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Systematic Review

Extended Producer Responsibility and the Circular Economy: A Systematic Review of Comparative Evidence from Sub-Saharan Africa

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Abstract

Extended Producer Responsibility (EPR) is increasingly expected to advance circularity beyond conventional collection and recycling, yet performance varies across waste streams and implementation contexts. This systematic review evaluates EPR across packaging waste, electronic waste, and end-of-life tires and examines the conditions shaping circular-economy outcomes. Following PRISMA 2020, Scopus, Web of Science Core Collection, Dimensions, PubMed/MEDLINE, and gray-literature sources were searched through 15 August 2026. Eligible evidence substantively addressed EPR policy, governance, implementation, or circular outcomes. Of 6924 records identified, 236 sources were retained, comprising 185 peer-reviewed publications and 51 policy, legislative, institutional, or technical documents. Sources were appraised against JBI, AMSTAR 2, or AACODS criteria according to their design, and evidence was synthesized thematically and comparatively using a five-level circularity-progression benchmark and weighted by evidence type, directness, and consistency. EPR performs most consistently in financing and organizing collection and recycling, while higher-order circularity depends on institutional capacity, producer accountability, financing, infrastructure, traceability, secondary-material markets, and stakeholder inclusion. Evidence from seven Sub-Saharan African jurisdictions shows that regulatory ambition must be matched by implementation readiness and context-appropriate integration of informal recovery systems. Evidence depth remains uneven across jurisdictions and study designs. EPR can contribute meaningfully to circularity when policy ambition is aligned with institutional and operational capability.

Keywords: Extended Producer Responsibility; circular economy; packaging waste; electronic waste; end-of-life tires; implementation readiness; Sub-Saharan Africa; circularity

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1. Introduction

Global waste generation continues to rise under the combined effects of population growth, urbanization, industrialization, rising incomes, changing consumption patterns, and shortening product life cycles. Municipal solid waste generation reached approximately 2.56 billion tonnes in 2022 and is projected to increase substantially by 2050 under prevailing production and consumption trajectories [1]. Packaging waste, electronic waste (e-waste), and end-of-life tires are particularly significant because they combine rapidly growing

material flows with considerable recovery potential and substantial environmental and human-health risks. Global e-waste generation reached 62 million tonnes in 2022, representing an increase of approximately 82% since 2010, and is projected to reach 82 million tonnes by 2030 [2]. Available estimates further indicate that approximately 1.0–1.6 billion tires reach end of life annually, representing roughly 19–29 million tonnes depending on reporting boundaries and methodological assumptions [3,4]. Inadequate management of these waste streams can expose workers and surrounding communities to hazardous substances, uncontrolled emissions, and unsafe recovery practices, particularly in low- and middle-income economies where waste generation often outpaces collection, treatment, and recycling capacity [5].

This growing waste burden has exposed the limitations of conventional waste-management systems that intervene predominantly after products become waste [6]. Although collection, treatment, and disposal remain essential for environmental protection, downstream systems alone provide limited leverage over the production and consumption decisions that generate material throughput. Circular-economy approaches seek to address this limitation by retaining products, components, and materials at their highest practicable value through prevention, durability, reuse, repair, refurbishment, remanufacturing, high-quality recycling, and reintegration of secondary resources into production [7,8]. Circularity therefore requires more than improved recovery technology. It also depends on governance mechanisms that redistribute costs, responsibilities, and incentives across the product life cycle and create stronger connections between end-of-life performance and upstream production decisions.

EPR has become one of the principal policy instruments through which governments seek to establish this connection. EPR extends producer responsibility beyond the point of sale by transferring significant financial and, increasingly, operational responsibility for post-consumer products from municipalities and taxpayers to producers and other actors that place products on the market [9,10]. Its contemporary scope extends beyond financing collection and recycling to encompass product stewardship, eco-design, material selection, recycling quality, secondary-material use, and producer accountability [11,12]. Producer Responsibility Organizations (PROs), take-back obligations, eco-modulated fees, recycled-content requirements, design-for-environment provisions, digital product passports, and life-cycle traceability systems increasingly form part of this policy architecture [13–16]. EPR has consequently evolved from a predominantly downstream waste-financing mechanism toward a broader instrument of circular resource governance.

The expansion of EPR policy, however, has not produced uniformly circular outcomes. A substantial body of evidence associates EPR with improvements in producer participation, collection, take-back, recycling, and resource recovery [17–20], while evidence of comparable progress in waste prevention, product-life extension, eco-design, high-value material retention, and displacement of virgin resources remains less consistent [21,22]. This distinction is important because an EPR system may perform effectively according to conventional waste-management indicators while achieving only modest progress toward higher-order circularity. Performance also varies among jurisdictions using apparently similar regulatory instruments. Differences in institutional authority, enforcement, producer registration, financing, infrastructure, market maturity, technological capability, and stakeholder participation can determine whether formally assigned responsibility becomes operational and materially consequential [23–25]. The relevant analytical question is therefore not simply whether EPR has been adopted, but what forms of circularity it produces, under which implementation conditions, and with what degree of effectiveness across different product systems.

Evidence across different regulatory and geographical contexts reinforces this distinction. Mature European systems demonstrate that EPR can institutionalize producer-financed collection and recycling while still providing limited upstream incentives where fee structures and compliance mechanisms are insufficient to influence product design and material choice [26–29]. Asian experiences, including those of India, Vietnam, and the Philippines, illustrate rapid regulatory expansion alongside continuing challenges involving producer registration, enforcement, free-riding, collection infrastructure, and treatment capacity [30,31]. Latin American experience provides further institutional contrast. Chile's Law No. 20.920 established mandatory producer responsibility for priority products including packaging, tires, and electrical and electronic equipment, while Colombia has progressively developed mandatory producer-responsibility arrangements for packaging and associated recovery systems [32,33]. These experiences demonstrate that EPR operates through different combinations of statutory obligation, collective compliance, market incentives, public oversight, and stakeholder participation. Its performance is consequently shaped by the institutional and economic environments in which these mechanisms function.

Despite the rapid growth of EPR studies, the evidence remains fragmented. Existing studies provide important insights into individual waste streams, reverse logistics, PRO structures, eco-modulated fees, recycling performance, and jurisdiction-specific implementation [34]. Compagnoni [26] identified persistent limitations in the contribution of e-waste EPR to eco-design and upstream change. Campbell-Johnston et al. [27] showed that strong tire recovery performance can coexist with substantial downcycling and energy recovery. Maitre-Ekern [28] argued for stronger extension of producer responsibility toward pre-market decisions, while Lifset et al. [29] questioned whether existing fee differentiation provides incentives strong enough to alter producer behavior. These contributions identify important components of the problem, but comparatively few studies integrate materially different waste streams while simultaneously examining circularity outcomes and the implementation conditions that shape them. It therefore remains difficult to distinguish whether weak circular outcomes arise primarily from EPR design, product and waste-stream characteristics, or the capabilities of the systems through which producer responsibility is implemented.

Sub-Saharan Africa provides a particularly revealing setting in which to examine these relationships. EPR is expanding across the region but frequently operates within waste systems characterized by uneven formal collection, incomplete producer registration, limited treatment capacity, fragmented institutional responsibilities, and extensive informal collection, repair, resale, dismantling, and material recovery [35,36]. The region also contains considerable institutional diversity. Ghana continues to develop its e-waste regulatory architecture [37], Rwanda has expanded institutional capacity for e-waste management [38], and Kenya is strengthening EPR implementation through producer registration, compliance, and emerging digital mechanisms [39]. South Africa combines comparatively mature producer-responsibility arrangements with continuing challenges in plastics circularity and domestic value retention [40], while Togo provides an emerging application of producer responsibility to end-of-life tires [41]. Wider African evidence demonstrates substantial variation in plastics governance and regulatory design [42,43], and Senegal represents a Francophone policy environment in which circular-economy and fiscal approaches have developed through a distinct institutional trajectory [44]. This diversity provides a useful basis for examining how common EPR principles operate where regulatory capacity, infrastructure, markets, and existing recovery systems differ substantially.

An important distinction in this review is made between implementation capacity and the implementation-readiness gap. Institutional or implementation capacity concerns

the resources, authority, infrastructure, information, market conditions, and stakeholder arrangements available to execute policy. The implementation-readiness gap is relational. It refers to the mismatch between the demands and circular ambitions embedded in an EPR regime and the capabilities actually available to implement them. A jurisdiction may therefore possess meaningful regulatory or technical capacity while still experiencing a readiness gap if policy requirements advance more rapidly than producer identification, enforcement, financing, collection, treatment, traceability, market development, or stakeholder integration. This distinction allows EPR performance to be examined not simply in terms of whether capabilities exist, but whether they are sufficiently aligned with the level of responsibility and circularity expected by the policy.

Against this background, this systematic review examines whether contemporary EPR can deliver circular-economy outcomes across packaging waste, electronic waste, and end-of-life tires. It draws on comparative international evidence and uses seven Sub-Saharan African jurisdictions, namely Nigeria, South Africa, Kenya, Ghana, Rwanda, Senegal, and Togo, as a critical implementation lens. Three interrelated questions guide the review. First, to what extent has EPR progressed from improving downstream waste management toward enabling broader circularity? Second, which institutional, regulatory, financial, technological, market, and stakeholder conditions explain differences in EPR performance across jurisdictions and waste streams? Third, what adaptations and sequencing strategies are required for EPR to function effectively under heterogeneous Sub-Saharan African conditions?

The study makes three related contributions. First, it formalizes a circularity-progression benchmark that distinguishes downstream collection and recovery from higher-order outcomes involving secondary-material substitution, product-life extension, value retention, waste prevention, and eco-design. Second, it develops the implementation-readiness gap as an analytical explanation for differences between EPR ambition and realized performance and interprets this relationship through Matland's Ambiguity-Conflict Model of policy implementation [45]. Third, it integrates evidence across three materially different waste streams and contrasting Anglophone and Francophone settings in Western, Eastern, and Southern Africa. In doing so, the review moves beyond the binary question of whether EPR works and instead examines what it achieves, why its performance varies, and the conditions under which producer responsibility can contribute meaningfully to circular transformation.

2. Materials and Methods

2.1. Review Design

This study employed a systematic review to evaluate the contribution of EPR to circular-economy outcomes and identify the conditions associated with differences in performance across waste streams and implementation environments. The design combined systematic procedures for evidence identification, screening, appraisal, extraction, and reporting with critical synthesis of heterogeneous empirical, regulatory, institutional, and policy evidence [46–50]. This approach was appropriate because the review sought not only to identify reported EPR outcomes but also to examine competing explanations for differences in performance across product systems and jurisdictions.

Study identification and selection followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) statement [51]. The completed PRISMA 2020 checklist is provided in the Supplementary Materials. The review was not prospectively registered, and no formal review protocol was deposited in a public repository. The review procedures were prespecified within the study workflow before screening and synthesis, and no amendments to a registered protocol were therefore applicable. Peer-reviewed re-

search was considered alongside authoritative legislative, policy, institutional, and technical documents because EPR operates simultaneously as an environmental-policy instrument, regulatory system, and waste-management intervention. Meta-analysis was not undertaken because the included literature differed substantially in study design, policy instrument, jurisdiction, waste stream, outcome definition, and measurement of EPR performance. These differences precluded meaningful statistical aggregation of comparable effect estimates.

2.2. Information Sources and Search Strategy

The systematic search covered Scopus, Web of Science Core Collection, Dimensions, and PubMed/MEDLINE. PubMed/MEDLINE was included to strengthen coverage of environmental, toxicological, occupational-health, and public-health evidence, particularly in relation to e-waste dismantling, informal recycling, and tire treatment. Publisher platforms such as ScienceDirect, SpringerLink, Wiley Online Library, and Taylor & Francis Online were not treated as independent databases because relevant publications from these platforms were captured through the bibliographic databases. Google Scholar was used only for supplementary discovery and citation tracking.

The primary search covered publications from 1 January 2020 through 15 August 2026. Earlier seminal publications were retained where necessary to establish the conceptual and historical development of EPR. Authoritative gray literature was identified through institutional repositories and websites of organizations including the World Bank, Organization for Economic Co-operation and Development (OECD), United Nations Environment Programme (UNEP), International Telecommunication Union (ITU), United Nations Institute for Training and Research (UNITAR), Basel Convention Secretariat, European Commission, relevant African regional institutions, national environmental regulators, and recognized Producer Responsibility Organizations.

The gray-literature search used organizational repositories, national regulator and PRO websites, and legislation databases. Each source was searched through available site-search functions using keywords derived from the four concept groups in Table 1, supplemented by browsing relevant publication, policy, legislation, and regulatory pages. The same primary date window, 1 January 2020 to 15 August 2026, was applied, while earlier foundational documents were retained only where necessary to establish EPR policy development. Gray sources were eligible when they were issued by an authoritative organization or regulator, were substantively relevant to EPR, and had accessible full text. Retrieved records were screened using the same eligibility criteria as the wider review, and included gray literature was appraised using AACODS. Together with supplementary discovery, these searches contributed to the 365 gray-literature and supplementary records reported in Section 2.3. The websites searched, search terms, search dates, retrieval information, and screening record are documented in Supplementary Table S1 to support reproducibility.

The search architecture combined four concept groups covering EPR, circular economy and resource recovery, priority waste streams, and governance and implementation. Synonymous terms within each group were combined using OR, while the concept groups were combined using AND. Database-specific field codes, truncation operators, wildcards, and controlled vocabulary were applied where appropriate. Searches were conducted in English, while eligible French-, Spanish-, and Portuguese-language evidence was considered where sufficient information or reliable translation was available for assessment. Table 1 summarizes the principal search concepts and representative terms. The search strings, field tags, filters, search dates, and retrieval counts are reported in Supplementary Table S1, where Part A reconstructs the executed architecture in platform syntax rather than reproducing the platform exports verbatim.

