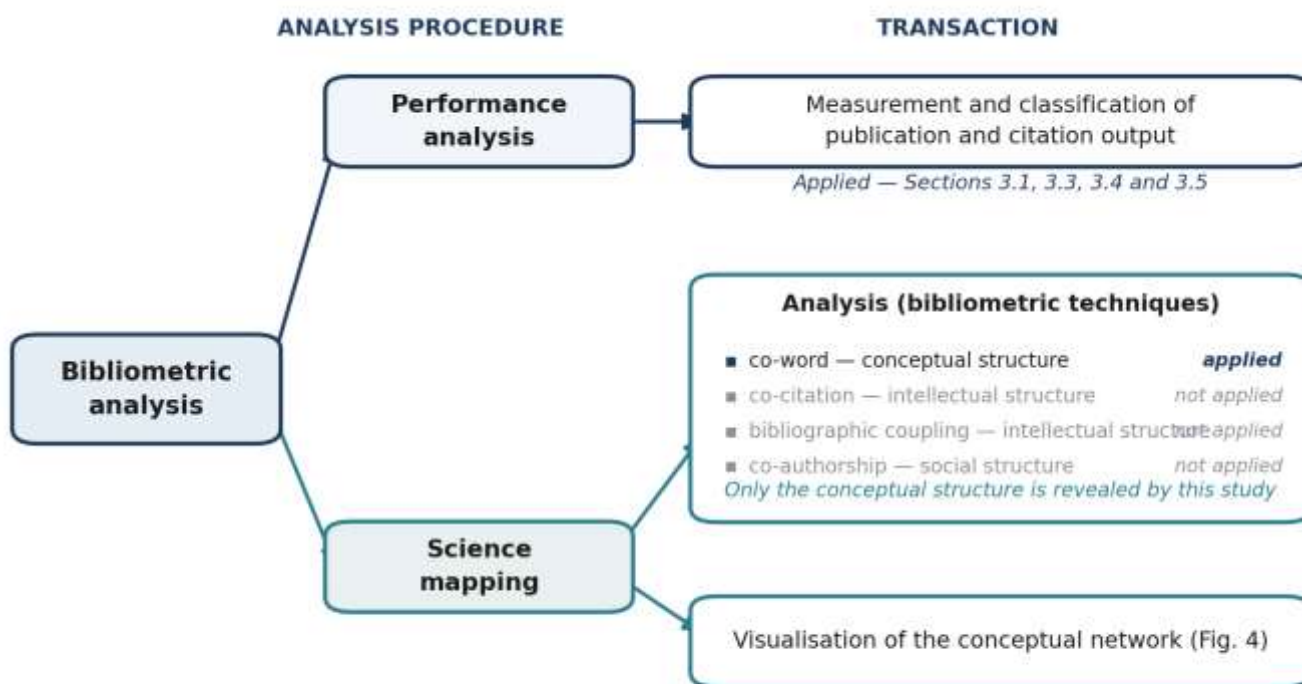
Raw bibliographic exports are not ready for analysis, and how they are cleaned has a real effect on the results (Passas, 2024). Three preprocessing operations were applied. First, author names were standardised. Variant renderings of the same author, arising from inconsistent initialisation or transliteration, were reconciled against Scopus author identifiers and affiliation history, and the remaining ambiguous cases involving common surnames were checked individually. Second, affiliation strings were harmonised. A single institution often appears under several forms in the raw export, including its English and local-language names, its abbreviation, and its constituent schools or laboratories, and leaving these unmerged would fragment its publication count across multiple entries.

Third, and most consequential for the thematic analysis, keyword variants were merged through a thesaurus file applied at import to VOSviewer. Terms differing only in orthography, number or hyphenation were mapped to a single canonical form. The field's central term is the clearest case: it appears in

the raw export as separate entries distinguished only by hyphenation and spacing. Without this step a term's occurrences and link strength are divided across its variants, which understates its centrality and can split what is conceptually one node across two clusters. Substantively distinct terms were left alone. We made no attempt to consolidate near-synonyms, since deciding that two such terms are equivalent is an interpretive judgement that would embed our own expectations in the cluster solution.

2.5 Analytical procedures and indicators

Bibliometric analysis works through two complementary procedures. Performance analysis measures and classifies the publication and citation output of a field's constituents, giving a general view of productivity and impact. Science mapping examines the relationships among those constituents, and involves two linked transactions: computing similarity matrices between items, then visualising the resulting networks (Öztürk et al., 2024; Cobo et al., 2011). Fig. 2 sets out the procedure as applied here.



Adapted from Öztürk et al. (2024), Cobo et al. (2011), Zupic and Čater (2015) and Donthu et al. (2021)

Fig -2: Analysis procedure applied in this study, showing which bibliometric techniques were employed and which structures of the field they reveal.

We applied both procedures. That is worth stating, because bibliometric papers frequently stop at performance analysis, ranking authors, institutions and journals without examining how they relate to one another, which on its own cannot describe the structure or dynamics of a field (Öztürk et al., 2024). Here, performance analysis answers RQ1 and RQ3 to RQ5, while science mapping, in the form of co-word analysis, answers RQ2.

Which structure of a field becomes visible depends on which mapping technique is used. Co-authorship analysis reveals social structure, meaning the collaboration network among authors, institutions and countries. Co-citation analysis and

bibliographic coupling reveal intellectual structure, the first through a field's historical foundations and the second through its current thematic fronts. Co-word analysis reveals conceptual structure, the relationships among the concepts a field studies. Since our aim is to establish the thematic composition of e-waste recycling research, co-word analysis on title, abstract and keyword data is the technique that fits, and it is the one we applied. The consequence is that this study reveals the field's conceptual structure and not its social or intellectual structure, a scoping decision the paper's title reflects. Section 6.4 examines what that leaves undone. Table 6 records which indicators and techniques were applied, which were considered and set aside, and which research question each addresses.

Table -6: Bibliometric indicators and science-mapping techniques considered and applied.

Family	Indicator or technique	What it measures	Structure or output revealed	Applied	RQ
Performance publication	Total publications (TP)	Number of corpus records attributable to an author, institution, country or source	Productivity	Yes	RQ1, RQ3, RQ4
Performance publication	Annual output	Distribution of records across the publication years	Growth trajectory	Yes	RQ1
Performance citation	Total citations (TC)	Cumulative Scopus citation count of an entity's corpus records	Impact	Yes	RQ4, RQ5
Performance citation	Document-level citation count	Citations accruing to an individual publication	Influence ranking	Yes	RQ5
Performance combined	h-index	Joint measure of an author's productivity and citation impact	Author standing	Yes (context only)	RQ3
Performance combined	CiteScore and subject quartile	Source-level average citation impact and category ranking	Outlet standing	Yes	RQ4
Performance combined	Collaboration index / coefficient	Extent and intensity of co-authorship across the corpus	Collaboration intensity	No	-
Science mapping	Co-word (keyword co-occurrence) analysis	Joint appearance of terms within records	Conceptual network	Yes	RQ2
Science mapping	Total link strength	Aggregate co-occurrence weight between a keyword and all others; a measure of structural centrality rather than raw frequency	Conceptual centrality	Yes	RQ2
Science mapping	Co-citation analysis	Frequency with which two documents are cited together	Citation network historical foundations	No	-
Science mapping	Bibliographic coupling	Shared references between citing documents	Citation network current thematic fronts	No	-

Family	Indicator or technique	What it measures	Structure or output revealed	Applied	RQ
Science mapping	Co-authorship analysis	Collaboration networks among authors, institutions and countries	Collaboration network social structure	No	-

Note: Taxonomy follows Öztürk et al. (2024), Passas (2024) and Van Raan (2014). Techniques marked 'No' were considered during technique selection (Table 2, Step 3.2) and not applied; the consequences are examined in Sec. 6.4. Note in particular that country and institutional distributions are reported as productivity counts rather than as co-authorship networks, and therefore describe where research is produced rather than how its producers are connected.

