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Design and Preliminary Evaluation of the Institutional Circular Resource Recovery Framework (ICRRF): A Socio-Technical Circular Economy Model for Sustainable Educational Resource Generation

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Abstract

Municipal solid waste and unequal access to educational resources remain per-sistent global challenges that are frequently addressed through independent inter-ventions. While recycling initiatives primarily focus on environmental outcomes, educational support programmes often depend on continuous external donations, limiting their long-term sustainability. This paper presents the design and prelim-inary evaluation of an institutional circular economy framework that transforms recurring recyclable waste streams into sustainable educational resources through certified recycling partnerships and decentralized community participation.

The proposed framework integrates educational institutions, residential com-munities, authorised recycling organisations, non-profit distribution partners, and student ambassadors into a coordinated resource recovery ecosystem. Rather than treating recyclable waste as an end-of-life disposal problem, the framework captures its residual economic value and redirects the recovered revenue towards educational resources for under-resourced children. The framework is further designed to incor-porate a digital platform for household collection requests, operational coordination, and impact tracking to support future scalability.

The framework was evaluated through its implementation by Divyadaan Foun-dation in Bengaluru, India. At the time of writing, the pilot has facilitated the responsible recycling of approximately 1.7 tonnes of paper and electronic waste, supported the distribution of more than 800 notebooks, and reached approximately 3,320 individuals through recurring collection campaigns conducted in collabora-tion with educational institutions, authorised recycling partners, and charitable organisations.

The pilot provides preliminary evidence supporting the operational feasibil-ity of integrating institutional waste recovery, circular economy principles, and community-led participation within a unified operational framework capable of supporting measurable environmental and educational outcomes. The proposed framework offers a transferable model that may be adapted by educational institu-tions, community organisations, and municipalities seeking sustainable approaches to

resource recovery and social impact.

Keywords: Circular Economy, Humanitarian Engineering, Resource Recovery, Edu-cational Sustainability, Waste Management, Social Innovation, Institutional Recycling

1 Introduction

Municipal solid waste (MSW) generation has grown rapidly over recent decades as a result of urbanization, population growth, and changing consumption patterns. Recyclable paper waste and electronic waste (e-waste) constitute a significant proportion of this waste stream and represent both an environmental challenge and a valuable resource if recovered effectively. However, inadequate segregation, inefficient collection systems, and improper disposal continue to limit resource recovery in many regions. At the same time, educational support initiatives that provide learning materials to under-resourced students frequently depend on charitable donations and periodic fundraising, making their long-term sustainability uncertain.

The circular economy has emerged as an alternative to the traditional linear "take–make–dispose" model by promoting resource recovery, reuse, and value retention through-out the lifecycle of materials. Rather than treating waste solely as a disposal problem, cir-cular economy approaches seek to recover economic value from discarded resources while reducing environmental impacts. Consequently, governments, industries, and researchers have increasingly explored circular economy strategies to improve waste management and resource efficiency.

Despite these advances, existing circular economy implementations are predominantly designed to optimize environmental outcomes, such as increasing recycling rates or re-ducing landfill waste. Comparatively less attention has been given to operational models that simultaneously generate measurable social value from recovered resources. Fur-thermore, limited research has examined scalable frameworks that integrate institutional recyclable waste streams with broader community participation to create sustained hu-manitarian outcomes. This presents an opportunity to explore socio-technical approaches that leverage circular economy principles to address both environmental and social chal-lenges within a unified operational framework.

To address this gap, this paper proposes the **Institutional Circular Resource Re-covery Framework (ICRRF)**, a scalable socio-technical framework designed to trans-form institutional recyclable waste into sustainable educational resources. Rather than introducing a new recycling technology, the framework provides an operational model for coordinating resource recovery and social value creation within a circular economy context. The proposed framework is evaluated through its pilot implementation by **Di-vyadaan Foundation** in Bengaluru, India.

This paper makes four principal contributions: **(i)** it proposes the Institutional Circu-lar Resource Recovery Framework (ICRRF), a transferable operational framework that integrates circular economy principles with sustainable educational resource generation;
(ii) it presents a real-world pilot implementation of the proposed framework; **(iii)** it provides a preliminary evaluation of the framework based on implementation outcomes and operational feasibility; and **(iv)** it discusses key lessons and considerations for scal-ing similar humanitarian engineering initiatives in other institutional and community settings.

The remainder of this paper is organized as follows. Section 2 presents the proposed Institutional Circular Resource Recovery Framework (ICRRF). Section 3 describes its pilot implementation.

Section 4 provides a preliminary operational evaluation of the framework. Section 5 discusses the implications, limitations, and future directions of the proposed approach. A review of related literature will subsequently position the framework within the broader context of circular economy and humanitarian engineering research.

2 Framework Design

The Institutional Circular Resource Recovery Framework (ICRRF) is proposed as a socio-technical reference architecture for transforming recurring institutional recyclable waste streams into measurable educational outcomes through coordinated stakeholder partici-pation. Unlike project-specific operational models, ICRRF is intended to provide a trans-ferable framework that can be adopted across diverse educational institutions, residential communities, and urban environments. The framework defines the functional compo-nents, stakeholder interactions, operational workflow, and governance principles required to establish a repeatable circular resource recovery system. By treating recyclable waste as an economic resource rather than a disposal challenge, the framework seeks to generate sustainable educational impact while promoting responsible environmental practices.

2.1 Framework Objectives

The design of ICRRF is guided by five primary objectives that collectively address both environmental sustainability and social impact.