Table 1. Search architecture used for systematic evidence identification.

Search Concept	Representative Search Terms	Principal Fields
Extended Producer Responsibility	"extended producer responsibility" OR "EPR" OR "producer responsibility" OR "product take-back" OR "producer responsibility organization" OR "PRO"	Title, abstract, keywords
Circular economy	"circular economy" OR "circularity" OR "resource efficiency" OR "closed-loop" OR "secondary material" OR "value retention"	Title, abstract, keywords
Priority waste streams	"packaging" OR "plastic" OR "electronic waste" OR "e-waste" OR "WEEE" OR "tire" OR "end-of-life tire"	Title, abstract, keywords; controlled vocabulary where applicable
Governance and implementation	"Implement" OR "governance" OR "policy" OR "regulation" OR "compliance" OR "enforce" OR "eco-modulation" OR "traceability" OR "informal sector" OR "waste picker"	Title, abstract, keywords

Search adequacy was checked against 12 benchmark publications representing foundational and contemporary EPR research across the three waste streams and principal analytical themes. All benchmark publications were retrieved through the search architecture or the predefined procedure for foundational literature. The benchmark publications and their information sources are identified in Supplementary Table S1. Google Scholar was searched using the supplementary query "Extended Producer Responsibility circular economy packaging e-waste tires," and the first 200 relevance-ranked results were examined for supplementary discovery and citation verification. These records were not treated as an independent systematic search set.

2.3. Eligibility Criteria and Study Selection

Sources were eligible when EPR constituted a substantive component of the investigation and the evidence addressed one or more relevant domains, including policy design, governance, implementation, financing, PRO operation, producer compliance, stakeholder participation, informal-sector integration, digital traceability, environmental performance, resource recovery, or circular-economy outcomes. The primary waste streams were packaging, e-waste, and end-of-life tires. Cross-stream and general EPR studies were retained where they provided evidence relevant to the comparative analysis. Eligible evidence included quantitative, qualitative, and mixed-methods studies, systematic and scoping reviews, case studies, policy and legal analyses, legislation, institutional reports, and recognized technical publications.

Sources were excluded when they addressed general waste management, recycling technology, life-cycle assessment, or circular economy without substantive EPR content, or examined waste streams outside the analytical scope without transferable EPR evidence. Editorials, news items, opinion pieces, conference abstracts without accessible full papers, duplicate publications, and sources lacking sufficient methodological, documentary, or linguistic information for reliable assessment were also excluded. Where multiple publications substantially reported the same evidence, the most comprehensive or recent version was retained.

Retrieved bibliographic records were exported to EndNote 20/21 and deduplicated through automated comparison of titles, authors, publication years, and digital object identifiers, followed by manual verification. Deduplicated records were imported into Rayyan for eligibility screening [52]. Title-and-abstract screening and full-text eligibility assessment were conducted independently by the two authors using the predefined criteria.

Inter-rater agreement was high at both stages, with $\kappa = 0.88$ and 94.2% raw agreement for title-and-abstract screening and $\kappa = 0.91$ and 95.6% raw agreement for full-text assessment. Disagreements were discussed by the two reviewers, and unresolved cases were referred to an independent adjudicator who had not participated in the initial decision. The adjudicator's role was restricted to resolving disputed eligibility and appraisal decisions.

The evidence-identification process yielded 6924 records. These comprised Scopus ($n = 2614$), Web of Science Core Collection ($n = 2180$), Dimensions ($n = 1245$), PubMed/MEDLINE ($n = 520$), and institutional gray-literature and supplementary discovery sources ($n = 365$). After 1742 duplicates were removed, 5182 records underwent title-and-abstract screening and 4328 were excluded. Full texts were assessed for 854 records, of which 618 were excluded because of incorrect intervention or focus ($n = 284$), exclusively technical or laboratory content without substantive EPR or governance relevance ($n = 176$), descriptive commentary without sufficient analytical evidence ($n = 92$), or duplicate or overlapping evidence ($n = 66$). The final synthesis comprised 236 sources, including 185 peer-reviewed publications and 51 authoritative policy, legislative, institutional, or technical documents. Figure 1 presents the complete PRISMA selection process, while Supplementary Table S2 provides the identifiable master catalog of the 236 included sources. The six totals reported above represent the records documented during retrieval and screening. The source-specific figures reflect the aggregate results returned by each database on the respective search dates and subsequently entered into the consolidated screening log, which provided the basis for deduplication, screening and eligibility assessment. The available retrieval documentation comprises these counts, the search dates and the recorded screening decisions, but does not include separately archived export files from individual databases. Supplementary Table S1, Part A, reconstructs the search strategies using the original conceptual structure, search fields, filters and limits, rather than reproducing the exact search strings exported from each platform. Part D documents the basis of the reported counts for each source and the format in which the corresponding retrieval information was retained. The source-specific classifications were subsequently updated during reconciliation of the evidence catalog. The resulting distribution of records across information sources is presented alongside the screening and eligibility decisions in Figure 1. Supplementary Table S1 documents the search strategies, retrieval information, and available search-execution records, while Supplementary Table S2 provides the corresponding catalog of included sources.

2.4. Methodological Quality Appraisal

Methodological quality was evaluated using appraisal instruments appropriate to the different forms of evidence. Empirical studies were assessed using the relevant Joanna Briggs Institute (JBI) Critical Appraisal Checklists [53], systematic and structured reviews were evaluated using AMSTAR 2 [54], and policy documents, legislation, institutional reports, and authoritative gray literature were assessed using the Authority, Accuracy, Coverage, Objectivity, Date, and Significance (AACODS) framework [55]. The instruments were applied separately because they differ in purpose, domain structure, and interpretation and therefore do not support direct conversion into a common numerical quality scale.

The appraisal instrument assigned to each source was determined using predefined criteria based on the document type and study design recorded in Supplementary Table S2. Empirical studies were assigned the Joanna Briggs Institute (JBI) critical appraisal checklist appropriate to their respective designs; systematic and structured reviews were assigned AMSTAR 2, and policy documents, legislation, institutional reports, and authoritative gray literature were assigned AACODS. Each instrument specifies the applicable assessment domains, permissible judgment categories and procedures for determining overall appraisal outcomes, together with limitations on how its findings may be interpreted or converted into

other assessment measures. Supplementary Table S3 documents the instrument assigned to each of the 236 sources, the corresponding assessment domains and the applicable judgment and reporting conventions, thereby providing a transparent framework for examining the appraisal requirements of individual sources.

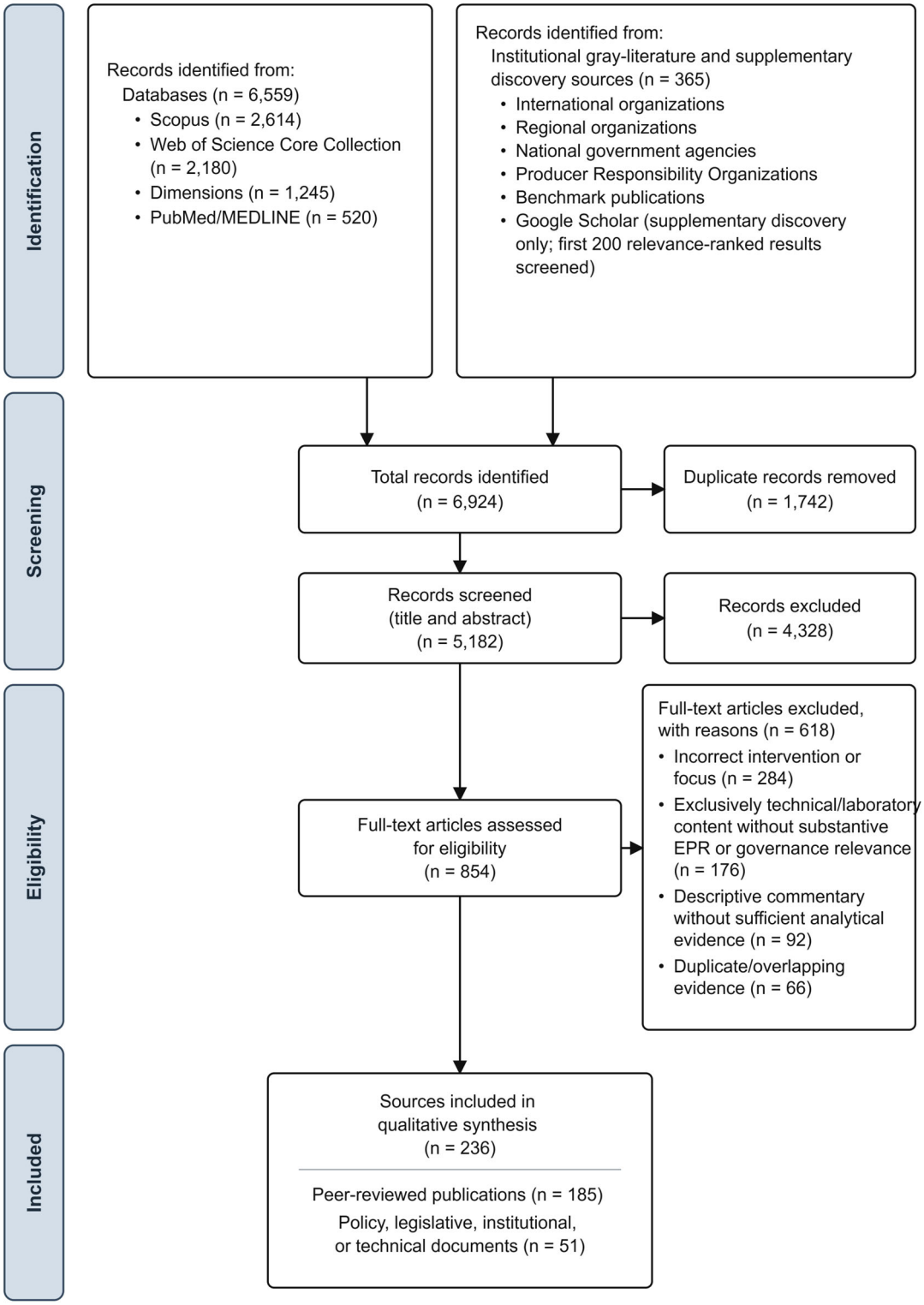


Figure 1. PRISMA 2020 flow diagram showing evidence identification, screening, eligibility assessment, and inclusion in the systematic review. Figure generated using Google Nano Banana 2 and verified by the authors against the documented study-selection records.

The review team evaluated the included sources using the instrument-specific decision rules presented in Supplementary Table S3, Part C, with appraisal considerations informing the interpretation and relative weighting of evidence during synthesis rather than serving as automatic exclusion criteria. However, criterion-level ratings for the 236 sources were not reconstructed for the present submission. Accordingly, Supplementary Table S3 documents the appraisal framework for each source, including the assigned instrument, applicable assessment domains, permissible judgment categories, rules for determining overall outcomes and restrictions on converting results between instruments, rather than presenting completed criterion-level assessments. No common classification of evidence quality as high, moderate or low was applied across JBI, AMSTAR 2 and AACODS, given the methodological differences between these instruments. Disagreements arising during the appraisal process were resolved through discussion, with cases requiring further consideration referred to the independent adjudicator responsible for resolving disagreements during eligibility assessment.

Formal statistical assessment of publication bias using funnel plots was not undertaken because comparable intervention effect estimates were not pooled. An overall certainty-of-evidence framework such as GRADE was likewise not applied because the review integrates heterogeneous empirical, legal, policy, and institutional evidence rather than estimating a common intervention effect. Publication, reporting, and language bias nevertheless remain possible and are considered when interpreting the findings.

2.5. Data Extraction and Corpus Characteristics

A standardized extraction framework was applied to all 236 included sources. One author extracted the data and the second author verified all entries against the source documents; disagreements were resolved through discussion. Study authors were not contacted for additional or missing information. Extracted variables included publication year, document type, study design or evidence type, geographical jurisdiction, waste stream, EPR policy instrument, governance arrangement, financing mechanism, PRO structure, producer-compliance mechanism, informal-sector relationship, technological or traceability mechanism, reported implementation barriers, conventional waste-management outcomes, and broader circular-economy outcomes. Circularity outcomes were coded separately from conventional collection and recycling outcomes to preserve the analytical distinction between downstream waste management and higher-order value retention. All results substantively compatible with these predefined outcome domains were sought. Where multiple reports substantially represented the same underlying evidence, the most comprehensive or recent version was retained in accordance with Section 2.3. Missing or unclear information was coded as "not reported" and was not imputed.

The evidence base was characterized descriptively before thematic synthesis. The characteristics of the 236 included sources were examined to establish the composition, geographical coverage, and methodological diversity of the evidence base. The corpus comprised 180 peer-reviewed journal articles, five other academic publications, and 51 policy, legislative, institutional, or technical documents. Packaging and plastics accounted for 65 sources (27.5%), e-waste for 52 (22.0%), end-of-life tires for 24 (10.2%), and cross-stream or general EPR evidence for 95 (40.3%). The evidence was also classified into five broad methodological categories comprising empirical or conceptual studies ($n = 103$), reviews ($n = 61$), institutional or technical reports ($n = 32$), modeling or life-cycle studies ($n = 20$), and legal or regulatory instruments ($n = 20$). These categories were used to distinguish the principal forms of evidence contributing to the synthesis, recognizing that individual publications may combine methodological approaches and that classification reflects their primary analytical contribution.

The publication distribution indicated a strong concentration of recent evidence. Of the 236 sources, 189 (80.1%) were published between 2020 and 2026, including 119 (50.4%) published from 2024 onward. The remaining 47 sources (19.9%) comprised earlier publications and foundational documents retained for their conceptual, methodological, historical, or regulatory relevance. Geographically, 130 sources (55.1%) addressed global or cross-regional contexts, followed by Sub-Saharan Africa with 55 (23.3%), Europe with 28 (11.9%), Asia-Pacific with 13 (5.5%), Latin America with seven (3.0%), and North America with three (1.3%). These distributions indicate that the synthesis draws predominantly on recent research while incorporating earlier foundational evidence and comparative experience from more established EPR systems. Supplementary Table S2 provides the source-level bibliographic and analytical classifications, including publication year, document type, study design, geographical orientation, and waste stream.