Three indicators recur throughout the results and need defining. Total publications (TP) is the number of corpus records attributable to an entity. Total citations (TC) is the cumulative Scopus citation count of those records. Total link strength is a VOSviewer measure of the aggregate co-occurrence weight between a keyword and every other keyword in the map. Because it reflects how widely a term connects to the rest of the network, not how often it appears, it captures structural centrality rather than raw frequency, and it is the ranking criterion used in Sec. 3.2.

2.6 Bibliometric parameters and reproducibility

The four-cluster result in Sec. 3.2 depends on decisions taken during keyword processing and network construction, so Table 7 reports those decisions. Keyword analysis is sensitive to them: the thesaurus determines whether variants of one concept are counted once or several times, and the harmonisation rules determine how author and affiliation strings are consolidated. Reporting them allows the cluster solution to be assessed and repeated.

Table -7: Bibliometric parameters, cleaning rules and software settings.

Parameter	Setting applied in this study
Bibliographic source and export	Scopus; full record and cited references exported in CSV and RIS in a single session
Exported fields	Authors, author identifiers, title, year, source title, volume/issue/pages, DOI, affiliations, abstract, author keywords, index keywords, citation count, publisher, language, document type
Analysis software	VOSviewer 1.6.20 for co-word mapping; Microsoft Excel for performance analysis; iipmaps.com for the geographic distribution map
Keywords analysed and reported	Top 20 by total link strength
Normalisation method	Association strength (VOSviewer default)
Thesaurus file	Applied at import to merge orthographic and morphological variants
Singular / plural harmonisation	Applied: plural forms mapped to the singular canonical term
Spelling and hyphenation variants	Applied: variants differing only in hyphenation, spacing or orthography mapped to one form, including the variants of the field's central term
Abbreviation merging	Applied: WEEE mapped to 'waste electrical and electronic equipment'; other established abbreviations mapped to their expanded forms
Generic term removal	Not applied no terms were removed as generic, since removal decisions would embed the analyst's view of what is peripheral into the cluster solution
Near-synonym consolidation	Not applied substantively distinct terms were not merged, as equivalence judgements would import interpretation into the data
Author name disambiguation	Variant renderings reconciled against Scopus author identifiers and affiliation history; ambiguous high-frequency surnames checked individually
Affiliation harmonisation	Institution name variants English and local-language forms, abbreviations, constituent schools and laboratories consolidated to a single parent entry

Note: The table reports the cleaning rules and software settings governing the co-word analysis. The cleaned dataset and the thesaurus file will be deposited as supplementary material so that the keyword network can be regenerated.

2.7 Scope of the corpus

One methodological point needs stating plainly, because it governs how the results should be read. The retrieved corpus is not a set of consumer-behaviour studies. The search string requires an e-waste term, a recycling or disposal term, a population term and a determinant or outcome term, but the last two blocks can be satisfied by a wide range of research designs. A toxicological study of the factors influencing blood lead concentrations among residents near a dismantling site satisfies every block, and so does a survey-based test of the determinants of household recycling intention.

The corpus therefore represents the e-waste recycling research landscape as delimited by the predefined search strategy, within which consumer behaviour forms one identifiable cluster among four. Because the string requires a population term and a determinant or outcome term simultaneously, it retrieves the portion of the literature framed in those terms rather than the entire global e-waste recycling literature. All results reported below are properties of that corpus, and references to the field should be read with this qualification in place. Where the behavioural sub-field is specifically at issue, it is named as such and its boundaries are stated.

3. RESULTS

The results are organised by research question and draw on both procedures set out in Fig. 2. Sections 3.1, 3.3, 3.4 and 3.5 report the performance analysis, describing the productivity and impact of the field's constituents. Section 3.2 reports the science mapping, describing the conceptual structure that connects them. Throughout, the interpretive focus is on the field's overall structure: its current state, its trends, and the gaps these reveal. We do not attempt to trace period-by-period evolutionary change or to derive a process framework, both of which would call for a different analytical design (Öztürk et al., 2024).

3.1 Evolution of scholarly output (RQ1)

The evolution of scholarly output reflects increasing research attention to e-waste recycling across the environmental, technical, managerial, health and behavioural domains that make up the corpus. Tracking publication volume over time shows how far the research community has engaged with the problem and when that engagement intensified. Fig. 3 presents the annual series.

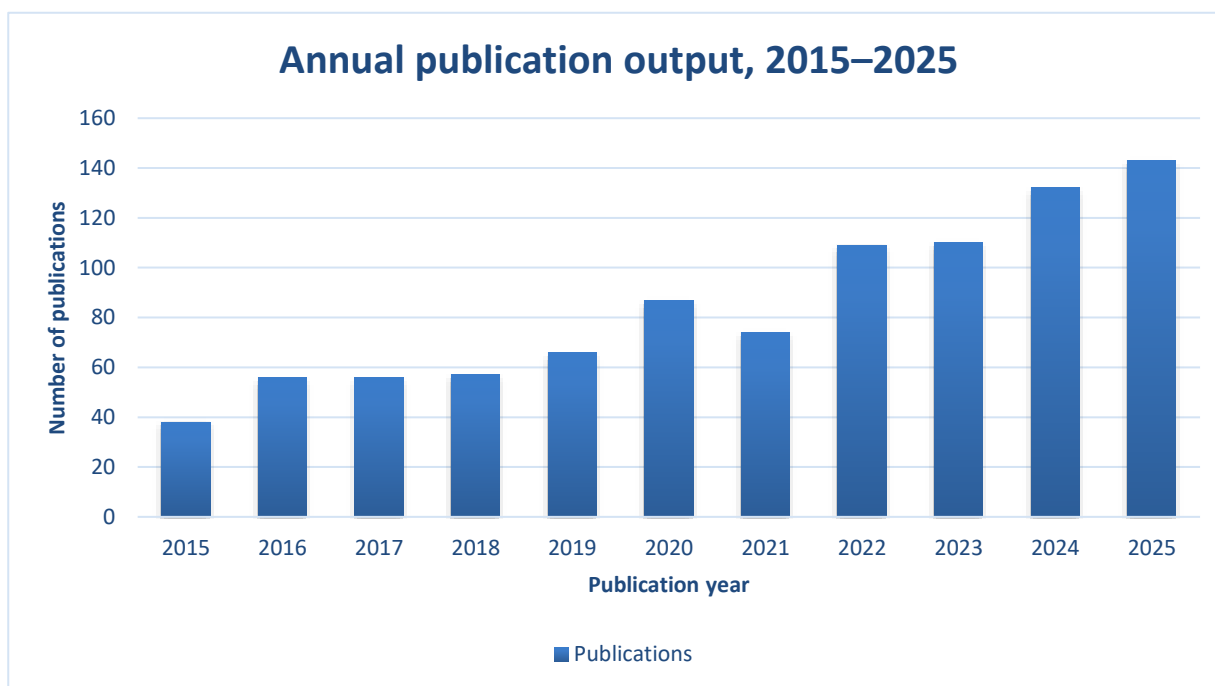


Fig -3: Annual publication output on e-waste recycling, 2015–2025 (n = 928 records retained after database limits).

Note: The annual series reports the 928 records retained after the database limits were applied. The three duplicate records subsequently removed could not be attributed to individual publication years, so they are not deducted from the annual counts. All other analyses in this paper use the final corpus of 925 records.

Figure 3 shows a clear upward trajectory in publications on e-waste recycling research between 2015 and 2025. Output began at 38 records in 2015 and grew steadily to 66 by 2019, before rising more sharply to 87 in 2020. A decline followed in 2021 (74 records), after which output expanded markedly, reaching 109 in 2022 and continuing to 132 in 2024 and 143 in 2025, the highest annual figure in the period. Annual output grew by more than 275% across the eleven years, and over 70% of the corpus was published from 2020 onwards. This growth coincides with escalating volumes of electronic waste and with the tightening of circular-economy and sustainability agendas over the same period.

Two features of this trajectory stand out. Growth has not been smooth: a temporary decline was observed in 2021, interrupting the otherwise upward publication trajectory. The data reported here do not identify the cause of that interruption, and no explanation is offered. Second, the continued increase toward the end of the observation period indicates that no publication plateau was evident within the study window.