Objective 1: Recover Value from Institutional Waste

Educational institutions and residential communities generate recurring quantities of re-cyclable paper waste and electronic waste. Rather than allowing these materials to enter conventional waste streams, the framework seeks to recover their economic value through certified recycling processes.

Objective 2: Generate Sustainable Educational Resources

Instead of relying solely on external donations or periodic fundraising campaigns, the framework converts recovered value into educational resources, creating a repeatable mechanism for supporting under-resourced students.

Objective 3: Coordinate Multiple Stakeholders

Effective circular economy initiatives require collaboration among organizations with dif-ferent capabilities. The framework therefore defines standardized responsibilities for waste generators, recycling organizations, nonprofit partners, volunteers, and adminis-trators to ensure coordinated operation.

Objective 4: Enable Transparent Impact Measurement

Every stage of the framework is designed to be measurable, allowing stakeholders to mon-itor waste recovered, value generated, educational resources distributed, and beneficiary reach through standardized reporting mechanisms.

Objective 5: Support Scalable Replication

The framework is designed as a modular architecture in which new institutions, commu-nities, recycling partners, or nonprofit organizations can be incorporated without funda-mental modifications to the operational structure.

2.2 Design Principles

The ICRRF is founded upon five engineering design principles that guide its architecture and operational workflow.

A. Institution-Based Resource Recovery

Institutions such as schools, colleges, universities, and corporate offices generate pre-dictable and recurring quantities of recyclable waste. Compared with household-level collection, institutional waste streams offer improved logistical efficiency, centralized col-lection points, administrative oversight, and higher participation rates. Consequently, institutional collection serves as the primary resource generation mechanism within the framework.

B. Closed-Loop Value Recovery

The framework extends beyond conventional recycling by establishing a complete circular pathway in which recyclable materials are transformed into educational resources. In-stead of terminating at material recovery, the recovered economic value is reinvested into educational support, thereby linking environmental sustainability with measurable social outcomes.

C. Stakeholder Integration

Rather than assigning overlapping responsibilities, ICRRF defines distinct functional roles for each participating stakeholder. Educational institutions generate recyclable materials, certified recyclers recover economic value, nonprofit organizations distribute educational resources, volunteers coordinate community participation, and framework administrators oversee monitoring and reporting.

D. Decentralized Coordination

Operational activities are distributed across student ambassadors and institutional rep-resentatives rather than managed solely through a centralized organization. This de-centralized coordination model reduces administrative overhead while enabling parallel implementation across multiple institutions.

E. Transparency and Traceability

Every material flow within the framework is designed to be traceable from waste genera-tion through recycling, value recovery, educational procurement, and beneficiary distribu-tion. This transparency enables accountability and facilitates evidence-based evaluation of environmental and social outcomes.

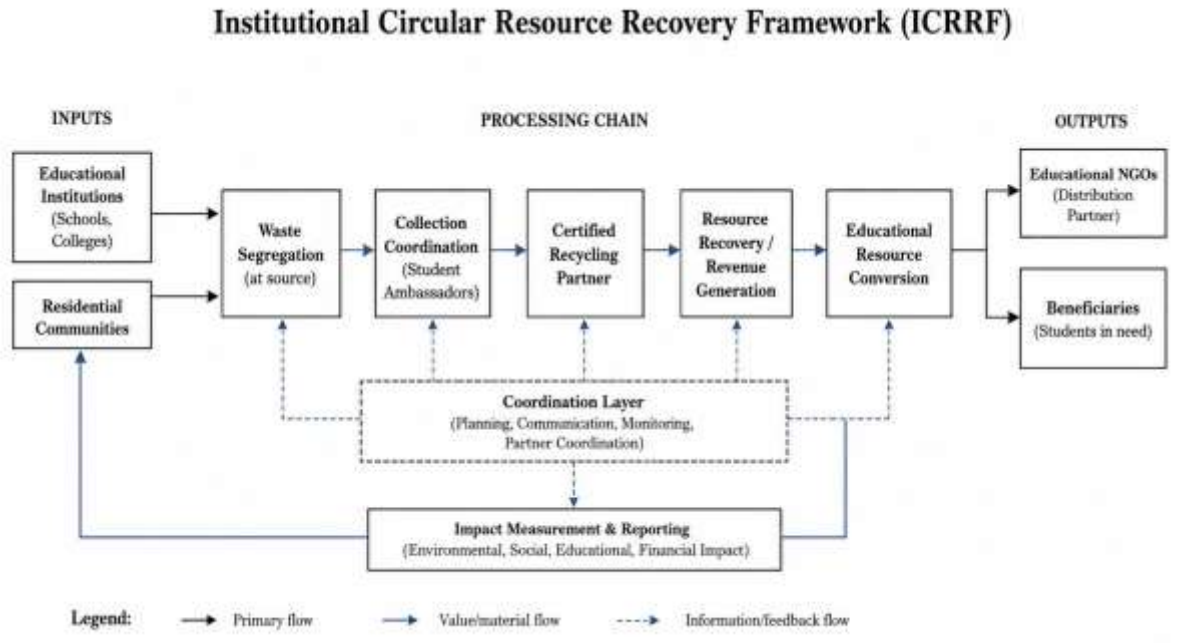

Figure 1: Overall architecture of the Institutional Circular Resource Recovery Framework (ICRRF).

2.3 System Architecture

The ICRRF comprises six interconnected functional components that collectively estab-lish a circular resource recovery ecosystem.

The first component consists of *resource generators*, including educational institutions, residential communities, and other organizations that produce recyclable paper waste and electronic waste. These stakeholders represent the primary source of recoverable materials.