The 23.3% Sub-Saharan African share reflects the comparative design of the review rather than a reduced analytical emphasis on the region [56–60]. Evidence from more mature EPR systems in Europe, Asia-Pacific, and Latin America was deliberately retained as a benchmark for interpreting the institutional and circularity challenges observed in African settings. Peer-reviewed EPR research focused specifically on Sub-Saharan Africa remains comparatively recent and is still developing, although the region constitutes the second-largest geographical group in the corpus with 55 sources. African findings were therefore triangulated with relevant policy, legislative, regulatory, and institutional documents. This evidence imbalance limits the depth of some regional comparisons and is considered explicitly in the limitations discussed in Section 7.

These characteristics were used to assess the distribution and balance of the evidence rather than as measures of EPR effectiveness. Areas represented by comparatively large bodies of empirical research were distinguished from those where conclusions depended more heavily on case studies, policy documents, or emerging regulatory experience. This distinction reduced the risk of interpreting differences in the volume or maturity of available literature as differences in EPR performance.

2.6. Analytical Coding and Comparative Synthesis

The extracted evidence was synthesized thematically and comparatively to explain how producer responsibility has evolved, what forms of circular performance it has produced, and why outcomes differ across waste streams and implementation environments. Coding proceeded iteratively from source-level findings to recurring explanatory categories and then to higher-order analytical themes. Contradictory findings were retained rather than forced into consensus, allowing differences in policy design, product characteristics, institutional capacity, financing, markets, stakeholder participation, technological capability, and socioeconomic context to be considered as possible explanations for divergent outcomes. No statistical conversions or imputations were required because the review did not undertake meta-analysis, and no additional data transformations were performed beyond the qualitative coding and categorization described above.

Conventional downstream outcomes, including collection, take-back, recycling, and controlled recovery, were coded separately from higher-order circularity outcomes involving secondary-material substitution, reuse, repair, refurbishment, product-life extension, material-value retention, waste prevention, and eco-design. This distinction provided the basis for the circularity-progression benchmark applied in the subsequent synthesis. The comparative assessment considered four interrelated dimensions, namely the volume of directly relevant evidence, consistency of findings across sources, methodological credibility, and the extent to which reported findings directly supported the circularity outcome under consideration. Methodological credibility was interpreted in relation to the applicable JBI,

AMSTAR 2, or AACODS appraisal criteria, recognizing that empirical studies, systematic reviews, and institutional or regulatory documents require different forms of quality assessment. Greater interpretive weight was assigned to findings supported by directly relevant and methodologically credible evidence, while conclusions based on limited, inconsistent, or predominantly descriptive sources were treated more cautiously. The resulting assessments were qualitative judgments of the strength and applicability of the available evidence rather than numerical estimates of EPR effectiveness. Principal supporting references were retained alongside the comparative assessments to facilitate examination of the evidence underlying each judgment.

The determinants of implementation were derived iteratively from the coded evidence rather than imposed as a fixed prior framework. Recurring explanatory factors were consolidated into institutional capacity and governance, producer compliance and accountability, stakeholder and informal-system integration, financing, infrastructure and secondary-material markets, and technology, traceability and information systems. These categories were subsequently examined in terms of their relationships and the different levels of circularity they enable. For operationalization, the five groups were disaggregated into the eight readiness conditions set out in Supplementary Table S4, Part A, as explained in Section 5.6.

The comparative implementation analysis covered Nigeria, South Africa, Kenya, Ghana, Rwanda, Senegal, and Togo. Cases were purposively selected through theoretical replication to capture variation in geographical subregion, legal and administrative tradition, EPR regulatory maturity, waste-stream experience, formal recovery capacity, and relationships between formal and informal recovery systems. The selection encompasses Southern, Eastern, and Western Africa, Anglophone and Francophone institutional environments, comparatively mature mandatory EPR systems and emerging arrangements, and experience across packaging, e-waste, and end-of-life tires. The cases are not treated as statistically representative of Sub-Saharan Africa. Instead, they provide contrasting implementation configurations through which the relationship between policy ambition and implementation readiness can be examined.

Cross-jurisdictional interpretation also considered plausible alternative explanations for observed differences in EPR performance. Income, urbanization, waste composition, international trade, vehicle-fleet characteristics, existing municipal waste-management capacity, industrial structure, secondary-material markets, and the scale and organization of informal recovery can influence both implementation capability and observed outcomes. These conditions were therefore considered as competing or complementary explanations rather than assuming that observed differences could be attributed exclusively to EPR.

The implementation-readiness analysis focused on the relationship between policy demands and the capabilities required to execute them. Observable indicators included regulatory mandates, producer registration and verification, compliance monitoring, financing, collection and treatment capacity, stakeholder participation, secondary-material demand, traceability, and information quality. These indicators were used analytically rather than combined into a universal country score. Supplementary Table S4, Part A, provides their operational definitions, potential data sources, measurement guidance, and links to the propositions developed later in the review, while Part B records the per-jurisdiction legal, institutional and source-level evidence.

The synthesis generated five interrelated analytical domains that structure the remainder of the review. These comprise the evolution of EPR, circularity performance across the three priority waste streams, determinants of implementation, comparative implementation conditions across Sub-Saharan Africa, and integration of the findings through the circularity-progression benchmark and implementation-readiness gap.

3. Evolution of Extended Producer Responsibility

EPR has changed considerably since its emergence as an environmental-policy principle. Early schemes were concerned primarily with transferring the financial and physical burden of post-consumer waste from municipalities and taxpayers to producers. Contemporary EPR is expected to perform a much broader role involving product stewardship, resource efficiency, circular material flows, producer accountability, and increasingly life-cycle information and systems governance. This expansion is important because current assessments often judge EPR against circular-economy objectives that extend well beyond those for which early schemes were designed.

3.1. Evolution of EPR

The development of EPR has not followed a single linear trajectory. Its scope has expanded as limitations in earlier approaches became apparent [61]. The concept emerged partly from concern that conventional end-of-pipe waste systems could manage some consequences of disposal but provided weak incentives for waste prevention, improved product design, or reduced virgin-material consumption [62–65]. Lindhqvist subsequently formalized EPR as a policy principle that extends producer responsibility beyond the point of sale to the post-consumer environmental consequences of products [66–69].

Early implementation consequently emphasized internalizing waste-management costs and reallocating financial and physical responsibility from municipalities to producers [18,25]. European packaging schemes became influential examples, establishing producer-financed collection, recovery targets, and organizational arrangements that were subsequently adapted to electronics, tires, batteries, and other product categories [61]. These systems demonstrated that EPR could strengthen collection and recycling, but also revealed that high recovery rates did not necessarily lead to comparable reductions in material consumption, improvements in product design, or broader circularity [70–76].

This limitation gradually changed the policy question from who should pay for post-consumer waste management to how continued producer responsibility might influence products and material flows before waste is generated [77–79]. Contemporary EPR consequently combines conventional financing and recovery obligations with increasingly ambitious expectations concerning product stewardship, recycling quality, resource efficiency, eco-design, and life-cycle responsibility. Its evolution therefore reflects a progressive widening of producer responsibility rather than the replacement of one policy objective by another.

3.2. From Waste Financing to Circular Governance

The changing philosophy of EPR can be understood through several overlapping functions involving waste financing, resource efficiency, circularity, producer accountability, and systems governance. These are not discrete historical stages. Producer-financed collection and treatment remain fundamental, but additional functions have accumulated as expectations of producer responsibility have expanded.

The initial emphasis on financing created more stable arrangements for post-consumer management and reduced the direct burden on municipalities [24,31]. Its influence on upstream production decisions, however, was often limited. Producers could satisfy their principal obligations by financing collection and recovery without substantially changing material intensity, product longevity, repairability, or recyclability. Recognition of this limitation encouraged greater attention to resource efficiency, durability, repair, reuse, recyclability, and material selection [80–83]. Eco-design requirements and differentiated producer fees developed partly from this logic by attempting to connect anticipated end-of-life consequences with decisions made during product development.

Circular-economy thinking broadened the objective further by emphasizing retention of products, components, and materials at their highest practicable value [84–87]. Recycling remains important, but it does not necessarily preserve the functional and economic value embodied in products. Reuse, repair, refurbishment, remanufacturing, and high-quality material recovery may retain greater value before lower-order recovery becomes necessary. Contemporary assessments of EPR therefore increasingly consider whether producer responsibility contributes to longer product lives, secondary-material substitution, reduced virgin-resource dependence, and waste prevention rather than treating collection or recycling alone as evidence of circularity.

Producer accountability has developed alongside this broader ambition. Registration, participation in Producer Responsibility Organizations, performance reporting, product identification, traceability, and disclosure increasingly supplement financial obligations [88–92]. These mechanisms make responsibility more visible and potentially more verifiable. They also expose an important distinction between payment and accountability. A producer may contribute financially to an EPR scheme while remaining weakly connected to the quantities placed on the market, subsequent material flows, or actual recovery outcomes.

EPR is also becoming integrated with wider systems of circular governance. Producer responsibility increasingly intersects with product regulation, recycled-content requirements, digital traceability, international trade, and supply-chain governance [93]. Digital product information and material-tracking systems can improve connections among producers, regulators, collectors, recyclers, and secondary-material users [94–96]. Their effectiveness, however, depends on reliable producer information, credible reporting, appropriate infrastructure, and institutions capable of acting on the information generated. Greater policy sophistication therefore expands the potential reach of EPR while simultaneously increasing the capabilities required for effective implementation.

3.3. Evidence on EPR Performance and Remaining Gaps

The literature does not support a simple conclusion that EPR either succeeds or fails. Outcomes depend on what is being measured, the characteristics of the product system, policy design, and the conditions under which responsibility is implemented. This distinction becomes obscured when collection, recycling, waste prevention, eco-design, and circularity are treated as equivalent measures of policy performance.

European experience provides substantial evidence that EPR can institutionalize producer-financed collection and recovery where regulatory targets, established PROs, collection infrastructure, and recycling markets are present. At the same time, the evidence is less consistent regarding upstream transformation. Mallick et al. [61] described the increasing integration of EPR with circular-economy policy, while Lifset et al. [29] questioned whether prevailing eco-modulated fees provide incentives strong enough to produce substantial changes in product design. Reverse-logistics evidence similarly indicates that effective take-back can improve circular material flows without necessarily addressing the upstream determinants of material consumption [18,97,98]. Mature systems can therefore perform strongly in downstream management without achieving equivalent progress in higher-order circularity.

Evidence from emerging Asian systems illustrates a different challenge. Expansion of EPR legislation demonstrates the international diffusion of producer-responsibility principles, but formal adoption does not guarantee effective implementation. Studies from India and Vietnam identify continuing difficulties involving compliance, enforcement, producer participation, administrative capability, and recycling infrastructure [20,24,31,99,100]. Under such conditions, formal EPR obligations may exist without consistently capturing

post-consumer products, ensuring equitable producer participation, or returning recovered materials to productive use.

These implementation questions become particularly significant in African settings, where EPR may operate alongside incomplete producer information, uneven formal infrastructure, constrained regulatory capacity, and extensive informal collection and recovery. Evidence from Ghana identifies institutional and organizational conditions as important influences on implementation [64], while research on used electronic equipment exported from Europe to Nigeria demonstrates how producer responsibility can become geographically separated from the location where products eventually reach end of life [101–103]. These conditions complicate the assumption that responsibility assigned where products first enter a market will remain effective across subsequent product, trade, and waste flows.

Across these settings, a recurring finding is that formal responsibility becomes consequential only when producers can be identified, obligations enforced, financing sustained, materials captured, performance verified, and recovered resources directed toward viable treatment and secondary markets. Weaknesses in one part of this chain can undermine performance elsewhere. Strong legislation cannot compensate indefinitely for incomplete producer registration, just as high collection rates cannot generate circularity where recovered materials have little prospect of returning to productive use.

A further source of disagreement in the literature concerns the definition of success. Collection, take-back, recycling, and recovery remain essential indicators, but contemporary circular-economy ambitions extend to waste prevention, product longevity, reuse, repair, material-value retention, secondary-material substitution, and reduced virgin-resource dependence. Compagnoni [26] identified this limitation in e-waste EPR, Maitre-Ekern [28] argued for stronger intervention before products reach the waste stage, and Campbell-Johnston et al. [27] demonstrated that high tire recovery can coexist with lower-order treatment pathways. EPR can therefore perform effectively as a waste-management instrument while remaining incomplete as a circular-economy strategy.

Table 2 positions the present review against selected studies that have shaped these different strands of EPR studies. The comparison shows that previous work has generated substantial knowledge on particular waste streams, legal principles, recovery hierarchies, and producer incentives. The present review builds on these contributions by examining three materially different waste streams through a common circularity lens and connecting differences in circular performance to implementation conditions.

Table 2. Positioning of the present review relative to selected prior EPR studies.