Three qualifications limit what this trend can be taken to show. The first concerns the final year. Scopus indexes records continuously, so a search executed during or shortly after 2025 captures an incomplete year: articles published late in the year, and those from sources with slower indexing, will not yet appear. The figure of 143 for 2025 is therefore a lower bound conditional on the date of retrieval, and the 2024 to 2025 comparison should be read as provisional rather than as evidence of any particular rate of increase.

The second concerns what growth actually measures. Annual output in a single field rises partly because the field attracts more attention and partly because scholarly publishing expands overall. Article volume, journal counts and database coverage have all grown across this period, so some of the increase reported here would show up in almost any domain. Showing that e-waste research has grown faster than publishing in general would mean normalising against total Scopus output over the same window, which we did not do. The trend documents absolute expansion in the field's output. It does not establish disproportionate growth relative to science as a whole, and still less increasing scientific importance, which is not something citation and publication counts can measure.

The third concerns coverage. Growth in a database-derived series partly reflects growth in the database itself, since Scopus has added sources across the period and back-indexing is uneven. Some part of the rise from 38 to 143 is attributable to more of the existing literature becoming visible rather than to more literature being produced.

3.2 Thematic structure of the field (RQ2)

Research on e-waste recycling has developed a range of interconnected themes, reflecting the multidimensional nature of the subject. To identify the predominant themes and how they relate to one another, we ran a keyword co-occurrence analysis in VOSviewer. The analysis covered the 20 most frequently occurring keywords, ranked by total link strength, which VOSviewer grouped into four thematic clusters based on how often terms appeared together across the corpus. Fig. 4 presents the resulting network map and Table 8 summarises the clusters.

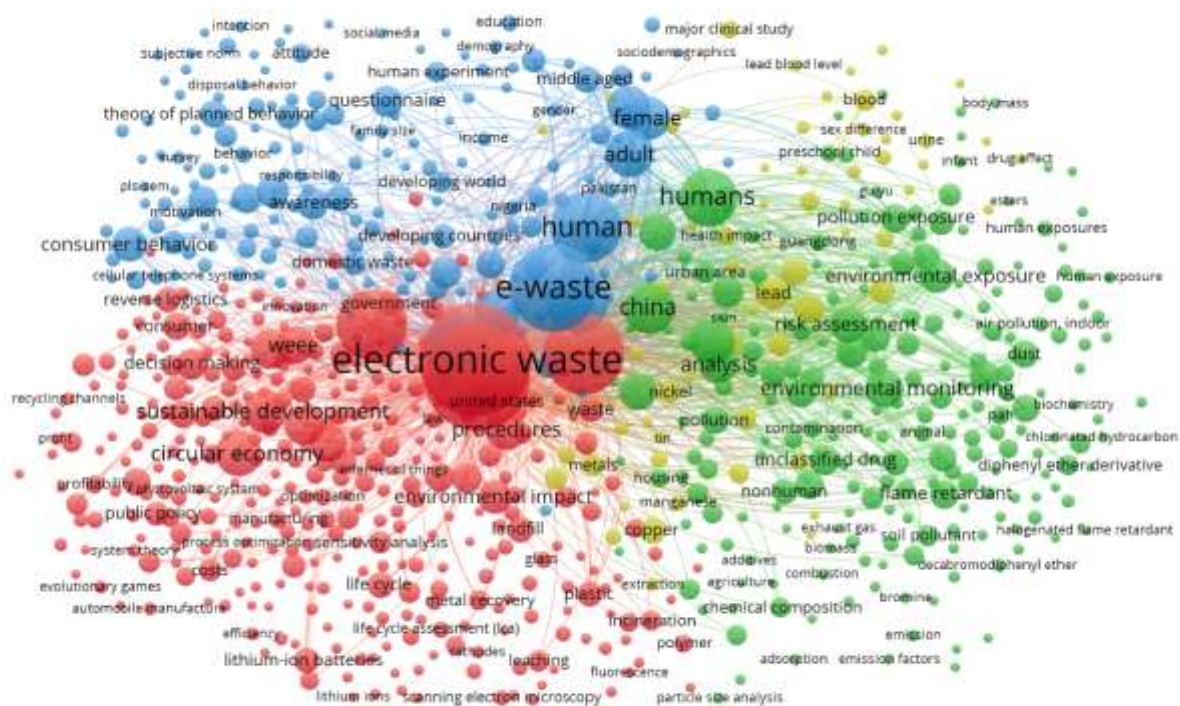


Fig -4: Keyword co-occurrence network of the corpus, showing four thematic clusters (top 20 keywords by total link strength).

Source: generated by the author(s) using VOSviewer.

In the network map, each node represents a keyword, and the size of a node is proportional to its occurrence frequency; the thickness and number of connecting lines reflect the strength of co-occurrence between terms, while the colour of each node denotes its cluster membership. “Electronic waste” (621 occurrences; total link strength 11,730), “recycling” (548; 10,572), “e-waste” (379; 7,207), and “waste management” (254; 4,963) emerged as the largest and most strongly connected nodes, positioned centrally in the map. Their centrality indicates that they function as the conceptual anchors of the field, linking the surrounding thematic domains. The four clusters distinguished by colour capture the managerial, behavioural, environmental, and health-related dimensions through which e-waste recycling has been studied.

The first cluster (red) represents the sustainability, circular-economy, and waste-management dimension. Anchored by “electronic waste,” “recycling,” and “waste management,” it encompasses terms such as “circular economy” (107; 1,291), “sustainable development” (92; 1,495), “reverse logistics,” “supply chain management,” “life cycle,” and “public policy” (30; 602). This cluster reflects the field’s concern with resource recovery, closed-loop systems, and the systemic and policy mechanisms that support sustainable e-waste management.

The second cluster (blue) captures the behavioural determinants of recycling, which are most central to the present review. It includes “consumer behavior” (61; 991), “awareness” (53; 1,146), “questionnaire” (51; 1,422), “decision

making” (49; 965), and “e-waste recycling” (69; 1,493), alongside demographic and survey-related terms such as “household,” “surveys,” and “cross-sectional study.” This cluster reflects the application of behavioural and survey-based approaches to understanding the antecedents of consumers’ recycling intentions and behaviour.

The third cluster (green) represents the environmental exposure and monitoring dimension, comprising “environmental monitoring” (73; 2,411), “environmental exposure” (63; 2,271), “risk assessment” (64; 1,968), “pollution exposure” (42; 1,495), and “flame retardant” (42; 1,417). These terms point to the ecological and contamination consequences of improper e-waste disposal, including the release of hazardous substances into environmental media.

The fourth cluster (yellow) concentrates on the human-health and toxicological effects of e-waste. It includes “lead” (54; 1,883), “health hazard” (51; 1,715), “health risk” (46; 1,586), “heavy metal” (46; 1,518), “cadmium” (39; 1,365), and related biomedical indicators such as “blood” and “mercury.” This cluster highlights the toxicological burden of e-waste contaminants on human health, particularly through exposure to heavy metals and persistent pollutants.

Two cautions apply to this map and govern how it should be read. The first concerns spatial position, which is not a measure of theoretical importance. Proximity and centrality reflect patterns of co-occurrence under the association-strength normalisation and the layout algorithm. A term sits at the centre

because it co-occurs with many others, not because the field treats it as foundational. Network centrality and substantive importance are different properties, and only the first is observable here. The second concerns total link strength, which measures how widely a keyword connects to the rest of the map. It is not a measure of research volume, citation impact or substantive significance. When we describe a cluster's share of link strength below, we are describing its extent within the co-occurrence network and making no wider claim.

Cluster labels were assigned through a set procedure rather than by impression. For each of the four clusters VOSviewer

returned, we ranked the constituent keywords by occurrence and by total link strength, then examined the highest-ranked terms together to identify the subject matter they share. A candidate label was drafted from that reading, checked against the full keyword membership for terms the label failed to accommodate, and revised where it did not fit. Two authors then reviewed the labels independently and resolved disagreements by discussion. The labels remain our interpretation of the cluster memberships and not a computed property of them. The memberships and link-strength values in Table 8 are reproducible; the labels are a reading of them. Table 8 reports the derivation for each cluster.