The second component performs *collection coordination*, organizing periodic collection campaigns and ensuring efficient transportation of segregated recyclable materials to certified recycling facilities.

The third component comprises *certified recycling organizations*, which process col-lected materials according to environmental regulations and recover economic value through material recycling.

The fourth component is responsible for *resource conversion*, whereby recovered value is translated into educational materials such as notebooks, stationery, or other learning resources.

The fifth component consists of *distribution partners*, including nonprofit organiza-tions that identify beneficiaries and ensure equitable allocation of educational resources. Finally, the framework incorporates an *impact measurement layer* that monitors oper-ational performance, environmental outcomes, stakeholder participation, and educational impact through standardized reporting metrics.

These components interact within a closed-loop operational system that supports continuous resource recovery and sustained educational benefit.

2.4 Operational Workflow

The operational workflow consists of eight sequential stages that define the lifecycle of recyclable materials within the framework.

1. **Waste Generation:** Participating institutions and residential communities gen-erate recyclable paper waste and electronic waste during routine activities.
2. **Collection:** Recyclable materials are segregated and collected through scheduled campaigns or coordinated collection mechanisms.
3. **Sorting and Verification:** Collected materials are inspected to ensure suitability for recycling and separated according to material category.
4. **Certified Recycling:** Approved materials are transferred to certified recycling organizations for environmentally responsible processing and value recovery.
5. **Value Recovery:** Economic value generated through recycling is allocated for educational resource procurement according to predefined operational policies.
6. **Educational Procurement:** Educational materials are acquired using recovered value while maintaining transparency in financial allocation.
7. **Distribution:** Partner organizations distribute educational resources to identified beneficiaries based on community needs.
8. **Impact Reporting:** Operational data, environmental metrics, and educational outcomes are recorded to evaluate framework performance and inform future im-plementation cycles.

2.5 Stakeholder Roles

The successful operation of ICRRF depends upon clearly defined stakeholder responsibil-ities. Assigning distinct functional roles minimizes operational overlap while improving accountability and coordination.

Table 1: Stakeholder roles within the Institutional Circular Resource Recovery Framework (ICRRF).

Stakeholder	Primary Function	Primary Output
Educational Institutions	Segregate and aggregate recyclable paper waste and e-waste through scheduled collection campaigns.	Recovered recyclable materials
Residential Communities	Participate in household waste collection initiatives and contribute recyclable materials.	Household recyclable waste
Student Ambassadors	Coordinate awareness campaigns, volunteer engagement, and institutional collection activities.	Organised collection drives
Certified Recycling Partner	Process recyclable materials in accordance with environmental regulations and recover economic value.	Recovered monetary value
NGO Partner	Procure and distribute educational resources to identified beneficiaries.	Educational resources delivered
Framework Administrator	Coordinate stakeholders, monitor implementation, and maintain impact reporting.	Operational and impact reports

As illustrated in Table 1, each stakeholder performs a specialized function within the framework. This modular allocation of responsibilities enables independent expansion of stakeholder groups without disrupting overall system operation.

2.6 Scalability

A fundamental design objective of ICRRF is scalability. Rather than depending upon a centralized operational model, the framework employs a modular architecture in which additional institutions, residential communities, certified recyclers, or nonprofit partners can be incorporated independently.

Because each stakeholder performs standardized responsibilities, expansion primarily involves replicating existing functional components rather than redesigning the overall system. Consequently, implementation complexity increases approximately linearly with the number of participating stakeholders while preserving the underlying operational workflow.

The framework is therefore intended to be applicable across multiple geographic re-gions, institutional sizes, and organizational contexts, allowing local adaptations without altering the core architectural design.

2.7 Future Digital Platform

Although the current framework is implementation-independent, future deployments may incorporate a dedicated digital coordination platform to improve operational efficiency and stakeholder engagement.

Potential platform capabilities include online pickup requests for recyclable materials, campaign scheduling, volunteer management, institution registration, impact dashboards, beneficiary reporting, and real-time analytics. Integration of digital tools would further enhance transparency, reduce administrative effort, and facilitate data-driven decision making across participating organizations.
The proposed platform is intended to function as an enabling layer that supports the existing framework rather than replacing its underlying operational principles.