Study	Primary Waste-Stream Scope	Geographic Orientation	Analytical Emphasis	Limitation Relative to the Present Review
Compagnoni [26]	E-waste	Predominantly global/ OECD evidence	EPR effectiveness, take-back, eco-design	Focuses principally on one waste stream
Campbell-Johnston et al. [27]	End-of-life tires	European/Dutch emphasis	Circularity and recovery hierarchy	Tire-specific analysis
Maitre-Ekern [28]	General product responsibility	European legal context	Upstream/pre-market responsibility	Primarily legal and conceptual
Lifset et al. [29]	EPR incentive design	OECD/global policy context	Eco-modulation and producer incentives	Focuses principally on incentive architecture
Present review	Packaging, e-waste, and end-of-life tires	Comparative evidence with seven Sub-Saharan African cases	Circularity progression, implementation readiness, policy transfer, and sequencing	Integrates cross-stream circularity performance with implementation conditions and context-sensitive policy design

The remaining problem is therefore not a shortage of EPR literature, but fragmentation across waste streams, jurisdictions, policy instruments, and definitions of successful performance. Two questions remain particularly important. The first is whether EPR can progress consistently from downstream waste management toward higher-order circularity across materially different product systems. The second is which implementation conditions explain variation in that progression. Section 4 addresses the first question through a common circularity-progression benchmark applied to packaging, electronic waste, and end-of-life tires.

4. Circularity Performance Across Waste Streams

The evolution of EPR described in Section 3 creates an important question of measurement. If contemporary producer responsibility is expected to contribute to the circular economy, performance cannot be assessed solely through collection rates, recycling quantities, or diversion from disposal. These remain important outcomes, but they principally describe what happens after products enter the waste-management system. Circular performance also depends on whether material quality is preserved, recovered resources substitute for virgin inputs, product life is extended, and producer responsibility influences the design and production decisions that determine future waste generation.

To compare these outcomes across materially different product systems, this review applies a five-level circularity-progression benchmark. The levels represent progressively broader forms of circular performance:

Level 1. Downstream Capture and Controlled Treatment. Collection, take-back, diversion from uncontrolled disposal, and environmentally sound treatment.

Level 2. High-Quality Recycling. Recovery of materials at sufficient quality to retain significant technical and economic value.

Level 3. Secondary-Material Substitution. Use of recovered materials in ways that displace virgin-material inputs in subsequent production.

Level 4. Product-Life Extension. Reuse, repair, refurbishment, remanufacturing, retreading, and related strategies that preserve products or components in service before material recovery becomes necessary.

Level 5. Upstream Prevention and Eco-Design. Changes in product design, material selection, durability, repairability, recyclability, and material intensity that prevent waste or reduce its environmental burden before products reach end of life.

The benchmark is ordinal rather than a quantitative index. It does not assume that every product must progress sequentially through all five levels or that each level is equally applicable to every waste stream. Instead, it distinguishes management of waste already generated from progressively stronger forms of value retention and prevention. Product characteristics remain important. Packaging is dominated by short-lived material flows, e-waste combines material recovery with substantial opportunities for repair and reuse, while tires may retain functional value through retreading before material recovery. Similar collection or recovery rates can therefore represent substantially different levels of circular performance.

Qualitative assessments used later in Table 3 were derived from the synthesis procedure described in Section 2.6. They reflect the amount of directly relevant evidence, consistency of findings across sources, methodological credibility of the supporting evidence, and directness of that evidence to the circularity outcome under consideration. Accordingly, the descriptors *Strong*, *Moderate*, and *Weak* represent comparative evidence judgments rather than numerical performance scores.

The waste-stream synthesis draws on peer-reviewed empirical and review evidence together with authoritative policy and technical sources relevant to packaging, e-waste, and

end-of-life tires. The relative weighting of evidence across waste streams was informed by the nature of the available sources, their relevance to the level of circularity being examined and the consistency of findings across studies. Greater interpretive caution was exercised where evidence was limited, indirect or contradictory. Supplementary Table S3 documents the appraisal framework established for the evidence corpus, including the instrument assigned to each source and the corresponding assessment criteria and decision rules. Accordingly, the differential weighting adopted in the synthesis was informed by the characteristics, relevance and consistency of the available evidence, with the appraisal framework providing methodological guidance rather than a documented set of completed criterion-level assessments.

4.1. Packaging Waste

Packaging is among the most established applications of EPR and one of its most demanding tests as a circular-economy instrument. Packaging systems generate large and continuous material flows involving short product lifetimes, heterogeneous materials, contamination, and geographically dispersed consumption. These characteristics make collection and recycling comparatively visible policy targets while making preservation of material value more difficult [14,17,19,30,104–108].

Evidence is strongest at Level 1. Producer-financed collection, sorting, take-back, and recovery can increase the capture of post-consumer packaging and reduce dependence on municipal financing. Where producer participation, collection infrastructure, and recovery targets are well established, greater quantities of packaging can be directed toward controlled recovery rather than disposal or uncontrolled leakage [14,17,19,109–117]. These outcomes are environmentally important, particularly for plastic packaging, but do not by themselves establish circularity.

Performance becomes less consistent at Level 2. Technical recyclability does not guarantee high-quality recycling. Mixed polymers, multilayer structures, additives, pigments, labels, contamination, and inadequate sorting can reduce both the quality and economic value of recovered materials [14,17,19,24,30,118–122]. Reported recycling rates may consequently combine relatively closed-loop recovery with applications in which material quality deteriorates. High collection and nominal recycling can therefore coexist with substantial losses in material value.

At Level 3, performance depends on whether recovered materials actually substitute for virgin inputs [123–131]. Producing recyclate is insufficient if it does not meet technical specifications, cannot compete economically, is available inconsistently, or lacks downstream demand. Recycled-content requirements and functioning secondary-material markets can strengthen the connection between EPR-supported recovery and actual substitution of primary resources.

Packaging has more restricted opportunities for Level 4 because much conventional packaging is designed for short-duration or single-use functions. Refillable and reusable systems provide important exceptions, but their performance depends on return logistics, cleaning infrastructure, consumer participation, repeated utilization, and sufficient reuse cycles. EPR arrangements dominated by recycling fees may therefore strengthen recycling without necessarily shifting packaging systems toward reuse [10,12,29,132–136].

Level 5 remains particularly demanding. Eco-modulated fees can in principle discourage unnecessary material use and difficult-to-recycle formats while rewarding recyclability, reuse, material reduction, and improved design [29,137–144]. Evidence is less consistent that prevailing fee differentials are sufficiently strong or precisely calibrated to alter major production decisions. Where EPR charges constitute a small proportion of product value, producers may absorb the additional cost rather than redesign packaging.

Packaging therefore presents a material-throughput challenge primarily [145]. EPR can organize and finance the management of large post-consumer flows, but stronger circularity requires influence over the amount and design of packaging entering the economy, the viability of reuse, the quality of recycling, and the extent to which secondary materials replace virgin resources.

4.2. Electronic Waste

Electronic waste presents a different circularity challenge [146–148]. Electrical and electronic products contain valuable metals, polymers, glass, and critical materials, together with hazardous substances and increasingly complex assemblies. Many devices and components also retain functional value after their first user relinquishes them. Circular performance therefore depends on both safe material recovery and continuity of responsibility across repair, resale, refurbishment, reuse, transboundary movement, and eventual end-of-life treatment.

At Level 1, EPR can improve formal take-back and controlled treatment by assigning producers responsibility for collection and financing. This is particularly important where uncontrolled dismantling, open burning, chemical extraction, and inappropriate disposal create environmental and occupational-health risks. Formal collection data, however, capture only part of the product flow. Electronics may remain stored in households, move through second-hand markets, undergo repeated repair, enter informal collection networks, or cross-national borders before final treatment [26,101,149–153]. Formal collection rates must therefore be interpreted alongside these alternative pathways.

At Level 2, circular performance depends on recovering materials at sufficient quality while controlling hazardous releases [154–156]. Advanced processing can recover valuable metals and other materials, but its viability depends on scale, technology, product composition, logistics, and access to downstream refining. Where formal treatment capacity is limited, valuable fractions may enter alternative processing channels while hazardous or low-value components remain inadequately managed.

Level 3 requires a further distinction between material recovery and actual secondary-material substitution [157–162]. E-waste contains resources whose recovery can potentially reduce dependence on primary extraction, but losses during dismantling and processing, insufficient separation, changing product composition, and manufacturing specifications may prevent recovered materials from returning to equivalent production cycles. The circular contribution of EPR therefore depends partly on whether recovered resources reconnect with manufacturing supply chains.

E-waste offers particularly significant opportunities at Level 4. Repair, refurbishment, resale, reuse, and component harvesting can preserve functional and embodied value before recycling becomes necessary [28,163–165]. These activities are especially important where active repair and second-hand markets extend product service lives. EPR can nevertheless undermine this value if compliance systems classify reusable products prematurely as waste or exclude actors involved in legitimate repair and refurbishment. Circular governance must therefore distinguish product-life extension from unsafe end-of-life processing.

Evidence remains less consistent at Level 5. Producer responsibility should theoretically encourage greater durability, repairability, upgradeability, disassembly, and reduced dependence on hazardous or difficult-to-recover materials. Compagnoni [26], however, found the influence of e-waste EPR on eco-design to be more limited than its influence on collection and treatment. Collective compliance systems can further weaken the relationship between an individual producer's design choices and the end-of-life costs associated with its products [166]. Improved product information and traceability may strengthen this

connection, provided that information remains available across repair, resale, collection, dismantling, and recycling [167].

The principal challenge in e-waste is therefore continuity of responsibility. Circular performance depends on maintaining meaningful responsibility as products change owners, locations, functional status, and economic value rather than allowing responsibility to become disconnected before final recovery. Sound treatment of the collected fraction also depends on technically qualified dismantling and processing capacity and on operators trained in the handling of hazardous components [168].

4.3. End-of-Life Tires

End-of-life tires present a third circularity challenge. Tires are durable engineered products with considerable embedded material and energy value, while uncontrolled accumulation, burning, and disposal can generate environmental and public-health risks. EPR can improve collection and diversion, but the circular significance of recovery depends heavily on what subsequently happens to the tire or its constituent materials [27,169–173].

Level 1 performance can be comparatively strong where EPR finances collection, reduces uncontrolled stockpiling, and diverts tires from illegal disposal or landfill [174–176]. These outcomes are readily measurable and explain why tire systems may report high recovery rates. The term recovery, however, encompasses markedly different pathways, including continued use of the casing, material recycling, and energy recovery. Aggregate recovery rates can therefore conceal major differences in value retention.

At Level 2, mechanical processing can generate crumb rubber, granulate, recovered steel, and other secondary materials, but the resulting applications differ considerably in their capacity to preserve material quality. Some pathways retain useful material value, whereas others result in lower-value applications with limited prospects for subsequent recovery. Energy recovery can divert tires from disposal and utilize their calorific value, but it destroys their material structure and is therefore not equivalent to material circularity [27,177–179].

Level 3 requires recovered rubber, steel, carbonaceous materials, and other outputs to substitute meaningfully for virgin resources [180–182]. Emerging recovery technologies may improve the quality and range of secondary outputs, but technical feasibility does not establish substitution. Market demand, standards, processing costs, consistency of recovered materials, and manufacturers' willingness to incorporate them determine whether recovery reduces primary-resource consumption.

Tires have an important Level 4 pathway through retreading. Retreading preserves the existing casing and extends service life before the tire is broken down for material recovery [27,169,183–185]. It therefore retains more of the functional and embodied value of the product than immediate shredding or energy recovery. EPR systems that emphasize collection without protecting suitable casings for retreading may consequently achieve high recovery while foregoing opportunities for higher-order value retention.

At Level 5, the relevant question is whether producer responsibility influences durability, material composition, retreadability, recyclability, and tire design [186–188]. Evidence of this upstream effect remains less developed than evidence concerning collection and recovery. Where compliance obligations are determined primarily by units or weight placed on the market, producers may receive limited incentive to improve characteristics such as durability or retreadability.

The principal circularity challenge for tires is therefore a recovery-hierarchy problem. High diversion from disposal is beneficial, but it does not establish how much product or material value has been retained. Stronger circular performance depends on pri-

oritizing product-life extension and high-quality material recovery before lower-value treatment pathways.

4.4. Cross-Stream Comparison

The three waste streams demonstrate why no single collection or recycling indicator can adequately represent EPR circularity. Packaging, e-waste, and tires differ in product lifetime, material complexity, residual value, repairability, recovery infrastructure, and the economic pathways available after initial use. Similar regulatory mechanisms can consequently generate different circular outcomes.

Packaging performs most consistently in downstream capture but faces increasing difficulty as circular ambition moves toward high-quality recycling, secondary-material substitution, reuse, and prevention. E-waste offers greater opportunities for product-life extension but presents difficulties in maintaining responsibility across repair, resale, informal recovery, and transboundary movement. Tires can achieve high collection and diversion while retaining relatively little circular value if suitable casings are destroyed or materials are directed predominantly toward lower-value recovery.

Table 3 summarizes these differences using the circularity-progression benchmark. The assessments synthesize the direction, consistency, credibility, and directness of the evidence reviewed for each waste stream and circularity level. They are therefore comparative evidence judgments rather than numerical scores or universal performance classifications.

Table 3. Comparative evidence on circularity performance of EPR across the three priority waste streams.

Circularity Level	Packaging Waste	Electronic Waste	End-of-Life Tires	Evidence Basis and Principal Interpretation
Level 1. Downstream capture and controlled treatment	Strong [14,17,19,30]	Moderate–Strong [26,101]	Strong [27,169,170]	Most consistently demonstrated EPR function. Evidence concerns collection, take-back, controlled treatment, and diversion from uncontrolled disposal.
Level 2. High-quality recycling	Moderate [14,17,19,24,30]	Moderate [26,101]	Moderate [27,169,170]	Performance is constrained by material complexity, separation and processing capability, output quality, and available recovery pathways.
Level 3. Secondary-material substitution	Moderate–Weak [14,19,29,30]	Moderate [26]	Moderate–Weak [27,169,170]	Recovery is documented more consistently than actual displacement of virgin materials. Evidence of substitution remains more conditional.
Level 4. Product-life extension	Weak–Moderate [17,29]	Strong potential, uneven realization [26,28,101]	Moderate–Strong where retreading is preserved [27,169]	Performance depends strongly on product characteristics and viable systems for reuse, repair, refurbishment, resale, or retreading.
Level 5. Upstream prevention and eco-design	Weak–Moderate [17,29]	Weak–Moderate [26,28]	Weak [27,169]	This is the least consistently demonstrated dimension. Evidence that EPR materially changes design and prevention decisions remains comparatively limited.