Table -8: Derivation of the four thematic clusters from the keyword co-occurrence analysis.

Cluster (colour)	Highest-ranked keywords (occurrences; total link strength)	Keywords in top 20	Cluster TLS	Label assigned
Cluster 1 (red)	electronic waste (621; 11,730); recycling (548; 10,572); e-waste (379; 7,207); waste management (254; 4,963); waste disposal (183; 4,033); circular economy (107; 1,291); sustainable development (92; 1,495)	7	41,291	Sustainability, circular economy and waste management the shared referent of the highest-ranked terms is resource recovery and the systems that deliver it
Cluster 2 (blue)	e-waste recycling (69; 1,493); consumer behavior (61; 991); awareness (53; 1,146); surveys (53; 1,122); questionnaire (51; 1,422); decision making (49; 965)	6	7,139	Behavioural determinants of recycling the cluster combines behavioural constructs with survey-instrument terms, indicating an individual-level, survey-based research design
Cluster 3 (green)	environmental monitoring (73; 2,411); risk assessment (64; 1,968); environmental exposure (63; 2,271); pollution exposure (42; 1,495); flame retardant (42; 1,417)	5	9,562	Environmental exposure and monitoring terms denote the measurement of contaminants in environmental media rather than their effects on people
Cluster 4 (yellow)	lead (54; 1,883); health hazard (51; 1,715); health risk (46; 1,586); heavy metal (46; 1,518); cadmium (39; 1,365)	5	8,067	Human health and toxicological effects specific contaminants appear alongside health-outcome terms, distinguishing this cluster from Cluster 3

Note: TLS, total link strength. Keywords listed are those among the 20 with the highest total link strength; cluster TLS is the sum for those keywords. Labels were assigned by the procedure described above and reviewed independently by two authors. Cluster colours correspond to Fig. 4.

Because total link strength quantifies how extensively a keyword connects to the rest of the network, the clusters can be compared on that measure. Fig. 5 reports each cluster's share of the aggregate link strength of the 20 leading keywords. Cluster 1 accounts for approximately 63% of the total, reflecting the

presence within it of the corpus's four highest-connectivity terms. Cluster 3 accounts for approximately 14%, Cluster 4 for approximately 12%, and Cluster 2 the behavioural cluster for approximately 11%.

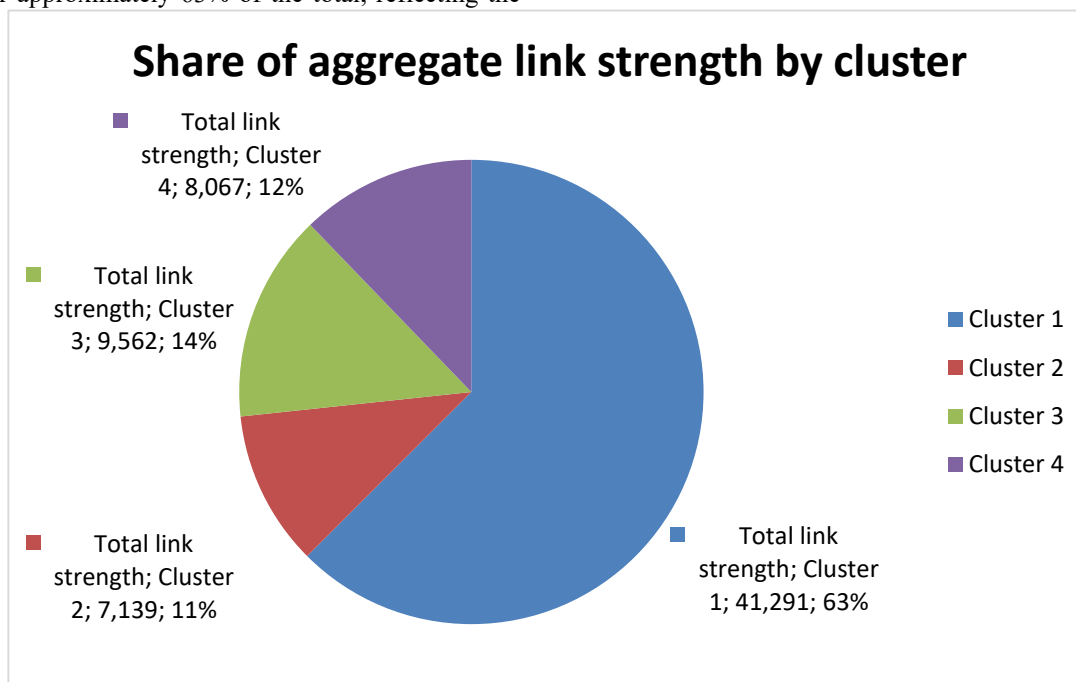


Fig -5: Share of aggregate total link strength by thematic cluster (top 20 keywords).

This distribution should be read carefully. It establishes that behaviour-related keywords form a smaller part of the co-occurrence network than the managerial, environmental or health components, even though they sit in a well-connected position within it. It does not establish that consumer behaviour constitutes 11% of the field, that behavioural research is 11%

as important, or that it receives 11% of scholarly attention. Link strength measures connectivity. Volume and importance are different quantities and need different evidence.

Volume can be measured directly, and doing so provides a second, independent estimate. Applying a behaviour-specific refinement to the corpus, which requires an explicit recycling

intention or behaviour outcome term together with a behavioural-construct or theory term, identifies 142 of the 925 records as consumer-behaviour studies, or roughly 15% of the corpus. The two estimates measure different things, so their rough agreement is informative rather than circular: the behavioural component is modest both in its keyword connectivity and in its share of records. Where we make claims below about the size of the behavioural literature, those rest on the article count and not on the link-strength share.

Taken together, the four clusters illustrate the breadth of scholarly interest in e-waste, spanning managerial and circular-economy concerns, behavioural determinants of recycling, environmental contamination, and human-health impacts. The behavioural cluster is well connected to the managerial cluster, which indicates that behavioural research is integrated into the field rather than isolated from it. At the same time, the strong links among the behavioural, managerial, environmental and health clusters underscore the interdisciplinary character of the field and the scope for integrative work connecting individual recycling behaviour to its wider environmental and public-health consequences.

3.3 Most prolific and most cited contributors (RQ3)

A point about terminology governs this section. Publication counts identify the most prolific contributors, citation counts the most cited, and collaboration measures the best connected. None of these is interchangeable with influence or leadership. An author who publishes most in a domain is its most prolific author, which says something about output and nothing about standing, and the same holds for institutions, countries and journals. Because this study applies performance analysis without co-authorship network analysis (Table 6), it can report productivity and citation indicators but not collaboration or

network centrality. We label the results accordingly and avoid claims of leadership or influence.

3.3.1 Most prolific authors

Table 9 reports the most prolific authors publishing in the e-waste recycling domain, with their publication records, citation totals, h-index values and institutional affiliations. These authors come from a range of countries and institutions, which reflects the international character of work in this area.

Among the top contributors, Li, J. from the China Metallurgical Group Corporation stands out with 493 publications, 25,662 citations, and an H-index of 88, making the most prolific author in the set. Similarly, Huo, X. from Jinan University, Guangzhou, records 195 publications, 9,771 citations, and an H-index of 58, while Zeng, L., also from Jinan University, contributes 163 publications, 10,440 citations, and an H-index of 59. Other highly prolific authors include Xu, X. from Shantou University Medical College (153 publications; 8,158 citations; H-index 56) and Wei, Y. from Guangzhou Medical University (120 publications; 6,656 citations; H-index 30), reflecting the strong concentration of highly cited scholars within Chinese institutions. Regional diversity is also evident: Lee, C. H. from National Dong Hwa University, Taiwan (144 publications; 2,194 citations), Nowakowski, P. from the Silesian University of Technology, Poland (24 publications; 1,025 citations), and Behdad, S. from the University of Florida, United States (138 publications; 4,423 citations) extend the field's reach beyond China. This diverse pool of authors reflects the interdisciplinary character of e-waste recycling research, with contributions spanning several continents and institutions. The variation in h-index and citation values reflects differences in career stage and disciplinary citation norms as much as anything specific to this field.