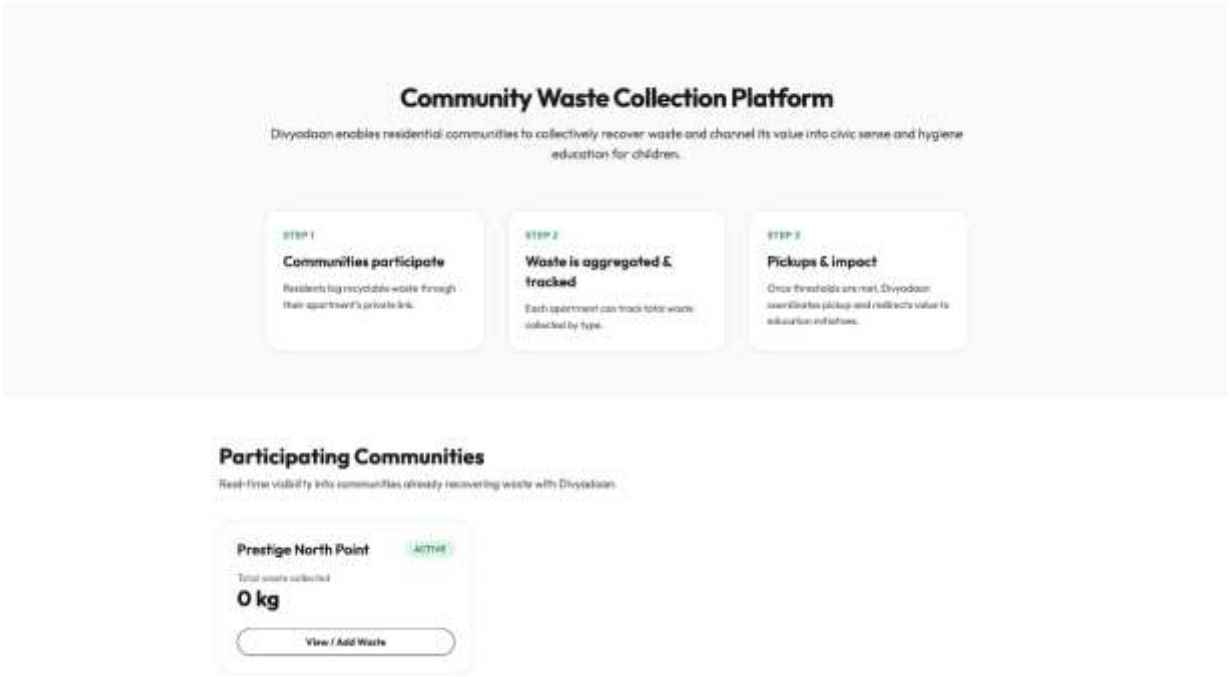

Figure 2: Conceptual digital platform supporting future implementations of the ICRRF.

2.8 Performance Metrics

To facilitate objective evaluation and comparison across different implementations, the Institutional Circular Resource Recovery Framework (ICRRF) defines a set of standard-ized performance metrics. These metrics quantify environmental, operational, and social performance while remaining independent of any specific implementation.

A. Waste Recovery Rate (WRR)

$$WRR = \frac{W_r}{W_g} \qquad (1)$$

where:

- W_r = Mass of recyclable waste recovered (kg)
- W_g = Estimated recyclable waste generated (kg)

B. Educational Resource Conversion Efficiency (ERCE)

$$ERCE = \frac{E_r}{W_r} \qquad (2)$$

where:

- E_r = Number of educational resources distributed

- W_r = Mass of recyclable waste recovered (kg)

C. Stakeholder Participation Rate (SPR)

$$SPR = \frac{S_a}{S_t} \quad (3)$$

where:

- S_a = Number of active participating stakeholders
- S_t = Total registered stakeholders

D. Circular Value Recovery Ratio (CVRR)

$$CVRR = \frac{V_r}{W_r} \quad (4)$$

where:

- V_r = Monetary value recovered through certified recycling
- W_r = Mass of recyclable waste recovered (kg)

E. Beneficiary Reach Index (BRI)

$$BRI = \frac{B}{I} \quad (5)$$

B = Number of beneficiaries receiving educational resources
I = Number of participating institutions or communities

F. Framework Cycle Time (FCT)

$$FCT = t_d - t_c \quad (6)$$

where:

- t_c = Date of waste collection
- t_d = Date of educational resource distribution

3 Pilot Implementation

3.1 Implementation Context

The proposed Institutional Circular Resource Recovery Framework (ICRRF) was evalu-ated through its pilot implementation by the *Divyadaan Foundation*, a student-led non-profit established in August 2025 to promote sustainable resource recovery and educa-tional support through circular economy principles. Rather than introducing a new recy-cling technology, the pilot sought to validate the operational feasibility of the proposed framework under real-world conditions.

The pilot was conducted in Bengaluru, India, one of the country's largest metropolitan regions and a major educational hub comprising numerous schools, colleges, universities, and residential communities. The city's extensive institutional ecosystem generates recur-ring quantities of recyclable paper waste and electronic waste, providing an appropriate environment for evaluating an institution-based resource recovery framework. Further-more, Bengaluru possesses a mature recycling ecosystem and an active nonprofit sector, enabling collaboration among educational institutions, certified recycling organizations, and charitable partners.

The pilot was intended to evaluate the operational feasibility of the proposed frame-work rather than to

maximize waste collection or educational output. Accordingly, em-phasis was placed on assessing stakeholder coordination, repeatability of operational pro-cesses, and the practicality of implementing a closed-loop resource recovery model within existing institutional environments.

3.2 Pilot Deployment Timeline

The pilot implementation was conducted over four sequential phases between August 2025 and March 2026.

The first phase focused on framework planning, stakeholder identification, partnership development, and campaign preparation. During this stage, operational procedures were established, participating institutions were identified, and partnerships were formed with *Saahas Zero Waste* for certified recycling and *Adarane Charitable Trust, Kritagyata Trust and NAMS Snehasadan* for educational resource distribution.

The second phase consisted of the initial pilot deployment during September 2025, providing the first opportunity to evaluate collection procedures, stakeholder coordina-tion, and logistical workflows under operational conditions.

The third phase involved a repeat implementation during November 2025. This cam-paign coincided with the academic mid-semester period, when accumulated paper waste from routine educational activities resulted in increased recyclable material availability. The repeat deployment enabled refinement of operational procedures while maintaining the same underlying framework architecture.

The fourth phase was conducted during March 2026, corresponding to end-of-academic-year disposal activities. This period was selected because participating institutions rou-tinely dispose of examination materials, outdated documents, and administrative paper records, while parent–teacher meetings also facilitated household contributions of re-cyclable materials. These conditions provided an opportunity to evaluate framework performance under comparatively larger waste volumes.