Note. Labels are interpretive evidence judgments based on four considerations: the amount of directly relevant evidence, consistency of findings across sources, methodological credibility, and directness to the outcome. Approximately: Strong denotes several directly relevant sources that are broadly concordant with no major contradiction; moderate–strong denotes generally concordant, directly relevant evidence on a smaller or less complete base; Moderate denotes relevant evidence supporting the direction of judgment with mixed findings, coverage or directness; Moderate–Weak denotes limited, conditional, indirect or inconsistent evidence; Weak–Moderate denotes limited evidence of realized performance, though mechanisms or partial examples are documented; Weak denotes little direct evidence of realized performance (absence of evidence is not treated as evidence of no effect). These labels apply to Table 3 only. The cells are prose characterizations of implementation conditions supported by the sources cited in its final column, and they are not assigned Strong, Moderate or Weak labels.

The cross-stream evidence reveals a clear pattern. EPR performance is most consistently demonstrated where obligations concern downstream capture and controlled treatment and becomes less certain as expected outcomes move toward material substitution, product-life extension, and upstream prevention. This pattern is understandable. Collection and treatment are comparatively observable and enforceable, whereas higher-order circularity depends increasingly on product characteristics, secondary-material markets, production decisions, consumer behavior, and coordination across multiple stages of the value chain.

This gradient should not diminish the importance of downstream achievements. Reliable collection and controlled treatment are necessary foundations for many subsequent circular activities. The problem arises when these outcomes are treated as sufficient evidence that a circular transition has occurred. The benchmark instead distinguishes successful waste management from progressively stronger forms of circular value retention.

The comparison also demonstrates that barriers to higher-order circularity are waste-stream specific. Packaging is constrained primarily by material throughput, e-waste by discontinuities in responsibility, and tires by the hierarchy of recovery pathways. EPR design should therefore respond to where value is being lost within each product system rather than applying identical instruments and performance expectations across materially different waste streams.

4.5. Implications of the Circularity-Progression Benchmark

The circularity-progression benchmark helps reconcile apparently contradictory assessments of EPR performance. A system may perform strongly at Level 1 while remaining weak at Levels 4 and 5. This does not necessarily indicate policy failure. It indicates that the system is achieving a narrower form of producer responsibility than contemporary circular-economy objectives increasingly require. Conversely, sophisticated eco-design provisions cannot compensate for weak producer registration, collection, or controlled treatment where those foundational functions remain ineffective.

The benchmark also provides a basis for comparing EPR systems at different stages of development without assuming that identical policy instruments are appropriate everywhere. Jurisdictions still establishing reliable producer identification, collection, financing, and controlled treatment face different priorities from mature systems in which these functions are already institutionalized. In the latter, continued reliance on collection and recycling indicators may underestimate the need to advance toward value retention, secondary-material substitution, product-life extension, and prevention.

This relationship becomes especially important when EPR policies are transferred between jurisdictions. Advanced instruments such as eco-modulated fees, detailed traceability requirements, or sophisticated circularity targets may represent desirable policy directions, but their effectiveness depends on the capabilities required to administer and enforce them. Where producer information, regulatory capacity, collection infrastructure, treatment systems, secondary-material markets, or reliable data remain incomplete, additional policy sophistication may increase formal obligations without generating equivalent improvements in circular performance.

The cross-stream analysis therefore establishes what EPR appears capable of achieving and where its circular performance becomes less consistent. It does not, by itself, explain why comparable producer-responsibility principles generate different outcomes across implementation environments. Section 5 addresses that question by examining the institutional, producer-accountability, stakeholder, financing, market, technological, and information conditions that shape EPR implementation and determine how far producer responsibility can progress toward higher-order circularity.

5. Determinants of EPR Implementation and Circularity Performance

The cross-stream analysis shows that product characteristics influence the circular pathways available to EPR but do not fully explain differences in performance. Similar producer-responsibility instruments can generate different outcomes across jurisdictions, while ambitious regulatory provisions may produce limited material effects where the conditions required for implementation are incomplete. Through the iterative coding and synthesis described in Section 2.6, recurring explanatory factors were consolidated into five determinant groups. These comprise institutional capacity and governance, producer compliance and accountability, stakeholder and informal-system integration, financing, infrastructure and secondary-material markets, and technology, traceability and information systems.

These determinants should not be interpreted as independent variables or as equally important under all circumstances. Some provide foundational capabilities required for basic EPR operation, while others become increasingly important as systems progress toward higher levels of circularity. Their significance also varies according to the waste stream and implementation context. What matters is therefore not simply whether individual capabilities exist, but whether they function together sufficiently to support the level of producer responsibility being pursued.

The determinant synthesis combines empirical, review, policy, institutional, and technical evidence rather than a single study design. The strength of each determinant was therefore interpreted alongside the type, directness, and consistency of the contributing sources, applying the instrument-specific decision rules set out in Supplementary Table S3 rather than a pooled quality score.

5.1. Institutional Capacity and Governance

Institutional capacity provides the foundation through which EPR obligations become operational. Effective implementation requires clear regulatory mandates, reliable producer registration, enforceable obligations, monitoring capacity, transparent reporting, credible sanctions, and coordination among responsible institutions [23–25,189]. Where responsibilities are fragmented among environmental regulators, ministries, municipalities, customs authorities, and PROs without effective coordination, accountability can become diffuse and enforcement inconsistent.

Regulatory clarity is particularly important [190]. Producers must be identifiable, covered products and responsibilities must be defined, reporting requirements must permit verification, and responsibilities for historical or orphan products must be clear. Ambiguity over financing, reporting, collection, or treatment responsibilities increases transaction costs and creates opportunities for non-compliance. The existence of EPR legislation therefore provides limited evidence of implementation effectiveness unless the responsible institutions possess sufficient authority, information, resources, and coordination capacity to enforce it.

Institutional requirements also increase with policy sophistication [191]. Basic producer registration and collection obligations require less administrative capability than eco-modulated fees, recycled-content requirements, differentiated circularity targets, or detailed digital traceability. Advanced instruments depend on reliable product information, verification procedures, technical expertise, and sustained regulatory oversight. Introducing them without these capabilities can increase formal complexity without generating equivalent improvements in environmental performance.

Continuity is equally important because EPR systems develop over time [192]. Collection networks, compliance organizations, reporting systems, recycling investments, and secondary-material markets require predictable rules and sustained implementation. Frequent regulatory changes, overlapping mandates, uncertain enforcement, or unstable ad-

ministrative arrangements can weaken investment and confidence throughout the system. Governance quality therefore depends not only on the existence of regulation but also on its clarity, coordination, continuity, and credible application.

5.2. Producer Compliance and Accountability

EPR depends on the ability to identify producers and connect products placed on the market with corresponding financial and operational obligations. Incomplete producer registries and weak free-rider controls can shift a disproportionate share of system costs onto compliant firms and undermine both financial sustainability and confidence in collective arrangements [23,24].

PROs can reduce transaction costs by coordinating collection, contracting recovery operators, managing reporting, and distributing compliance costs among producers. Collective responsibility, however, can weaken individual accountability where producer performance becomes difficult to distinguish. This matters particularly when EPR is expected to influence upstream outcomes such as durability, recyclability, material selection, and eco-design.

Accountability therefore extends beyond payment of producer fees. Effective systems require credible connections among quantities placed on the market, financial contributions, collection, treatment pathways, recovered materials, and reported outcomes. Independent verification and transparent reporting can reduce free-riding, under-reporting, and unsupported recovery claims. Without such mechanisms, compliance may remain largely documentary rather than materially connected to circular performance.

Fee design can also influence producer behavior. Flat or weakly differentiated fees may finance collection while providing little incentive for product improvement. Eco-modulation attempts to strengthen this connection by relating producer costs to characteristics such as recyclability, durability, repairability, recycled content, hazardous-material use, or treatment requirements [29]. Its effectiveness depends on the strength of the financial signal and the ability to measure and verify the characteristics on which differentiation is based. Complex fee structures provide little additional circular benefit if the underlying information or enforcement system is weak.

These accountability requirements are particularly consequential in developing-country settings, where limited enforcement capacity, incomplete producer information, financing constraints, and extensive informal recovery can weaken the connection between formal obligations and actual material flows [35,36,64]. In many Sub-Saharan African systems, producer compliance must therefore be assessed alongside the capacity to identify obligated firms, finance collection and treatment, and connect existing informal recovery networks to verifiable downstream pathways. Where these capabilities lag behind regulatory ambition, the implementation-readiness gap widens even when formal EPR obligations are already in place.

5.3. Stakeholder and Informal-System Integration

EPR operates through networks that include producers, regulators, municipalities, PROs, retailers, consumers, formal recyclers, repair enterprises, collectors, waste pickers, aggregators, and informal dismantlers. These relationships are especially important where informal and semi-formal actors already undertake substantial collection, repair, resale, refurbishment, and material recovery before formal EPR arrangements are introduced [35,36].

Informal recovery can support circularity by extending collection coverage, recovering economically valuable materials, and preserving products through repair, refurbishment, resale, and component harvesting. These activities can be particularly important for electronics and other products with residual functional value. At the same time, unsafe dismantling, open burning, uncontrolled chemical processing, and inadequate handling of hazardous

fractions can create serious occupational and environmental risks [5,193]. The relevant policy challenge is therefore not a simple choice between formalization and exclusion. It is to retain useful recovery and value-retention functions while progressively eliminating unsafe practices.

Practical integration can include PRO-financed service or collection payments, contractual relationships with collector cooperatives or associations, designated municipal spaces for collection and aggregation, training, occupational safeguards, record keeping, and documented transfer to authorized downstream processors. Such arrangements can connect existing recovery networks with producer financing and environmental oversight rather than attempting to replace them entirely.

Integration also has important distributional implications. Formal EPR arrangements can redirect valuable material flows away from existing collectors if compliance organizations obtain control over recoverable materials without creating participation pathways. Conversely, dependence on poorly protected informal labor can allow producers to meet formal obligations while environmental and occupational risks remain concentrated among workers. Effective integration must therefore consider both who captures the economic value created by EPR and who bears the risks associated with collection and recovery.

Gender is relevant within this distributional dimension because participation, earnings, occupational exposure, and access to higher-value activities within informal recovery systems are not necessarily distributed evenly. Where women participate disproportionately in lower-paid sorting, trading, or peripheral recovery activities, formalization that recognizes only registered collectors or larger enterprises may reproduce existing inequalities or displace livelihoods. Gender-sensitive integration should therefore examine participation and benefit distribution alongside environmental and occupational safeguards rather than treating informal workers as a homogeneous category.

5.4. Financing, Infrastructure, and Secondary-Material Markets

Producer financing is necessary for EPR, but financial contributions alone do not establish circular performance. Funds must translate into collection networks, aggregation systems, sorting capacity, treatment facilities, logistics, monitoring, and viable end markets. Weakness in any of these components can result in materials being collected without appropriate processing or recycled without returning to productive use.

Collection and treatment capacity must develop in relation to one another. Aggressive collection targets can create bottlenecks where sorting or processing capacity is insufficient, while sophisticated treatment facilities may remain underutilized where collection systems cannot supply adequate and predictable feedstock. Infrastructure planning should therefore respond to actual material flows and recovery pathways rather than operate as an isolated technological intervention.

Secondary-material markets become increasingly important as EPR progresses beyond collection and treatment. Greater recovery does not guarantee circularity if manufacturers cannot or will not use the resulting materials. Price volatility, contamination, inconsistent quality, inadequate standards, competition from inexpensive virgin materials, and uncertain demand can weaken recycling economics even where collection performs well. This is especially important at Level 3 of the circularity-progression benchmark because the relevant outcome is actual substitution of secondary resources for virgin inputs.

EPR may consequently require coordination with demand-side instruments. Recycled-content requirements, quality standards, green public procurement, product specifications, and other market-development measures can strengthen demand for recovered materials. Their feasibility nevertheless depends on domestic processing and manufacturing capability.

Requirements that exceed available supply, quality, or industrial capacity may create formal compliance obligations without establishing viable circular flows.

Financing arrangements should also recognize differences in material value and recovery cost. High-value fractions may attract commercial collection, whereas low-value, hazardous, contaminated, or geographically dispersed materials may require stronger producer support. Uniform financing can encourage selective recovery of profitable materials while leaving environmentally important but economically unattractive fractions unmanaged. Effective financing should therefore reflect the actual costs of achieving the intended environmental and circular outcomes.

5.5. Technology, Traceability, and Information Systems

Information systems are increasingly important to EPR implementation. Producer registries, electronic reporting, product identifiers, material databases, digital product passports, and tracking technologies can improve visibility over products placed on the market and their subsequent recovery [15,16,94]. These tools can strengthen compliance verification, identify material flows, support treatment decisions, reduce free-riding, and provide evidence for policy adjustment.

Digitalization, however, cannot substitute for foundational implementation capacity. A sophisticated traceability platform cannot correct incomplete producer registration, unreliable reporting, weak enforcement, or inadequate collection infrastructure. Its value depends on data quality, interoperability, verification, and the ability of regulators and PROs to act on the information generated. Technology strengthens governance most effectively when it is embedded within functioning institutions.

Traceability is particularly important where products move through multiple ownership stages or across jurisdictional boundaries. E-waste illustrates this problem because repair, resale, refurbishment, export, and informal recovery can separate a product from the producer-responsibility arrangement under which it was initially marketed [101]. Better information continuity can help distinguish legitimate product-life extension from uncontrolled waste movement and support more accurate allocation of end-of-life responsibilities.