Table -9: The most prolific authors publishing in the e-waste recycling domain.

#	Author	Current affiliation	Country	TP	TC	H-index
1	Li, J.	China Metallurgical Group Corporation	China	493	25,662	88
2	Huo, X.	Jinan University, Guangzhou	China	195	9,771	58
3	Nowakowski, P.	Silesian University of Technology, Gliwice	Poland	24	1,025	13
4	Xu, X.	Shantou University Medical College, Shantou	China	153	8,158	56
5	Lee, C. H.	National Dong Hwa University, Shoufeng	Taiwan	144	2,194	27
6	Zeng, L.	Jinan University, Guangzhou	China	163	10,440	59
7	Guo, C.	Chinese Research Academy of Environmental Sciences, Beijing	China	50	622	16
8	Li, Z.	Chinese Research Academy of Environmental Sciences, Beijing	China	58	1,023	17
9	Wei, Y.	Guangzhou Medical University, Guangzhou	China	120	6,656	30
10	Behdad, S.	University of Florida, Gainesville	United States	138	4,423	30

Note: TP, total publications; TC, total citations; H-index as recorded in the author's Scopus profile. These indicators are whole-career values covering each author's entire Scopus record, not output within this corpus, and should be interpreted as measures of general standing rather than of contribution to e-waste recycling research specifically. Common surnames carry a residual risk of author-profile conflation; entries were checked against affiliation and subject area.

3.3.2 Most prolific institutions

Figure 6 reports the most prolific institutions in the corpus. They span several regions, which reflects the international distribution of research output on e-waste recycling.

The Chinese Academy of Sciences leads the field with 25 publications, followed by Jinan University with 21 and Tsinghua University with 19, underscoring the dominance of Chinese institutions in driving research output. The Ministry of Education of the People's Republic of China (16 publications) and the University of Chinese Academy of Sciences (13

publications) further reinforce this concentration. Notable contributions also come from institutions beyond China, including the University of Ghana (12 publications), Universiti Malaya, Malaysia (11 publications), and, with eight publications each, the University of Toronto, KU Leuven, and the University of Michigan, Ann Arbor. The spread across Asia, Europe, Africa and North America shows that output is not confined to one region, although the counts reported here describe where research is produced and not how its producers collaborate.

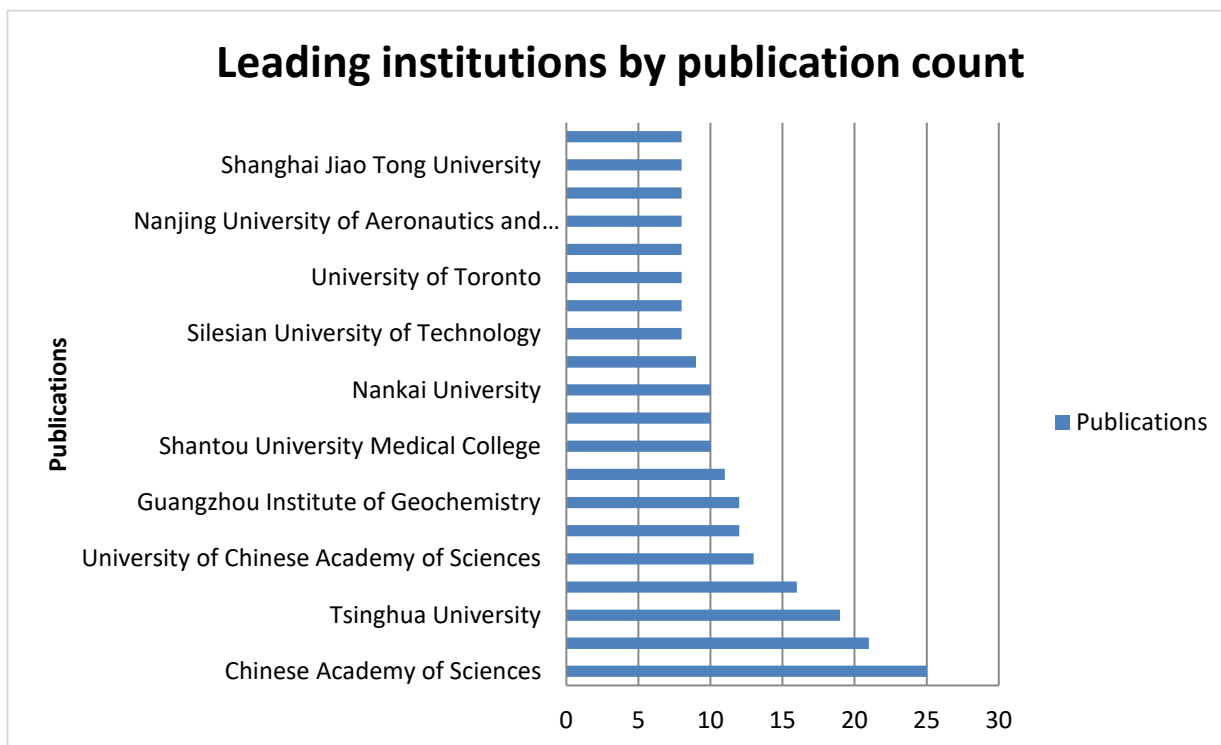


Fig -6: The ten most productive institutions by number of publications in the corpus.

The full ranking, including institutions outside the leading ten, appears in Table 10.

Table -10: The most prolific institutions in the corpus.

#	Affiliation	TP	#	Affiliation	TP
1	Chinese Academy of Sciences	25	11	Nankai University	10
2	Jinan University	21	12	Universidade Federal de Pernambuco	9
3	Tsinghua University	19	13	Silesian University of Technology	8
4	Ministry of Education of the People's Republic of China	16	14	Beijing Institute of Technology	8
5	University of Chinese Academy of Sciences	13	15	University of Toronto	8
6	University of Ghana	12	16	Sun Yat-Sen University	8
7	Guangzhou Institute of Geochemistry	12	17	Nanjing University of Aeronautics and Astronautics	8
8	Universiti Malaya	11	18	KU Leuven	8
9	Shantou University Medical College	10	19	Shanghai Jiao Tong University	8
10	Peking University	10	20	University of Michigan, Ann Arbor	8

Note: TP, total publications within the corpus (n = 925).

3.3.3 Most productive countries

Moreover, the global distribution of contributions demonstrates the international scope and collaborative nature of this field. Both developed and developing countries have made significant contributions, reflecting a shared commitment to addressing the challenges of e-waste recycling. Fig. 7 illustrates the most prominent countries or districts, restricted to those contributing at least 20 documents.

Figure 7 reports the counts for each qualifying country. China leads with 265 publications, roughly 29% of the corpus,

followed by India with 118 and the United States with 109. Malaysia contributes 47, Australia 38, Brazil 31 and Japan 29. Pakistan (26), Indonesia (25), Bangladesh (25), South Africa (20) and Ghana (20) complete the set of countries clearing the 20-document threshold. Germany and Italy also clear it; their counts are shown on the map. Because a co-authored paper is credited to every contributing country, these counts sum to more than the number of unique records, so each share describes coverage rather than a partition of the corpus.