Collectively, the three pilot campaigns enabled iterative refinement of operational procedures while preserving a consistent implementation methodology across deployment cycles.

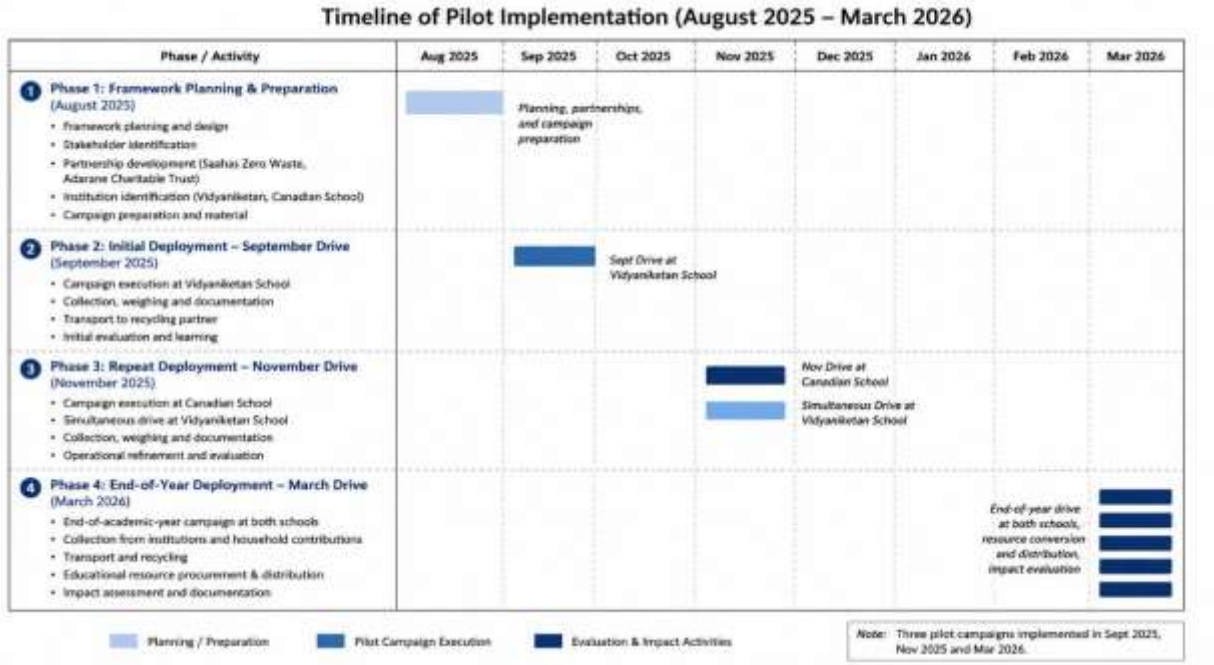

Figure 3: Timeline of the pilot implementation conducted between August 2025 and March

2026.

Table 2: Chronology of pilot implementation phases.

Phase	Period	Deployment Site	Purpose
Pilot 1	September 2025	Secondary School	Initial implementation and validation of the proposed framework
Pilot 2	November 2025	Secondary School	Operational refinement through repeat deployment during the academic year
Pilot 3	March 2026	Secondary School	Framework evaluation under increased end-of-year recyclable waste generation

3.3 Operational Deployment

Implementation of the pilot followed the principles defined by the proposed framework while adapting operational procedures to the requirements of participating institutions. Educational institutions were first engaged to identify suitable collection periods, tem-porary storage locations, and logistical arrangements that would minimize disruption to routine academic activities. Collection campaigns were intentionally scheduled to coin-cide with periods of increased paper disposal, including mid-semester clean-up activities and end-of-academic-year administrative clearance, thereby improving resource recovery efficiency.

Following institutional confirmation, student ambassadors coordinated awareness cam-paigns encouraging students, teachers, staff members, and, where applicable, parents to segregate recyclable paper waste and electronic waste before collection days. Commu-nication materials, school announcements, and volunteer coordination were employed to maximize participation while maintaining consistent operational procedures across par-ticipating institutions.

On scheduled collection days, recyclable materials were gathered at designated col-lection points, inspected for suitability, and segregated according to material category. Accepted materials were transported through pre-arranged logistics to the certified recy-cling partner, while materials unsuitable for recycling were excluded in accordance with established recycling guidelines.

Following material recovery, the economic value generated through certified recycling was allocated toward procurement of educational resources. Distribution activities were subsequently coordinated by the nonprofit partner responsible for identifying beneficiary communities and managing equitable allocation of educational materials.

Throughout each deployment cycle, operational records documenting campaign activ-ities, stakeholder participation, material transfers, and logistical operations were main-tained to support subsequent evaluation of framework performance.

3.4 Stakeholder Partnerships

Successful implementation of the pilot depended upon collaboration among organizations with complementary expertise and clearly defined operational responsibilities.

Participating educational institutions served as the primary generators of recyclable materials while

providing administrative support for campaign organization, temporary storage, and participant engagement. Their recurring generation of paper waste made them suitable environments for evaluating institutional resource recovery.

Certified recycling was undertaken through *Saahas Zero Waste*, ensuring environmen-tally responsible processing of collected recyclable materials and transparent recovery of economic value in accordance with recognized recycling practices.

Educational resource procurement and distribution were coordinated through *Adarane Charitable Trust, Kritagyata Trust and NAMS Snehasadan*, which identified beneficiary communities and managed equitable allocation of notebooks and other educational mate-rials. Separating waste recovery from educational distribution allowed each organization to focus on its respective area of expertise while maintaining accountability throughout the implementation process.