Information systems also support policy learning. Reliable data on products placed on the market, collection, treatment, material quality, recovery pathways, producer participation, and compliance can reveal where implementation is failing and where policy adjustment is required. Traceability therefore contributes most strongly to circularity when information feeds back into enforcement, fee design, infrastructure planning, target setting, and system improvement rather than functioning solely as a reporting requirement.

5.6. Interdependence and Operationalization of the Determinants

The five determinant groups are analytically distinguishable but operationally interdependent. Producer financing cannot compensate indefinitely for weak regulation, treatment infrastructure cannot generate circularity without reliable collection and viable markets, digital traceability cannot resolve incomplete producer registration, and ambitious targets cannot deliver sustained outcomes where the actors responsible for material recovery are excluded.

This interdependence helps explain why EPR performance cannot be inferred from policy design alone. Jurisdictions with similar statutory obligations may produce different outcomes because the systems surrounding those obligations differ. Conversely, comparatively simple regulatory arrangements may produce meaningful results where producer identification, enforcement, financing, collection, stakeholder participation, treatment, and markets function coherently.

The determinants also become important at different stages of circular progression. Institutional capacity, producer identification, financing, collection, and accountability provide foundational conditions for Levels 1 and 2. Progress toward secondary-material substitution requires stronger processing capability and market demand. Product-life extension additionally depends on repair, reuse, refurbishment, retreading, and the participation of actors capable of preserving functional value. Upstream prevention and eco-design place still greater demands on producer incentives, product information, verification, and the ability to connect product characteristics with environmental costs. Implementation requirements therefore become broader as circular ambition increases.

Table 4 translates these determinant groups into observable indicators. Its purpose is not to rank jurisdictions through a universal readiness score. Rather, it identifies evidence through which the capabilities required for implementation can be examined and compared. The relevance and relative importance of individual indicators may vary according to waste stream and institutional context. For operational use, the five groups were disaggregated into eight readiness conditions in Supplementary Table S4, Part A. Producer visibility and identification separates the registration and identification component of producer compliance and accountability; financial accountability and additionality separates the financing component of financing, infrastructure and secondary-material markets; and recovery hierarchy and processing quality separates the infrastructure and processing component of the same group. The three additional conditions do not introduce explanatory factors beyond those developed here. They make components of the five groups separately observable and measurable, and they are used in that operational sense throughout Supplementary Table S4.

Table 4. Determinants and observable indicators of EPR implementation readiness.

Determinant	Observable Indicators	Indicative Evidence and Data Sources	Circularity Relevance
Institutional capacity and governance	Clear statutory mandates; functioning regulator; producer-registry coverage; monitoring; enforcement actions; institutional coordination	Legislation; regulatory reports; producer registries; enforcement records; institutional assessments	Provides the governance foundation required across all benchmark levels
Producer compliance and accountability	Producer registration; free-rider controls; verified quantities placed on the market; fee payment; PRO reporting; independently verified recovery	PRO reports; regulatory databases; audits; compliance records	Connects producer obligations with measurable downstream and upstream outcomes
Stakeholder and informal-system integration	Participation mechanisms; service contracts; cooperative or association involvement; designated operating spaces; occupational safeguards; documented material transfers	Municipal records; PRO contracts; cooperative records; field studies; occupational-health assessments	Supports collection, repair, reuse, refurbishment, value retention, and socially inclusive recovery
Financing, infrastructure, and secondary-material markets	Revenue sufficiency; collection coverage; sorting and treatment capacity; facility utilization; recyclate quality; secondary-material demand; recycled-content uptake	Financial reports; facility data; market statistics; material-flow studies; industry reports	Determines whether captured materials progress from collection toward value retention and substitution
Technology, traceability, and information systems	Digital producer registration; product or material identification; electronic reporting; verified chain of custody; data interoperability; performance feedback	Digital registries; traceability platforms; audits; regulator and PRO information systems	Strengthens accountability, material tracking, policy learning, and higher-order circularity

The indicators in Table 4 make implementation readiness observable without assuming that a single composite score can adequately represent diverse jurisdictions and waste

streams. For example, informal-system integration may be particularly important where existing collectors dominate material capture, whereas secondary-material demand may become the principal constraint after collection and treatment systems are well established.

The evidence therefore supports a capability-dependent interpretation of EPR implementation. Formal adoption identifies the existence of producer responsibility, but not whether the capabilities required to execute that responsibility have developed sufficiently or in a compatible sequence. The resulting mismatch between policy demands and available implementation capability provides the basis for the implementation-readiness gap examined through the Sub-Saharan African cases in Section 6.

6. EPR Implementation in Sub-Saharan Africa

The implementation conditions identified in Section 5 are particularly visible in Sub-Saharan Africa, where EPR is developing within waste systems that differ substantially in regulatory capacity, infrastructure, market development, and the organization of material recovery. Formal producer-responsibility arrangements frequently coexist with incomplete producer registration, uneven collection coverage, limited treatment capacity, fragmented institutional responsibilities, and extensive informal recovery [35,36]. These conditions make the region useful for examining how EPR performs when regulatory ambition and implementation capability develop at different rates.

Two characteristics are especially important. First, EPR often enters material economies in which informal and semi-formal actors already undertake collection, repair, resale, refurbishment, dismantling, and recycling. These activities can preserve considerable product and material value, although unsafe practices and weak traceability can create environmental and occupational risks. Second, increasingly sophisticated EPR instruments depend on foundational capabilities involving producer identification, enforcement, financing, reliable data, collection, treatment, and markets. The central issue is therefore whether policy requirements are matched by the capabilities necessary to make them operational.

6.1. Comparative Context

EPR development across the selected Sub-Saharan African jurisdictions reflects different regulatory and implementation trajectories rather than a common regional pathway. South Africa has comparatively institutionalized mandatory producer-responsibility arrangements, while Kenya has developed a more comprehensive statutory EPR architecture. Nigeria combines formal producer-responsibility requirements and active PRO structures with fragmented material flows. Ghana has established important regulatory and financing arrangements for e-waste within a recovery economy that remains strongly influenced by informal activity. Rwanda provides evidence of formal e-waste infrastructure, while Senegal and Togo contribute emerging perspectives on circular financing and end-of-life tire management [37–44,194–196].

The seven cases are used for theoretical comparison rather than statistical representation of Sub-Saharan Africa [197–199]. Nigeria, South Africa, Kenya, and Ghana provide the deeper evidence base and therefore serve as the principal comparative cases. Rwanda, Senegal, and Togo are retained as supplementary cases because they broaden the institutional and geographical comparison, but conclusions drawn from them are interpreted more cautiously where the available literature is thinner. This distinction is important because differences in the quantity of available evidence should not be mistaken for differences in implementation performance.

The comparison considers both the legal basis of EPR and the capabilities available for implementation [200–202]. Primary legislation and regulations are used to establish formal obligations, while peer-reviewed and institutional evidence is used to examine how those

obligations operate in practice. This distinction prevents regulatory adoption from being treated as equivalent to implementation readiness.

The Sub-Saharan African comparison is supported by a mixed evidence base of peer-reviewed studies and authoritative legislative, regulatory, institutional, and technical sources [203–205]. Evidence depth is strongest for Nigeria, South Africa, Kenya, and Ghana and thinner for Rwanda, Senegal, and Togo; the type, directness, and volume of evidence available for each jurisdiction, together with the source characteristics recorded in Supplementary Table S2, therefore inform the degree of caution applied to each country's interpretation. Supplementary Table S3 records the appraisal instrument and decision rules applicable to each contributing source.

Figure 2 presents the geographical distribution of the seven Sub-Saharan African jurisdictions included in the comparative analysis, locating each case within Western, Eastern and Southern Africa. Legal and regulatory status, and the corresponding evidence on implementation readiness, are reported separately in Table 5 and Supplementary Table S4 (Parts A and B).

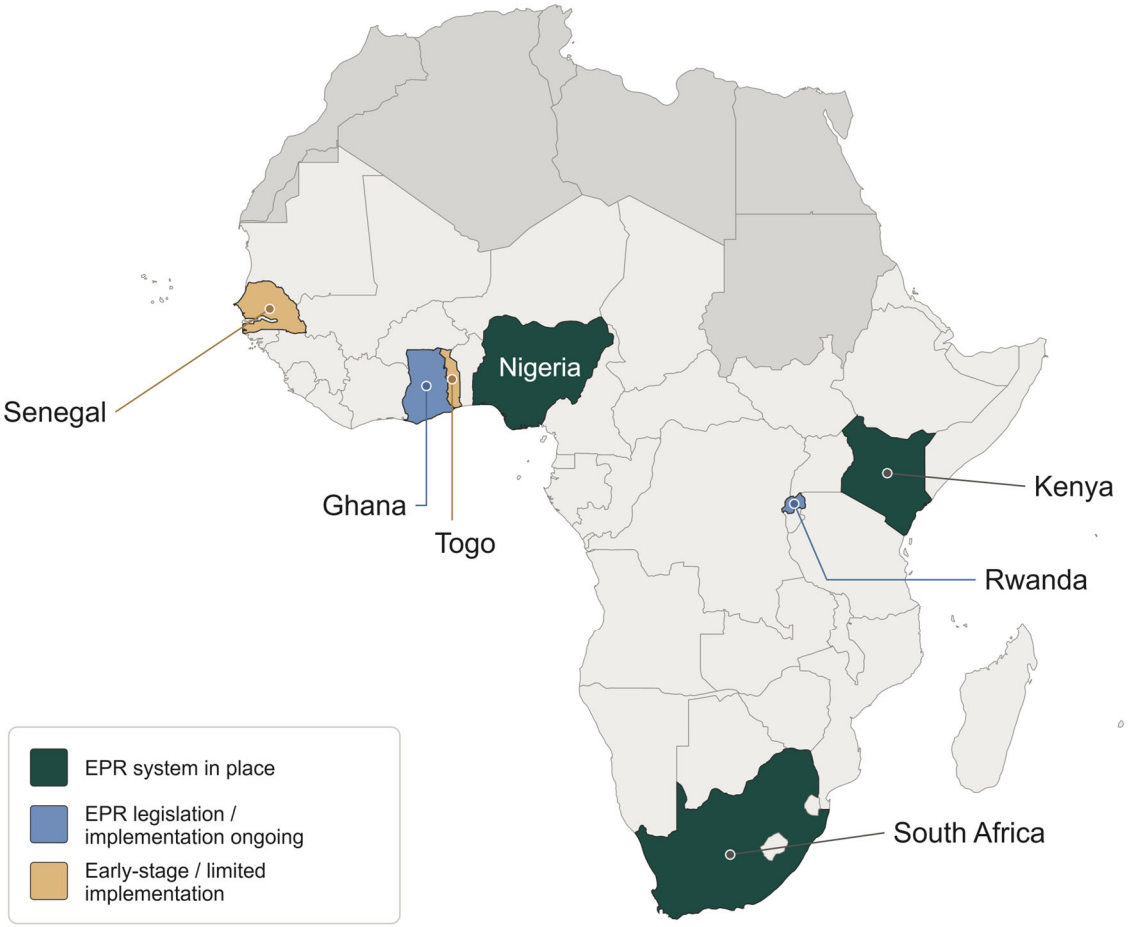


Figure 2. Geographical distribution of the seven Sub-Saharan African jurisdictions included in the comparative EPR analysis. Authors' own compilation. Figure generated using Google Nano Banana 2 and verified by the authors against the documented study-selection records.

6.2. Nigeria

Nigeria illustrates the difficulty of connecting formal producer responsibility with material flows in a large and fragmented waste economy [206–208]. Producer-responsibility provisions and PRO arrangements provide a regulatory basis for EPR, but implementation

continues to operate alongside uneven producer participation, substantial informal recovery, limited traceability, and variable collection and processing capacity. The principal problem is therefore not simply the existence or absence of policy. It is whether formal obligations can be translated into identifiable and verifiable material outcomes.

Packaging and plastics make this challenge particularly visible [209,210]. Weak source separation, fragmented collection, variable processing quality, and uncertain demand for recovered materials can restrict the circular value generated by producer financing. Greater collection can reduce leakage and uncontrolled disposal, but higher-order circularity depends on whether recovered materials reach suitable processing systems and return to productive use. The Nigerian experience therefore reflects the material-throughput problem identified in Section 4.

E-waste adds informality and transboundary movement. Used electronics may pass through importation, resale, repair, secondary ownership, component harvesting, and informal dismantling before final treatment. Evidence concerning used electronics entering Nigeria demonstrates how the jurisdiction in which producer responsibility originates can become separated from the jurisdiction in which products ultimately reach end of life [101,211–213]. Informal operators nevertheless perform important collection, repair, reuse, and recovery functions. Effective EPR must therefore connect these functions with producer financing, safer dismantling, occupational safeguards, traceability, and authorized downstream treatment rather than simply attempting to displace them.

End-of-life tires present a different value-retention problem [214,215]. Collection and diversion are beneficial, but their circular significance depends on whether suitable tires remain available for continued use or retreading and whether recovered materials enter productive applications rather than predominantly lower-value pathways. Across the three streams, the common Nigerian constraint is the incomplete connection among producer obligations, material capture, processing, information, and downstream markets.

6.3. South Africa

South Africa provides a contrasting case because producer responsibility is more institutionalized across several product categories [216]. Mandatory arrangements, established compliance organizations, regulatory oversight, and a more developed formal recycling sector provide comparatively stronger foundations for producer registration, financing, collection, and reporting. Greater institutional maturity, however, changes the nature of the implementation challenge rather than eliminating it.

This is particularly evident in packaging. Evidence indicates progress in plastics circularity while also identifying continuing limitations in pathways capable of retaining recovered material at higher value [40,217]. As foundational functions become more established, attention shifts from whether materials are collected toward recycling quality, secondary-material substitution, market demand, accountability for producer expenditure, and domestic value retention.