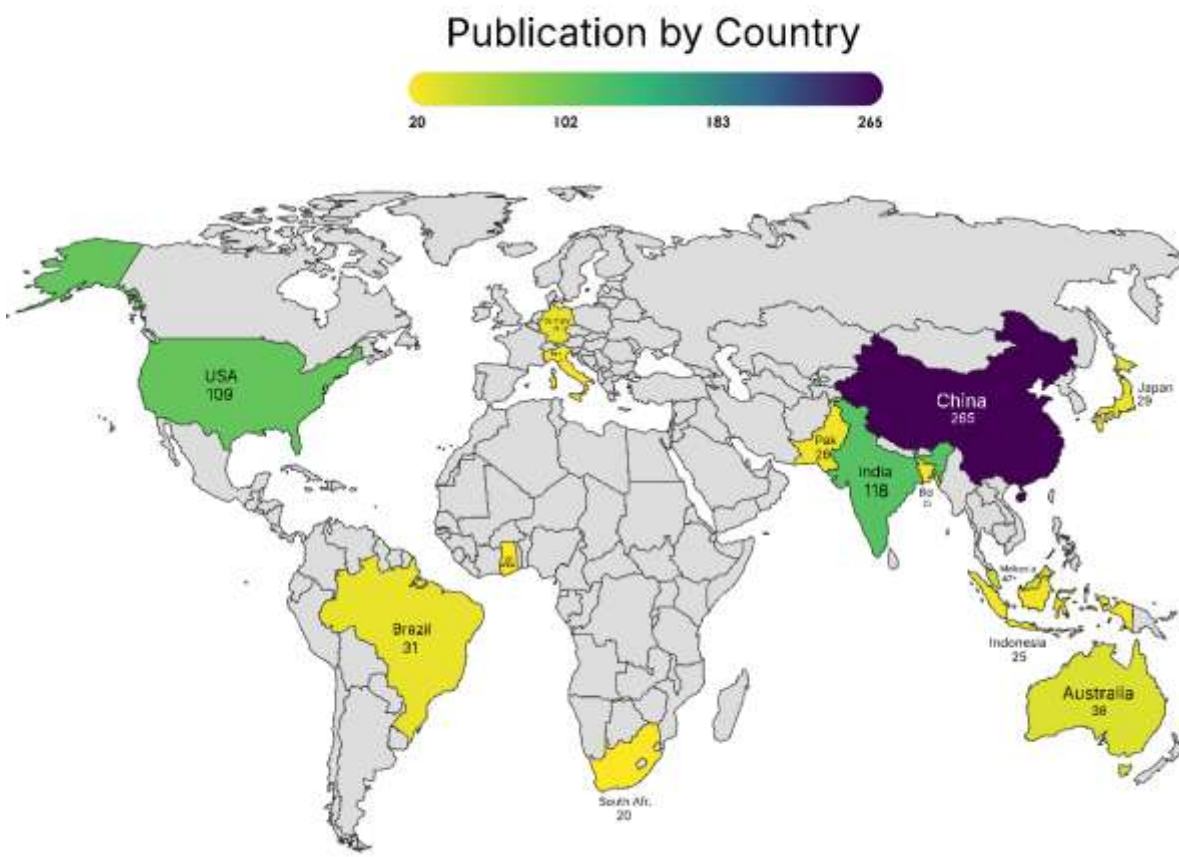


Fig -7: Geographic distribution of publications, restricted to countries contributing at least 20 documents.

Source: generated by the author(s) using iipmaps.com.

The distribution is genuinely international, but it is also uneven. China dominates with 265 publications, which reflects sustained research funding, rapid industrial transformation and the scale of its domestic e-waste burden. India follows with 118 and the United States with 109, both supported by well-established research networks. Asian countries together account for the majority of output, which reflects the growing research capacity of the Global South and the pressing relevance of e-waste management in rapidly developing economies. European and North American contributions show that developed nations remain active. The presence of Ghana and South Africa is worth noting, since both address the local environmental and public-health consequences of e-waste directly. Their combined output of 40 publications is nonetheless small set against the volume of e-waste those regions process informally, a mismatch taken up in Sec. 4.2.

3.4 Primary publication outlets (RQ4)

Table 11 reports the journals that serve as the primary outlets for this research. They span cleaner production, waste management, environmental science and sustainability, which reflects both the interdisciplinary nature of the field and the demand for research linking consumer behaviour to environmental and circular-economy objectives.

Notably, all ten journals occupy the first quartile (Q1) of their respective Scopus subject categories, indicating that research in

this field is consistently disseminated through the most reputable and high-impact outlets. The table highlights a range of journals contributing to research in this domain, with the Journal of Cleaner Production leading in publications (65) and accumulating 2,215 citations, showcasing its significant impact; its most-cited article examines end users' willingness to support e-waste reverse logistics for the circular economy (346 citations). Waste Management follows closely with 62 publications and 1,565 citations, while Resources, Conservation and Recycling (47 publications) records the highest CiteScore in the set (21.5), underscoring its influence in the resource-recovery and recycling literature. Sustainability (Switzerland) stands out with the highest citation count among the leading outlets (2,241 citations across 42 publications), reflecting its broad reach in behavioural and sustainability-oriented research. High-impact environmental journals such as Science of the Total Environment (39 publications; CiteScore 17.9) and Journal of Environmental Management (17 publications; CiteScore 13.7) emphasize the environmental and contamination dimensions of e-waste, whereas more behaviourally and policy-oriented outlets including Waste Management & Research and Environmental Science and Pollution Research (25 publications each) address consumer behaviour and e-waste policy. Together these outlets carry the bulk of the corpus and span its environmental, technical and behavioural components.

Table -11: The most prolific journals in the corpus, with citation indicators.

Journal	TP	TC	TC / TP	CiteScore (2024)	Most cited article (times cited)	Publisher	Q
Journal of Cleaner Production	65	2,215	34.1	15.8	Sharing economic responsibility: Assessing end user's willingness to support e-waste reverse logistics (346)	Elsevier	Q1
Waste Management	62	1,565	25.2	15.9	Recycling of NMC black mass from spent lithium-ion battery using supercritical fluid extraction (132)	Elsevier	Q1
Resources, Conservation and Recycling	47	963	20.5	21.5	Printed circuit board identification using deep convolutional neural networks to facilitate recycling (427)	Elsevier	Q1
Sustainability (Switzerland)	42	2,241	53.4	6.8	E-device purchase and disposal behaviours in the UAE: An exploratory study (305)	MDPI	Q1
Science of the Total Environment	39	855	21.9	17.9	Complex interactions of rare earth elements in aquatic systems (316)	Elsevier	Q1
Waste Management & Research	25	595	23.8	7.4	Understanding consumer behaviour in small WEEE collection: Insights from Australia (80)	SAGE	Q1
Environmental Science and Pollution Research	25	519	20.8	8.3	Design, adoption and implementation of electronic waste policies in India (129)	Springer Nature	Q1
Journal of Environmental Management	17	543	31.9	13.7	Sociodemographic drivers of waste management behaviours in coastal communities, Canada (80)	Elsevier	Q1
International Journal of Environmental Research and Public Health	16	465	29.1	7.3	Impact of illegal dumping of solid waste on public health in Nigeria: Lagos State (195)	MDPI	Q1
Chemosphere	16	118	7.4	15.3	Chlorinated paraffins and dechloranes in free-range chicken eggs and soil, Tanzania (34)	Elsevier	Q1

Note: TP, total publications; TC, total citations; TC / TP, mean citations per publication within the corpus. CiteScore values are 2024 Scopus CiteScores. Ranked by total publications. Q denotes the Scopus subject-category quartile. Source: Scopus export.

The composition of this list reinforces the structural picture from Sec. 3.2. Four of the ten outlets Science of the Total Environment, Environmental Science and Pollution Research, the International Journal of Environmental Research and Public Health, and Chemosphere publish predominantly environmental and toxicological work, and their most-cited articles in the corpus concern contamination and public-health outcomes rather than consumer decisions. Behavioural research is concentrated in a smaller subset, principally the Journal of Cleaner Production, Sustainability, Waste Management & Research and Resources, Conservation and Recycling.

3.5 Most cited documents and their contributions (RQ5)

RQ5 asks two questions that call for different kinds of evidence. Citation counts answer which documents are most cited. They do not answer what those documents contributed, which requires reading them. We address both here.

Raw citation counts favour older publications, which have had longer to accumulate them. Table 12 therefore reports citations

per year alongside the total. One complication has to be handled first. Scopus records the issue year, and several records in this set carry a long gap between online-first release and issue assignment: Ofori appeared online in November 2023 but carries a 2025 issue year, and Shang et al. appeared online in December 2024 against the same 2025 issue year. Dividing by years since the issue year would overstate their annual rate substantially. Rates are therefore computed from the earliest public availability of each record, counting both that year and the search year. On this basis the 2023 study of persistent organic pollutants in farmland surrounding a dismantling site leads on both measures. Below the top position the two rankings diverge: Hoang et al. rise from ninth on total citations to second on annual rate, and Leite et al. from seventh to fourth. Age normalisation therefore does not overturn the leading document, but it does bring forward recent work whose influence the raw count understates, and the two columns are best read together.