Student ambassadors and volunteers supported campaign organization, participant communication, awareness activities, and coordination among stakeholders, enabling de-centralized implementation across participating institutions.

During the later stages of the pilot, implementation was also extended to selected residential communities, allowing preliminary evaluation of the framework beyond ed-ucational institutions and demonstrating its adaptability to broader community-based resource recovery initiatives.

3.5 Data Collection and Evaluation

Operational data were collected throughout each implementation cycle to facilitate sub-sequent evaluation of framework performance.

The mass of recyclable materials recovered during each campaign was measured using calibrated digital weighing scales immediately prior to transfer to the certified recycling partner. Educational resources procured through recovered value were documented us-ing procurement records maintained by the implementation team. Revenue generated through certified recycling was verified using transaction records provided by the certi-fied recycling partner and was used solely to quantify recovered economic value during the pilot evaluation.

Stakeholder participation was estimated using institutional enrolment records, volun-teer logs, campaign attendance, and participating community populations. These data were used to quantify engagement while avoiding collection of unnecessary personal in-formation.

Additional operational information, including campaign dates, participating institu-tions, logistics activities, and stakeholder coordination records, was documented through-out implementation to support process evaluation and framework refinement.

The pilot focused exclusively on operational metrics and organizational activities. No personally identifiable information was collected from participants or beneficiaries during implementation. Consequently, the evaluation was limited to aggregated operational data rather than individual-level assessment.

3.6 Implementation Limitations

The pilot implementation represents an initial validation of the proposed framework and should therefore be interpreted within its operational scope.

First, implementation was limited to participating institutions and communities within Bengaluru, which may influence the generalizability of operational observations to regions with different waste management infrastructure or stakeholder ecosystems. Second, the evaluation was based on three collection campaigns conducted over a limited implementa-tion period. Longer-term deployments may

reveal additional operational considerations that were not observable during the pilot.

The framework also depends upon sustained institutional participation and the avail-ability of certified recycling organizations capable of processing collected materials. Fur-thermore, the economic value recoverable from recyclable waste is influenced by regional recycling markets, potentially affecting implementation outcomes across different geo-graphical contexts.

Finally, although the framework has been designed to incorporate digital coordination capabilities, the proposed digital platform remains under development and was therefore not evaluated during the present pilot. Similarly, the present study evaluates operational feasibility rather than long-term educational outcomes, which should be investigated in future work through longitudinal implementation studies.

4 Preliminary Evaluation

4.1 Evaluation Methodology

The objective of the preliminary evaluation is to assess the operational feasibility of the Institutional Circular Resource Recovery Framework (ICRRF) under real-world condi-tions. The evaluation focuses on determining whether the framework can be consistently executed across multiple deployment cycles while maintaining coordinated stakeholder participation, reliable material recovery, and traceable impact generation.

The evaluation is based on operational data collected during three pilot campaigns conducted between September 2025 and March 2026. Data sources include on-site waste measurement records, campaign logs, stakeholder participation records, logistics docu-mentation, and procurement records for educational resources.

The metrics used in this evaluation correspond directly to the framework-level perfor-mance indicators defined in Section 3.8, including Environmental Recovery (ER), Edu-cational Resource Conversion Efficiency (ERCE), and Stakeholder Participation metrics. These indicators were selected because they capture the three primary dimensions of the framework: material recovery, social output generation, and operational feasibility.

Since this study represents a pilot implementation, the evaluation is preliminary in nature and does not assess long-term educational or socio-economic impact. Instead, it focuses on validating whether the framework can function as an operational system in a real deployment environment.

4.2 Operational Performance

The pilot implementation consisted of three institutional collection campaigns conducted across two secondary schools in Bengaluru between September 2025 and March 2026. All three planned campaigns were successfully completed, demonstrating repeatability of the proposed framework across multiple deployment cycles.

Across the implementation period, a total of approximately 1.7 tonnes of recyclable waste was recovered. This included approximately 1.2 tonnes of paper waste and 500 kg of electronic waste. The recovery process was conducted through structured institutional collection events, followed by transfer to a certified recycling partner.

The implementation engaged approximately 3,320 participants, including students, school staff, and volunteers across the three campaigns. These participants contributed to waste segregation, collection, and campaign coordination activities.

No disruptions were observed in institutional functioning during the implementa-tion, and all campaigns were completed within the planned operational schedule. The framework suggested

consistent execution across all three cycles, indicating operational repeatability.

Table 3: Summary of pilot implementation outcomes.

Metric	Value	Remarks
Pilot campaigns	3	All planned campaigns successfully executed
Participating institutions	2	Two secondary schools in Bengaluru
Total waste recovered	1.7 tonnes	Includes paper and electronic waste
Paper waste recovered	1.2 tonnes	Major component of institutional waste stream
E-waste recovered	500 kg	Collected during institutional drives
Participant reach	3,320+ individuals	Aggregated across three campaigns

4.3 Environmental Outcomes

The environmental outcomes of the pilot are primarily reflected in the diversion of recy-clable materials from conventional waste streams into certified recycling processes. Paper waste constituted the majority of recovered material due to its high generation rate within educational institutions. Electronic waste, although smaller in volume, was also success-fully collected and processed through appropriate recycling channels.

All collected materials were transferred to a certified recycling partner, ensuring com-pliance with environmental standards and proper material recovery. This process pre-vented recyclable waste from entering landfill systems and enabled its reintegration into formal recycling supply chains.