Similar considerations apply to e-waste and tires [40]. Formal treatment capacity does not ensure that all products are captured or that recovered resources return to high-value applications. Repair, refurbishment, retreading, recycling, and lower-value recovery also preserve different amounts of functional and material value. South Africa therefore demonstrates that narrowing foundational implementation gaps can expose a second set of constraints associated with higher-order circularity. The policy challenge increasingly concerns accountability, inclusion, processing quality, viable secondary-material markets, and stronger incentives for value retention and upstream improvement.

6.4. Kenya

Kenya represents a comparatively recent but increasingly structured EPR environment. Its regulatory development places growing emphasis on producer registration, recovery planning, reporting, compliance, and responsibility for post-consumer materials [39,218]. This creates an important test of whether operational capability can develop alongside ambitious regulatory requirements.

Packaging and plastics are especially relevant. Evidence from Kenya and the wider East African context identifies continuing challenges in sustainable packaging and plastic management [43]. Digital systems can improve producer identification, reporting, traceability, and accountability [39], but their effectiveness depends on the underlying institutional system. Electronic registration cannot compensate for non-registration, inaccurate reporting, weak enforcement, inadequate collection, or insufficient processing capacity.

Kenya also has an opportunity to integrate existing recovery actors while its EPR institutions are developing [93]. Producer-financed service arrangements, recognized collector organizations, designated collection and aggregation spaces, occupational safeguards, and traceable transfer to authorized processors could connect existing material-recovery functions with the formal system. The principal implementation risk is therefore not excessive regulatory ambition itself, but ambition advancing faster than the institutional, infrastructural, stakeholder, and information capabilities required to support it.

6.5. Ghana

Ghana presents a distinctive configuration because formal environmental governance intersects with a deeply established informal e-waste economy. Regulatory and financing developments coexist with material and livelihood networks through which electronics are collected, repaired, traded, dismantled, and recovered [37,219,220]. Formal assignment of producer responsibility does not automatically reorganize these networks.

Informal e-waste recovery illustrates this duality [221,222]. Repair, resale, component harvesting, and material recovery can extend product life and preserve economic value. Unsafe dismantling and processing, however, can expose workers and surrounding communities to hazardous substances. The relevant distinction is therefore not between formal activity as inherently desirable and informal activity as inherently problematic. It is between practices that retain value safely and those that externalize environmental and occupational costs.

EPR financing can support safer collection and aggregation, improved equipment, occupational protection, training, traceability, and connections with authorized processors [223,224]. Compensated participation and organized collector associations can also provide interfaces between producers and dispersed recovery workers. Ghana consequently demonstrates that informal-system integration is not peripheral to implementation readiness. Where existing recovery networks account for substantial material flows, their relationship with formal producer responsibility becomes part of the system itself.

6.6. Rwanda

Rwanda provides a supplementary East African case in which organized institutional arrangements coexist with formal e-waste treatment infrastructure. Available evidence indicates progress in e-waste management while identifying continuing constraints involving collection, financing, public awareness, technical capability, and institutional coordination [38]. Rwanda's e-waste regulatory framework establishes clear producer obligations under Regulation No. 002 of 2018, which requires producers to finance and organize environmentally sound systems for e-waste collection and treatment and to provide dismantling information for products placed on the market [225,226]. The principal challenge therefore

lies not in the absence of legal obligations but in translating these requirements into sustained collection, effective treatment, and verifiable material recovery. Given the smaller evidence base relative to the four principal cases, the conclusions drawn here are necessarily more limited.

The case nevertheless illustrates an important distinction between installed infrastructure and functional recovery capacity [227]. A treatment facility contributes to circularity only when sufficient material reaches it through reliable collection channels and when financing, technical capability, and downstream markets permit productive recovery. Physical infrastructure can therefore coexist with unmanaged material flows or low utilization where collection, producer participation, logistics, or public engagement remain weak.

Rwanda consequently reinforces the systemic interpretation developed in Section 5 [225,228]. Treatment capacity is an important component of readiness, but its circular contribution depends on how effectively it is connected to material capture, financing, information, producer responsibility, and downstream outlets.

6.7. Senegal

Senegal provides a supplementary Francophone West African perspective in which circular-economy development intersects with financing, infrastructure, public policy, and market development. The available evidence identifies opportunities for improved resource recovery alongside constraints involving collection, recycling capacity, investment, institutional coordination, and markets [44]. The legal basis for this distinction is established in Article 11 of Loi n° 2020-04, which assigns producers responsibility for managing waste arising from plastic products placed on the Senegalese market [193,229]. As with Rwanda, the more limited evidence base warrants caution in drawing conclusions beyond the specific evidence reviewed.

Senegal is particularly useful for distinguishing revenue mobilization from circular financing. Environmental charges, fiscal instruments, or producer-related payments can generate revenue, but revenue collection alone does not demonstrate improved circular performance. The relevant question is whether such resources provide additional and identifiable support for collection, sorting, recycling, treatment, regulatory oversight, and market development.

The case therefore highlights financial additionality and expenditure accountability as components of implementation readiness. Financing becomes consequential when it produces demonstrable improvements in material-management capacity rather than functioning primarily as a revenue-collection mechanism.

6.8. Togo

Togo provides a supplementary waste-stream-specific perspective through the emerging application of producer responsibility to end-of-life tires. Available evidence identifies opportunities for improved tire management together with constraints involving collection, financing, institutional coordination, processing capacity, informal participation, and markets for recovered outputs [41]. Togo's environmental law framework establishes the general legal foundation for waste management obligations and the application of the polluter-pays principle [230]. However, no tire-specific producer-responsibility instrument is currently in force. The proposed environmental levy on end-of-life tires should therefore be understood as a potential mechanism for implementing producer responsibility rather than an existing legal obligation [41,231]. The narrower evidence base means that the case is used primarily to illuminate the relationship between treatment pathways and circular value rather than to support broad conclusions about national EPR performance.

Tire circularity depends not simply on whether tires are collected but on what happens after collection. Continued use, technically appropriate retreading, repurposing, material recycling, and lower-value recovery preserve different amounts of product and material value [27,41]. An EPR system may therefore increase collection while achieving limited higher-order circularity if reusable casings are prematurely destroyed or recovered materials enter predominantly low-value applications.

Togo consequently illustrates why processing capacity should not be evaluated solely by the existence of treatment. Technical standards, retreading capability, material quality, downstream markets, and the organization of recovery pathways determine how much circular value is preserved.

6.9. Cross-Country Comparison and the Implementation-Readiness Gap

The seven cases show that the principal distinction in EPR implementation is not simply between jurisdictions with and without producer-responsibility legislation. The nature of the constraint changes with the surrounding implementation system. Nigeria illustrates weak connectivity between formal responsibility and fragmented material flows. South Africa shows how stronger institutionalization shifts attention toward accountability, processing quality, market development, and higher-order value retention. Kenya demonstrates the challenge of building operational capability alongside an increasingly comprehensive regulatory architecture, while Ghana highlights the importance of integrating established informal recovery systems. The supplementary cases add narrower insights into the relationship between treatment infrastructure and material capture in Rwanda, financing and operational additionality in Senegal, and recovery hierarchy in Togo.

Table 5 synthesizes these differences. The classifications are interpretive summaries of the evidence reviewed rather than country scores or rankings. To make the comparison auditable, the table identifies the principal evidence supporting each characterization. Supplementary Table S4 documents the sources underlying this comparison: Part A defines the implementation-readiness indicators, and Part B links each jurisdiction to its implementation configuration, principal readiness constraint, and primary legal/regulatory instrument(s) in force, with the corresponding source identifiers in Supplementary Table S2.

Table 5. Comparative EPR implementation conditions across the seven selected Sub-Saharan African jurisdictions.

Jurisdiction	Implementation Configuration	Principal Readiness Constraint	Circularity Implication	Principal Evidence
Nigeria	Formal EPR operating within fragmented material systems	Producer identification, enforcement, traceability, collection, treatment, and market connectivity	Formal responsibility can remain disconnected from actual material flows	[101,213]
South Africa	Comparatively institutionalized mandatory EPR	Accountability, inclusion, processing quality, secondary-material demand, and value retention	Greater maturity shifts the challenge toward higher-order circularity	[40,232,233]
Kenya	Developing comprehensive mandatory EPR architecture	Compliance, institutional capacity, collection, processing, stakeholder integration, and reliable information	Regulatory ambition requires corresponding operational capability	[39,43,234]

Table 5. *Cont.*

Jurisdiction	Implementation Configuration	Principal Readiness Constraint	Circularity Implication	Principal Evidence
Ghana	Formal regulation interacting with extensive informal e-waste recovery	Safe integration, occupational protection, traceability, and technological upgrading	Formalization should improve rather than displace valuable recovery functions	[37,235]
Rwanda	Formal e-waste institutions and treatment infrastructure	Material capture, financing, utilization, and system coordination	Installed infrastructure does not automatically produce functional recovery	[38,225]
Senegal	Circular-economy and financing-oriented pathway	Financial additionality, infrastructure, institutional coordination, and markets	Revenue must translate into identifiable material-management capacity	[44,229]
Togo	Emerging tire-focused producer-responsibility pathway	Processing capability, financing, markets, and recovery hierarchy	Recovery quality is as important as recovery quantity	[41,230]

The comparison supports the implementation-readiness gap as a relational concept rather than a binary classification of countries as ready or unready. The gap arises when the responsibilities and circular outcomes expected by policy exceed the institutional, financial, infrastructural, informational, market, or stakeholder capabilities available to deliver them. Its form therefore differs across jurisdictions and can change as implementation develops.

This interpretation is consistent with Matland's Ambiguity-Conflict Model [45]. EPR involves multiple actors whose responsibilities, resources, and interests may not align fully. Where responsibilities or expected outcomes remain ambiguous, implementation becomes more dependent on local institutional conditions. Where objectives are clear but actors contest costs, access to materials, enforcement, or institutional authority, implementation may instead be constrained by conflict. The implementation-readiness gap extends this perspective by identifying the practical capabilities through which producer responsibility becomes observable material performance.

The synthesis gives rise to five propositions for subsequent empirical testing:

P1. More complete and verifiable producer registration should be associated with stronger compliance, more reliable EPR financing, and improved traceability of material flows.

P2. Increases in collection should generate stronger circular outcomes where treatment capacity and secondary-material demand develop concurrently than where collection expands in isolation.

P3. Where informal recovery is extensive, EPR systems that provide compensated and traceable participation pathways for existing collectors should achieve greater material capture and safer recovery than systems based principally on exclusion.

P4. Advanced instruments such as eco-modulated fees and digital traceability should have stronger effects where foundational capabilities in producer identification, enforcement, collection, and data quality are already established.

P5. The relationship between EPR financing and circularity performance should be stronger where producer-related revenues are demonstrably additional and linked to identifiable collection, treatment, market-development, or value-retention functions.

In P5, producer-related revenues refer to identifiable fiscal or quasi-fiscal flows generated through producer responsibility. African examples include PRO-administered membership or EPR fees under Kenya's Sustainable Waste Management (Extended Producer

Responsibility) Regulations, 2024 and South Africa's Extended Producer Responsibility Regulations, 2020 [232,234], product-related environmental levies such as the plastic bag levy imposed under the Customs and Excise Act, 1964 [233], and Ghana's advance eco-levy on electrical and electronic equipment under the Hazardous and Electronic Waste Control and Management Act, 2016 (Act 917) [235]. These instruments do not have identical fiscal treatment. For the purpose of P5, the expected circularity effect is stronger where the relevant revenues are ring-fenced or otherwise transparently dedicated to identifiable collection, treatment, market-development, or value-retention functions, with clear reporting on how the funds are used.

These propositions are not presented as established causal relationships. They translate the comparative synthesis into testable expectations and provide a basis for future empirical assessment of the implementation-readiness gap.

7. Discussion

This review indicates that the contribution of EPR to the circular economy depends on a distinction that is often obscured in assessments of policy performance. EPR has demonstrated its strongest and most consistent contribution in assigning responsibility for post-consumer products, financing collection, improving take-back, and supporting controlled recovery. These achievements remain important, particularly where waste collection and treatment systems are incomplete. They do not, however, establish that producer responsibility has generated equivalent progress in material-value retention, product-life extension, secondary-material substitution, waste prevention, or eco-design. The circularity-progression benchmark developed in this review makes this distinction explicit and helps explain why apparently successful EPR systems may still deliver relatively limited upstream transformation.

This finding is broadly consistent with previous studies that have questioned the extent to which conventional EPR influences product design and higher-order circularity [26,28,29,90,91,95]. The contribution of the present review lies in showing that this limitation is not confined to a particular product category. Across packaging, e-waste, and end-of-life tires, the evidence becomes less consistent as expected outcomes move further from collection and treatment toward preservation of functional and material value. The mechanisms differ across waste streams. Packaging is strongly affected by material throughput and recycling quality, e-waste by discontinuities in responsibility across repair, resale, reuse, and transboundary movement, and tires by the hierarchy through which reusable casings and recovered materials are directed. The implication is that EPR should not be judged through a common recovery metric when the forms of value that can be preserved differ substantially among products.

This also has consequences for EPR design. Collection and recycling targets remain necessary, but reliance on these indicators can encourage systems to optimize what is easiest to measure rather than what retains the greatest circular value. A high collection rate may coexist with downcycling, energy recovery, premature destruction of reusable products, or weak substitution of virgin materials. Performance systems should therefore become progressively more discriminating as implementation capacity develops. Measures of recycling quality, recycled-content uptake, repair and reuse, retreading, material substitution, product durability, and waste prevention can complement conventional collection indicators where the underlying data and verification systems are sufficiently reliable. The appropriate performance architecture should consequently reflect both the characteristics of the waste stream and the maturity of the implementation system.