Table -12: The ten most cited documents in the corpus, with age-normalised citation rates and stated contributions.

#	Document (author, year, source)	Year	TC	TC/y r	Domain	Stated contribution to the field
1	The spatial distribution and potential risk assessment of POPs in farmland around a typical e-waste dismantling site Zhang et al. (2023), Archives of Environmental Contamination and Toxicology	2023	751	187.8	Environmental contamination	Quantifies the spatial extent of persistent organic pollutant contamination in agricultural soil surrounding a dismantling site, establishing that informal processing contaminates the food-production system beyond the site boundary
2	Circular economy practices in third world nations: challenges and implications for environmental sustainability Ofori (2025), Environment, Development and Sustainability	2023 (2025 issue)	558	139.5	Circular-economy policy	Synthesises the structural obstacles to circular-economy implementation in developing economies, arguing that infrastructural and governance deficits rather than awareness constrain adoption
3	Printed circuit board identification using deep convolutional neural networks to facilitate recycling Soomro et al. (2022), Resources, Conservation and Recycling	2022	427	85.4	Recycling technology	Demonstrates that automated visual identification of circuit boards is feasible at recycling-line throughput, opening a route to sorting that does not depend on manual disassembly

#	Document (author, year, source)	Year	TC	TC/y r	Domain	Stated contribution to the field
4	Sharing economic responsibility: assessing end user's willingness to support e-waste reverse logistics Koshta et al. (2022), Journal of Cleaner Production	2022	346	69.2	Consumer behaviour	Establishes that end users will bear part of the cost of reverse logistics under specified conditions, linking consumer willingness directly to the economics of collection-system design
5	Environmental awareness factor of used cell phones Wibowo et al. (2022), Global Journal of Environmental Science and Management	2022	323	64.6	Consumer behaviour	Identifies environmental awareness as a determinant of used-handset disposal decisions in an emerging-economy setting, and documents the extent of household device hibernation
6	Optimised redesign of reverse logistics network with multi-level capacity choices for household appliances Che et al. (2022), International Journal of Production Research	2022	317	63.4	Operations research	Provides a capacity-planning model for reverse-logistics networks, showing how collection-point siting and capacity jointly determine system cost
7	Complex interactions of rare earth elements in aquatic systems Leite et al. (2024), Science of the Total Environment	2024	316	105.3	Ecotoxicology	Characterises the ecotoxicological behaviour of rare earth elements released from electronic waste, extending contamination concern from heavy metals to the critical materials that make recovery economically attractive
8	E-device purchase and disposal behaviours in the UAE: an exploratory study Siddiqua et al. (2022), Sustainability (Switzerland)	2022	305	61.0	Consumer behaviour	Documents purchase and disposal patterns in a high-income Gulf setting, extending the behavioural evidence base beyond the developing-economy contexts that dominate it
9	Assessing factors affecting students' e-waste recycling intention among households in Ho Chi Minh City Hoang et al. (2025), Inzynieria Mineralna	2025	292	146.0	Consumer behaviour	Applies an extended theory of planned behaviour to a Vietnamese student sample, illustrating the TPB-plus-extension design that dominates the behavioural cluster
10	Hybrid combinatorial remanufacturing for PCB-based products in reversed supply chain Shang et al. (2025), Annals of Operations Research	2024 (2025 issue)	288	96.0	Operations research	Models remanufacturing and recycling as a combined decision, linking recovery-route choice to carbon outcomes as well as cost

Note: TC, total citations (Scopus); TC/yr, total citations divided by the number of years since the record first became publicly available, counting both that year and the search year. Where the online-first year differs from the Scopus issue year, both are shown and the earlier is used. Documents are ranked by total citations; contributions were characterised from each document's abstract and stated findings.

The composition of the set is itself a finding. Of the ten most cited documents, four address consumer behaviour, two address environmental contamination or ecotoxicology, three address technical or operations-research problems in recycling and reverse logistics, and one addresses circular-economy policy. Citation impact in this field is therefore not concentrated in any single disciplinary stream, and the distribution broadly mirrors the four-cluster structure reported in Sec. 3.2 with the qualification that behavioural work is better represented among the most cited documents than its share of the keyword network or of the record count would suggest.

4. DISCUSSION

Reporting bibliometric results is not the same as interpreting them. A persistent weakness of the genre is that studies describe what the analyses produced without establishing what it means for the field (Öztürk et al., 2024; Lim and Kumar, 2023). This section therefore follows the three-step sensemaking sequence of scanning, sensing and substantiating that Lim and Kumar (2023) propose for bridging quantitative bibliometric output and qualitative interpretation.

4.1 Scanning: the patterns in the results

Three patterns emerge from the analyses. The first is sustained and accelerating growth: annual output rose from 38 articles in 2015 to 143 in 2025, an increase of more than 275%, with over 70% of the corpus appearing from 2020 onwards and no plateau by the end of the window. The second is a stable four-part thematic architecture covering sustainability and waste management, behavioural determinants, environmental exposure and human health, all strongly interlinked through the corpus's anchor terms. Within it, the behavioural cluster carries the smallest share of aggregate link strength, roughly 11% against 62% for the managerial cluster. The third is concentration operating on three dimensions at once: geographic, with one country contributing around 29% of output; institutional, with Chinese organisations holding six of

the ten most productive positions; and editorial, with ten first-quartile journals absorbing a substantial share of the corpus.

4.2 Sensing: why these patterns arise and what follows from them

Each pattern is treated below in three steps: what the data show, what we infer from them, and why the inference matters. Keeping those separate makes the boundary between measurement and interpretation visible.

Growth

Finding. Annual output rose from 38 records in 2015 to 143 in 2025, with a single interruption in 2021. Interpretation. The period of growth coincides with the consolidation of circular-economy policy agendas and the strengthening of extended producer responsibility regimes, though bibliometric data establish co-occurrence in time and not causation. Subject to the qualifications in Sec. 3.1, the corpus expanded in absolute terms across the window. Implication. The literature is large enough and recent enough to reward structural mapping, and recent enough that a synthesis conducted before 2020 would now be substantially out of date.

Thematic composition

Finding. Co-word analysis returns four clusters that remain strongly interlinked through the corpus's highest-connectivity terms. Behaviour-related keywords form a distinct cluster that connects closely with the sustainability and waste-management cluster, and account for approximately 11% of the aggregate link strength of the leading keywords; consumer-behaviour studies account for 142 of the 925 records.

Interpretation. Behavioural research is integrated into the field rather than isolated from it, and its connection to the managerial cluster suggests behavioural work is read and cited alongside systems-level work. It is nonetheless less extensively represented than the material and environmental themes, on the connectivity measure and on the independent record count alike. Two measures of different quantities pointing the same

way strengthens the inference, although neither shows that behavioural research is less important. They show only that it is less extensive.

Implication. This gives a rationale for a dedicated synthesis of consumer-level determinants. The sub-field is coherent enough to be synthesised, integrated enough for its findings to matter to the wider field, and small enough for a qualitative review to cover. Whether the field's allocation of attention is appropriate is a question this analysis raises but cannot settle. Answering it would need evidence about which research questions most constrain e-waste recovery in practice, and that is not bibliometric evidence.

Concentration

Finding. One country contributes around 29% of output, Chinese institutions hold six of the ten most prolific positions, and ten first-quartile journals absorb a substantial share of the corpus. **Interpretation.** Each dimension has a defensible explanation on its own: China's domestic e-waste burden and research funding, the institutional networks that accumulate around well-funded programmes, the disciplinary preferences of established outlets. Taken together, though, they narrow the empirical base more than any one of them does alone. **Implication.** Findings drawn largely from a small number of rapidly industrialising economies, produced within a small number of institutional networks and filtered through a small number of editorial communities, may generalise less readily than the field's global framing implies. The modest presence of African and Latin American research is striking, since those regions bear a disproportionate share of informally processed e-waste. The geography of the research and the geography of the problem are misaligned. That marks those regions as priorities for new primary research, though productivity counts cannot explain why the imbalance persists; that would need the collaboration-network analysis this study does not perform.