The composition of recovered waste is illustrated in Figure 4.

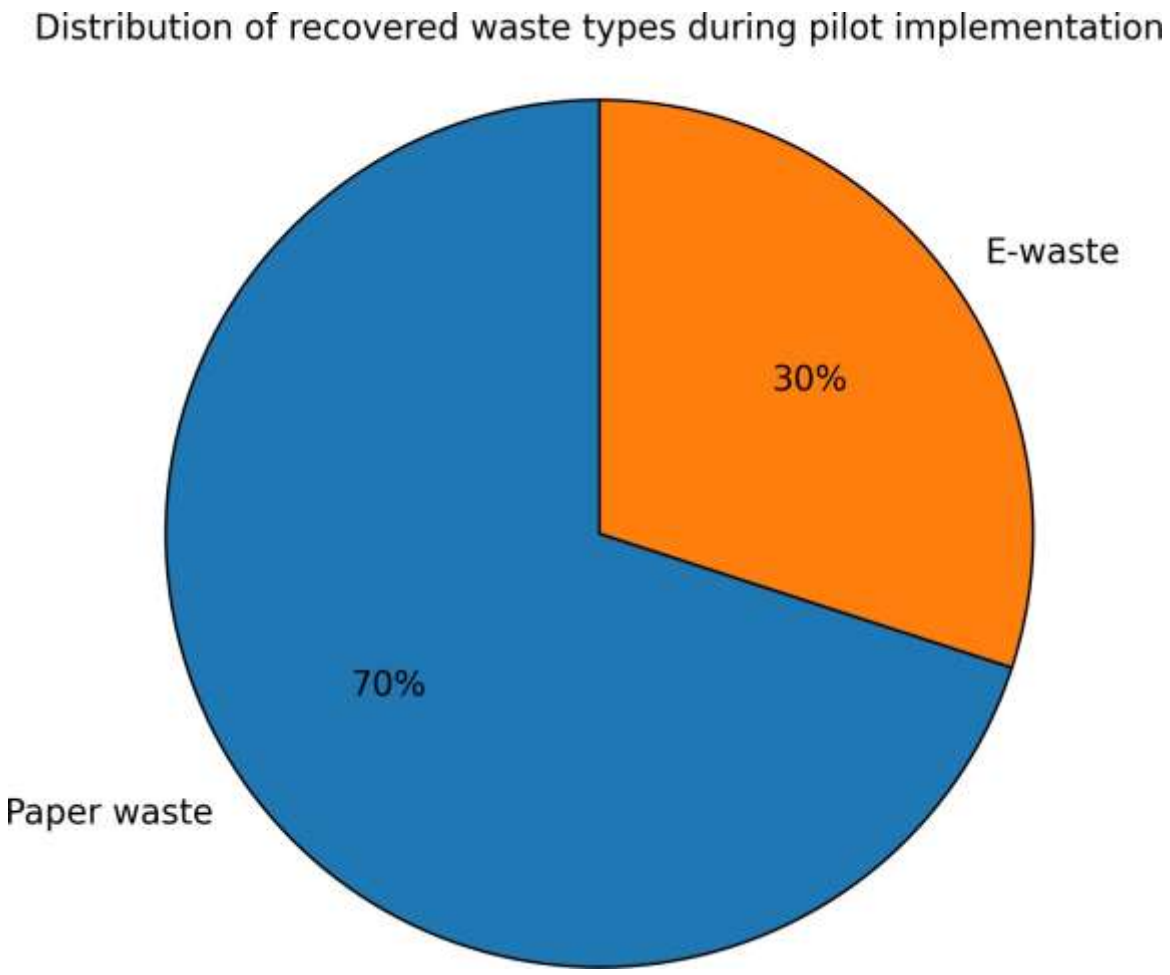

Figure 4: Distribution of recovered waste types during pilot implementation.

4.3 Social Outcomes

The pilot implementation also suggested the feasibility of converting recovered mate-rial value into educational resources. Approximately 800 notebooks were procured using revenue generated through certified recycling processes and distributed through partner nonprofit organizations, Adarane Charitable Trust, Kritagyata Trust and NAMS Sne-hasadan.

This closed-loop conversion establishes a direct linkage between environmental re-covery and educational support, forming a core operational component of the proposed framework. The distribution of educational materials supported under-resourced student communities identified by the partner organization.

In addition to resource distribution, the implementation facilitated awareness among participating students and institutions regarding waste segregation practices and circular economy principles. Student ambassadors played a key role in coordinating campaigns and encouraging participation across institutional stakeholders.

The closed-loop process from waste generation to educational resource distribution is illustrated in Figure 5.