The findings further suggest that policy design cannot be separated from implementation readiness [96]. The implementation-readiness gap developed in this review differs

from a general statement that institutional capacity matters. It concerns the relationship between the demands created by an EPR regime and the capabilities available to execute those demands. A jurisdiction may possess functioning environmental institutions and still experience a substantial readiness gap if EPR requirements exceed available capabilities in producer registration, enforcement, financing, collection, treatment, information, stakeholder coordination, or secondary-material markets. Conversely, improvements in these capabilities can narrow the gap without requiring the policy objective itself to become less ambitious.

This relational interpretation helps explain why regulatory sophistication does not automatically translate into circular performance. Digital traceability, eco-modulated fees, detailed reporting requirements, recycled-content obligations, and product-level information can strengthen EPR, but they depend on more basic systems that identify producers, verify information, collect materials, enforce obligations, and provide environmentally sound treatment. Where those foundations are weak, additional policy complexity can increase administrative requirements without generating corresponding material outcomes. This does not imply that resource-constrained jurisdictions should adopt permanently simplified forms of EPR. Rather, the instruments used at a particular stage should be compatible with the capabilities available to operate them, while institutional development progressively enables more demanding circular objectives.

The Sub-Saharan African cases illustrate this point without supporting a single regional prescription. South Africa's comparatively developed EPR arrangements shift the implementation challenge toward accountability, material quality, inclusion, market development, and higher-order value retention. Kenya illustrates how increasingly comprehensive regulation creates corresponding demands for enforcement, infrastructure, information, and stakeholder participation. Nigeria demonstrates the difficulty of connecting formal obligations to fragmented material flows, while Ghana shows why established informal recovery systems cannot be treated as external to EPR implementation. Rwanda, Senegal, and Togo provide more limited but useful evidence concerning treatment utilization, financial additionality, and recovery hierarchy. These differences support the implementation-readiness gap as a dynamic condition rather than a fixed classification of jurisdictions.

The cross-country comparison also cautions against the direct transfer of EPR instruments between jurisdictions without considering differences in implementation conditions [97]. EPR instruments developed in jurisdictions with mature producer registries, municipal collection, formal recycling industries, reliable reporting, and established secondary-material markets may depend on institutional conditions that are absent or only partially developed elsewhere. Transferring the legal form of such instruments without the systems that make them functional can create compliance structures that appear sophisticated on paper but remain weakly connected to material flows. Policy learning should therefore focus not only on which instruments have been adopted elsewhere but also on the conditions that allowed those instruments to work. The relevant question for policy transfer is not simply whether a particular mechanism represents international good practice, but whether the receiving system can perform the functions on which that mechanism depends.

Informal recovery makes this issue particularly important in many Sub-Saharan African settings. Existing collectors, repairers, traders, aggregators, dismantlers, and recyclers frequently provide functions that formal EPR systems seek to establish, including collection, product-life extension, and material recovery [35,36,236]. Their exclusion can therefore reduce collection reach, destroy livelihoods, or shift valuable material flows without necessarily improving environmental performance. At the same time, integration cannot mean preserving unsafe dismantling or transferring producer obligations to workers with limited protection. PRO-financed service arrangements, collector associations and cooperatives,

designated collection and aggregation spaces, occupational safeguards, training, and traceable transfer to authorized processors provide practical mechanisms through which useful recovery functions can be retained while environmental and occupational standards improve. The gender and livelihood implications identified in Section 5 further indicate that integration should be assessed not only by the quantity of material collected but also by how benefits, risks, and opportunities are distributed.

The evidence therefore supports capability-based sequencing rather than a uniform implementation timetable. The stages proposed in Table 6 are not defined by fixed numbers of years. Progression should occur when observable capabilities demonstrate that additional instruments can be implemented credibly. This approach avoids assuming that jurisdictions with very different starting conditions should advance through EPR development at the same rate.

Table 6. Capability-based sequencing of EPR development.

Stage	Principal Objective	Priority Capabilities and Instruments	Indicators Supporting Progression
Foundational	Establish credible responsibility and controlled material capture	Clear legal mandates; producer registration; free-rider controls; basic reporting; sustainable producer financing; collection and aggregation systems; environmentally sound treatment; practical participation pathways for existing recovery actors	High and improving producer-registration coverage; identifiable financial flows; expanding collection coverage; verified treatment pathways; basic compliance and enforcement functioning
Operational consolidation	Improve accountability, recovery quality, and system coordination	Verified PRO reporting; independent audits; differentiated performance targets; stronger collection-treatment coordination; occupational safeguards; digital reporting; secondary-material standards; market-development measures	Reliable material-flow data; declining free-riding; sufficient treatment utilization; improving recyclate quality; demonstrable stakeholder participation; growing demand for recovered materials
Advanced circularity	Shift incentives toward value retention and upstream change	Robust eco-modulated fees; recycled-content requirements; product-level traceability; repair and reuse incentives; design-for-circularity requirements; durability and repairability measures; advanced secondary-material markets	Verified secondary-material substitution; measurable product-life extension; functioning traceability across value chains; evidence that producer incentives affect design and material choices; reduced dependence on virgin resources

The sequencing in Table 6 should not be interpreted as requiring complete mastery of one stage before any instrument associated with the next can be introduced. Some development will necessarily overlap. Its purpose is to identify dependencies. Eco-modulation, for example, can be introduced before every foundational problem has been resolved, but its effectiveness will remain limited where producer identification and product information are unreliable. Similarly, ambitious recycled-content requirements may stimulate markets, but their implementation becomes difficult where domestic recyclate supply is inconsistent or quality standards are poorly developed. Sequencing therefore concerns the alignment of policy ambition with enabling capability rather than rigid policy stages.

Illustrative findings from the included corpus provide support for, while also qualifying, Propositions P1–P5. For P1, studies of producer compliance and emerging EPR systems show that incomplete registration and free-riding weaken cost allocation and accountability, while Kenyan evidence on producer registration and digital mechanisms points toward stronger traceability when obligated actors can be identified [23,24,39,93]. The evidence for P2 is similarly conditional. Packaging and tire studies show that increased collection or recovery can coexist with downcycling, energy recovery, or weak secondary-material substitution when processing quality and end markets do not develop concurrently [17,19,27,169,170]. For P3, research on waste-picker inclusion and African e-waste systems indicates that existing informal actors can extend collection, repair, and recovery, whereas exclusion or poorly governed informal processing can shift livelihoods and environmental risks rather than resolve them [34–36].

Evidence relevant to P4 also supports a capability condition rather than an automatic technology or fee effect. Lifset et al. [29] found that eco-modulated fees may provide weak design signals when fee differentials, data, or evaluation are inadequate, while digital traceability studies emphasize the dependence of advanced information tools on reliable registration, reporting, and institutional use of the resulting data [94]. P5 is supported by evidence that producer financing can strengthen collection and recovery only when revenues translate into operational capacity and viable material pathways [25]. Senegal provides a useful qualification because financing-oriented circular policy does not by itself establish additional collection, treatment, or market capacity [44]. These examples do not constitute causal tests of the propositions. Rather, they show that the propositions are consistent with recurring patterns in the reviewed evidence while retaining clear conditions under which the expected relationships may weaken or fail.

This interpretation also clarifies the role of Matland's Ambiguity-Conflict Model [45]. EPR implementation problems do not arise solely from technical shortages. Ambiguity over responsibilities, reporting requirements, recovery standards, or the treatment of informal actors can make outcomes dependent on local implementation environments. Conflict can arise over compliance costs, access to valuable materials, allocation of producer fees, institutional authority, and enforcement. Greater administrative capability may reduce some forms of ambiguity without resolving conflicts over costs or material value. The implementation-readiness gap complements this perspective by identifying the operational capabilities through which these policy conditions are translated into, or prevented from becoming, material outcomes.

Several qualifications are necessary when interpreting these findings. The reviewed evidence is heterogeneous in design, outcome measurement, waste-stream coverage, and geographical depth, which is why the synthesis does not treat qualitative evidence judgments as effect estimates. Evidence is also uneven across the seven African cases, with substantially deeper literature for Nigeria, South Africa, Kenya, and Ghana than for Rwanda, Senegal, and Togo. The latter cases broaden the institutional comparison but should not be interpreted as carrying equivalent evidentiary weight. Publication and language bias may also remain despite the inclusion of multilingual and institutional evidence. In addition, the implementation-readiness propositions developed here are analytically derived from the reviewed evidence and require empirical testing before they can support causal claims or universal thresholds. These limitations constrain the strength of some comparative conclusions but do not alter the central distinction between formal EPR adoption, implementation capability, and realized circular performance.

The review process also has limitations. The primary search was restricted to the period from 1 January 2020 to 15 August 2026, with earlier seminal sources retained only where required for conceptual or historical context. Searches were conducted in English, although

eligible French-, Spanish-, and Portuguese-language evidence was considered where sufficient information or reliable translation was available. Gray-literature retrieval depended on the indexing and search functions of institutional, regulatory, PRO, and legislative websites and may therefore have missed poorly indexed documents. Data extraction was undertaken by one author and verified by the second rather than performed independently in duplicate. The review was not prospectively registered, and no formal protocol was deposited, although the review procedures were prespecified within the study workflow. Finally, the appraisal framework in Supplementary Table S3 assigns an instrument, a domain set, and decision rules to every included source but does not tabulate criterion-level appraisal ratings for the 236 sources, so the appraisal operates as a weighting framework rather than as a reported scoring exercise and source-level scores cannot be inspected by readers.

Future research should therefore move beyond documenting whether EPR legislation or PRO arrangements exist and test how particular capabilities influence measurable outcomes over time. Longitudinal analysis could examine whether changes in producer-registration coverage, enforcement, financing, treatment capacity, or secondary-material demand precede improvements in circular performance. Comparative case designs could test whether similar EPR instruments produce different outcomes under different readiness conditions. Material-flow analysis could determine whether increased recovery actually displaces virgin inputs, while agent-based modeling could examine interactions among producers, PROs, regulators, collectors, consumers, and informal actors under alternative policy designs. Multi-criteria decision analysis may also help jurisdictions evaluate instrument choices where environmental, institutional, economic, and social objectives must be balanced. The five propositions developed in Section 6 provide a starting point for this empirical agenda.

The broader implication is that EPR should be understood neither as a stand-alone recycling policy nor as an automatic route to circularity. It is a governance mechanism whose contribution expands as responsibility becomes more effectively connected to products, material flows, recovery actors, markets, and upstream production decisions. Collection and controlled treatment remain essential foundations, particularly where unmanaged waste presents immediate environmental and health risks. Higher-order circularity requires additional capabilities and incentives that preserve product and material value before it is lost. The policy challenge is therefore not to choose between basic waste management and ambitious circularity, but to build implementation systems capable of progressing from one toward the other without allowing regulatory ambition to become detached from operational reality.

8. Conclusions

This systematic review examined whether EPR can deliver circular-economy outcomes across packaging waste, electronic waste, and end-of-life tires, with evidence from seven Sub-Saharan African jurisdictions providing a comparative implementation perspective. The findings show that EPR can make an important contribution to circularity, but the extent of that contribution depends on both the level of circular ambition and the conditions under which producer responsibility is implemented. Its most consistent achievements remain in financing and organizing collection, take-back, controlled treatment, and recycling. Progress toward higher-order outcomes, including secondary-material substitution, product-life extension, waste prevention, and eco-design, is more variable.

The circularity-progression benchmark developed in this review helps distinguish these different levels of performance. This distinction is important because high collection or recovery rates do not necessarily indicate equivalent preservation of product and material value. Packaging, e-waste, and tires also present different circularity challenges, which

limits the usefulness of uniform performance expectations across waste streams. Effective EPR should therefore be assessed according to both the quantity of material recovered and the extent to which products and resources remain in productive use at higher value.

The comparative evidence further shows that formal EPR adoption does not by itself determine performance. Institutional capacity, producer accountability, financing, infrastructure, stakeholder participation, traceability, and secondary-material markets influence whether regulatory obligations translate into observable material outcomes. The implementation-readiness gap captures the mismatch that arises when the demands embedded in EPR policy exceed the capabilities available to execute them. The experiences of Nigeria, South Africa, Kenya, Ghana, Rwanda, Senegal, and Togo demonstrate that this gap takes different forms according to existing regulatory, economic, infrastructural, and recovery conditions.

These findings support a capability-based approach to EPR development. Foundational functions involving producer identification, credible enforcement, sustainable financing, collection, and environmentally sound treatment provide the basis on which more demanding instruments can operate. As these capabilities strengthen, greater emphasis can be placed on recovery quality, secondary-material markets, traceability, product-life extension, eco-modulation, and upstream product design. Such progression should be determined by demonstrated implementation capability rather than a uniform timetable or the direct replication of instruments developed under different institutional conditions.

EPR should therefore be understood as an evolving system of producer responsibility rather than a stand-alone recycling mechanism. Its contribution to the circular economy increases when responsibility remains connected to products, material flows, recovery actors, markets, and production decisions throughout the value chain. For Sub-Saharan African jurisdictions, the central challenge is not simply to adopt increasingly ambitious EPR rules, but to develop the institutional and operational capabilities that allow those rules to produce measurable improvements in resource retention and circularity. Under these conditions, EPR can progress from managing waste after it is generated toward influencing how products and materials are designed, used, recovered, and returned to productive use.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su182111410/s1, Table S1: Database search strategies, parameters, retrieval counts, and benchmark-publication verification; Table S2: Master catalog of the 236 included sources with bibliographic and analytical characteristics; Table S3: Appraisal framework applied to the corpus, recording for each of the 236 sources the applicable JBI, AMSTAR 2, or AACODS instrument, its domains, permitted judgments, and decision rules, with the source-level framework record (Part B) and the instrument-specific decision rules (Part C); Table S4: Implementation-readiness operationalization matrix with observable indicators, data sources, and measurement guidance (Part A), and per-jurisdiction legal, institutional, and source-level evidence linkage (Part B); PRISMA 2020 checklist: Completed checklist reporting where each of the 27 items is addressed in this article.

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