4.3 Substantiating: the trustworthiness of these interpretations

Three considerations bear on how much weight these interpretations can carry. On credibility, the analyses were run on a corpus whose construction is documented in Sec. 2 and whose arithmetic reconciles at every step, and the quantitative claims above can be traced to specific tables and figures. On dependability, the protocol in Table 2 records each decision and the section reporting its output, so the procedure can be re-executed. The main residual risk is that the four-cluster solution depends on VOSviewer's clustering parameters and was not validated against an independent implementation, as Sec. 6.2 explains.

On confirmability, one interpretive step should be marked explicitly. The cluster labels in Sec. 3.2 were assigned by inspecting constituent keywords; they are not computed properties of the data, and a different analyst might label the same partition differently. The cluster memberships and link-strength values are reproducible; the labels are an interpretation of them. On transferability, the structural findings describe e-waste recycling research as retrieved by the string in Table 4 and should not be read as properties of e-waste research under any alternative retrieval specification.

4.4 What the analysis can and cannot establish

Finally, the boundary of the contribution should be stated plainly. Bibliometric analysis describes where a literature is dense and where it is thin. It cannot establish what that literature has found. Nothing above licenses a claim about which determinants of recycling behaviour hold, which theories explain them best, or which interventions work; those belong to the qualitative synthesis reported separately. What the analysis does establish is the structural context within which such a synthesis should sit, and it identifies the behavioural cluster as the part of the field most in need of one.

5. CONCLUSIONS AND IMPLICATIONS

This study mapped the research landscape of e-waste recycling published between 2015 and 2025, drawing on 925 Scopus-indexed articles. Annual output rose from 38 records to 143 over the period, subject to the indexing and normalisation qualifications set out in Sec. 3.1. The literature is organised into four interlinked thematic clusters spanning sustainability and waste management, behavioural determinants of recycling, environmental exposure and human health. Behaviour-related keywords form a comparatively less extensive component of the co-occurrence network despite occupying a structurally well-connected position within it, and consumer-behaviour studies account for 142 of the 925 records. Output is concentrated geographically, institutionally and by publication outlet.

What the study establishes is the field's conceptual structure, meaning the relationships among the concepts its literature uses. It does not establish the field's intellectual structure, its collaboration networks, or whether what any cluster has found is sound. Those would require citation-based mapping, co-authorship analysis and qualitative synthesis respectively.

For researchers, the map carries three practical implications. It identifies the behavioural cluster as a coherent, established, but comparatively small stream, and therefore a priority for dedicated synthesis and primary research. It identifies the geographic narrowness of the evidence base as a structural limitation, with African, Latin American and rural settings under-represented. And it makes the boundaries between the field's disciplinary streams visible, which is useful for cross-disciplinary work linking consumer decisions to the contamination and health outcomes documented in Clusters 3 and 4.

For editors and research funders, the concentration findings indicate where deliberate intervention would broaden the evidence base: supporting behavioural research in under-represented regions, and encouraging submissions that connect the behavioural and environmental-health streams rather than developing them in parallel.

6. LIMITATIONS AND FUTURE RESEARCH

Three classes of limitation shape bibliometric findings: the coverage of the underlying corpus, the behaviour of the software used to analyse it, and the reductive character of quantitative indicators (Passas, 2024; Haustein and Larivière, 2015). Each applies here. We take them in turn, with the mitigation adopted and the risk that remains.

6.1 Coverage of the corpus

Retrieval was confined to Scopus. The rationale is set out in Sec. 2.3 and the trade-off was made deliberately, but the consequence stands: records indexed only in Web of Science, Dimensions, Google Scholar or discipline-specific repositories are absent, and indexing policies differ across databases in ways that can shift both counts and cluster structure. Scopus coverage is also uneven by region and language, which compounds the geographic concentration reported in Sec. 3.3.

Two inclusion decisions narrow coverage further. Restricting to English-language records introduces language bias and probably under-represents research from China, Brazil, Indonesia and Ghana, which are among the settings the field most needs to describe. Restricting to journal articles excludes conference proceedings, book chapters, theses and grey literature. In e-waste research that last category carries real weight, since national monitoring reports and agency policy evaluations are rarely issued as journal articles.

A third constraint is specific to the query. The corpus reflects the string in Table 4, and a differently specified string would return a different corpus and quite possibly a different cluster solution. Because the string admits general determinant terms, it retrieves environmental and health research alongside behavioural research. That is appropriate for field mapping and is stated explicitly in Sec. 2.7, but it does mean the results describe the field as this query renders it. Database indexing errors add further noise that cannot be removed: mis-assigned document types, incomplete affiliation strings and missing keywords all propagate silently into the counts.

6.2 Technological and analytical bias

Bibliometric software is not a neutral instrument. Cluster solutions produced by VOSviewer depend on its association-strength normalisation and on the resolution, minimum-occurrence and counting parameters reported in Table 7; altering these can merge or split clusters without any change to the underlying data. The four-cluster solution in Sec. 3.2 is therefore one defensible partition of the keyword network rather than a uniquely correct one, and it is sensitive to the thesaurus decisions described in Sec. 2.4, since keyword merging directly determines node weights.

The analysis also treats keywords as a proxy for content. Author keywords are chosen inconsistently, index keywords are assigned from database vocabulary rather than by authors, and neither necessarily captures a paper's substantive argument. A conceptual structure derived from keywords is a structure of the terms a literature uses, not directly of the ideas it contains. The usual mitigation for the software dependency is tool triangulation: running the same corpus through CiteSpace or Bibliometrix (Aria and Cuccurullo, 2017) and treating structures that survive across tools as more robust. We used a single mapping tool, so the stability of our cluster solution under alternative algorithms is untested.

6.3 The limits of quantitative indicators

The deeper limitation is intrinsic to the method. Bibliometric indicators are descriptive, not causal: they record what was published and what was cited, and support no inference about why. They count publications, citations and co-occurrences; they do not assess theoretical contribution, methodological quality or practical significance. A highly cited paper may be cited for being contested rather than sound, and citation accrual

is confounded by publication age, field citation norms, journal visibility and self-citation. Table 12 mitigates the age component through citations per year but addresses none of the others.

Three specific instances arise here. The author-level indicators in Table 9 are whole-career Scopus values rather than corpus-specific counts, and describe general standing rather than contribution to e-waste recycling research. Author and institution disambiguation remains imperfect despite the procedures in Sec. 2.4, since common surnames, inconsistent initialisation and unlinked affiliation histories can split one entity across records or merge two into one. And the cluster labels in Sec. 3.2 are interpretive assignments made by inspecting constituent keywords, not properties computed from the data. The derivation procedure in Table 8 makes them auditable; it does not make them objective.

The recommended remedy for the last of these is to complement quantitative mapping with qualitative analysis of content. The companion systematic review serves this function for the behavioural cluster, examining what that stream has established rather than how extensive it is. The remaining three clusters have no such counterpart in the present work, and the structural claims made about them should be read accordingly.

6.4 Directions for future bibliometric work

Four extensions follow from the limitations above. First, citation-based analyses would establish the field's intellectual structure, which the co-word design used here cannot reach. Co-citation analysis would identify its historical foundations, and bibliographic coupling would surface the emerging thematic fronts that keyword analysis, weighted as it is toward established terminology, tends to miss. Second, co-authorship network analysis would establish how the field's producers are connected, complementing the productivity counts in Sec. 3.3, which show where research is produced but not how it is organised.

Third, longitudinal overlay visualisation would trace how the four clusters have shifted in relative weight across the period, turning the static picture reported here into a dynamic one. That would be particularly informative given the behavioural cluster's later emergence. Fourth, field-normalised author and source metrics, together with output normalised against total database growth, would replace the whole-career and absolute indicators used here with values comparable across disciplines and across time.

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Data availability. The bibliographic records analysed in this study were retrieved from the Scopus database using the search string reported in Table 4. The exported dataset and the analysis files are available from the corresponding author on reasonable request.

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