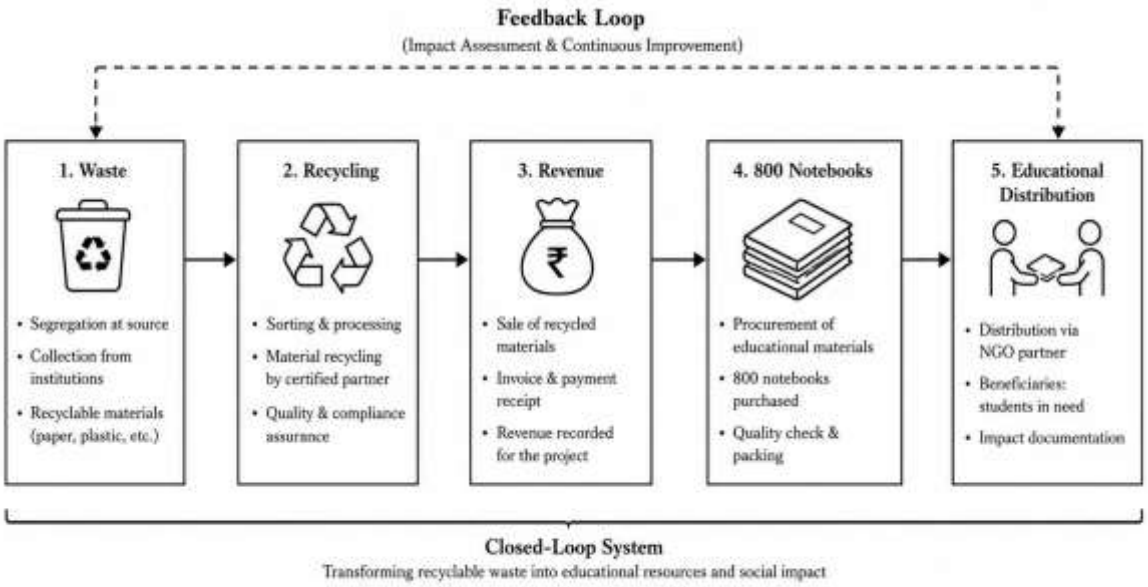

Figure 5: Closed-loop conversion of recyclable waste into educational resources.

4.4Framework Evaluation Against Design Objectives

The pilot implementation results were evaluated against the five design objectives defined for the Institutional Circular Resource Recovery Framework (ICRRF).

Objective 1: Recover Value from Institutional Waste. The recovery of approx-imately 1.7 tonnes of recyclable waste across three campaigns suggests that institutional waste streams can be systematically captured and processed through the framework.

Objective 2: Generate Sustainable Educational Resources. The conversion of recovered value into approximately 800 notebooks confirms the feasibility of linking material recovery with educational resource generation.

Objective 3: Coordinate Multiple Stakeholders. The successful involvement of schools, student ambassadors, a certified recycling partner (Saahas Zero Waste), and nonprofit distribution partners (Adarane Charitable Trust, Kritagyata Trust and NAMS Snehasadan) suggests effective multi-stakeholder coordination under a unified framework structure.

Objective 4: Enable Transparent Impact Measurement. The implementa-tion incorporated structured measurement of waste quantities, participation levels, and resource procurement, enabling traceable evaluation of framework outputs.

Objective 5: Support Scalable Replication. Although full-scale deployment was not part of the pilot, the successful extension of the framework from schools to include residential apartment communities (during later stages of implementation) indicates po-tential for broader applicability. A total of 36 apartment communities were engaged in preparatory expansion activities, suggesting feasibility for scaling beyond educational in-stitutions. However, full validation of scalability remains outside the scope of this pilot study.

Overall, the results indicate that the ICRRF provides a functional operational struc-ture capable of coordinating multi-stakeholder circular resource recovery processes while maintaining measurable environmental and social outputs.

Table 4: Recomputed ICRRF performance metrics based on pilot implementation data.

Metric	Value	Interpretation
ERCE	0.471 notebooks/kg	Indicates conversion efficiency from recyclable waste to educational output.
CVRR	Rs. 47.06/kg	Economic recovery efficiency from recyclable waste through certified recycling channels.
BRI	400 beneficia-ries/institution	Average educational beneficiaries supported per participating institution.
FCT	~90 days	Average operational cycle time from collec-tion to educational distribution across cam-paigns.

5 Discussion

The pilot implementation of the Institutional Circular Resource Recovery Framework (ICRRF) suggests that structured circular economy systems can be operationalized within institutional environments with measurable environmental and social outputs. Across three deployment cycles conducted between September 2025 and March 2026, a total of approximately 1.7 tonnes of recyclable waste was recovered, including 1.2 tonnes of paper waste and 500 kg of electronic waste. This quantitative distribution highlights the dominance of paper waste in institutional settings, accounting for approximately 70.6% of total recovered material.

Although WRR and SPR are defined as standardized framework metrics, the present pilot did not collect the baseline institutional data required to compute these indicators reliably. These metrics are therefore retained as part of the proposed framework for future large-scale deployments incorporating comprehensive waste audits and stakeholder registration.

A key quantitative observation from the pilot is the conversion efficiency of recyclable waste into educational outcomes. The framework achieved an Educational Resource Con-version Efficiency (ERCE) of 0.471 notebooks per kilogram, resulting in the production and distribution of approximately 800 notebooks from the recovered material stream. This direct conversion suggests the feasibility of linking waste recovery processes to tan-gible educational outputs through a structured value recovery pipeline.

Economic analysis further reinforces the viability of the framework. The total revenue generated from certified recycling amounted to Rs. 80,000, corresponding to a Circular Value Recovery Ratio (CVRR) of approximately Rs. 47.06 per kilogram of waste pro-cessed. This value indicates that institutional waste streams can generate non-trivial economic returns when integrated into certified recycling systems, enabling the transfor-mation of waste recovery into a funding mechanism for social impact initiatives.

From a participation perspective, the pilot engaged approximately 3,320 individuals across two secondary schools in Bengaluru. This level of engagement suggests that institu-tional environments can support large-scale behavioral participation in circular economy initiatives without requiring external enforcement mechanisms. On average, each deploy-ment cycle engaged over 1,000 participants, indicating strong scalability potential at the institutional level.

A notable structural insight from the pilot is the effectiveness of temporal alignment between academic cycles and waste generation patterns. The three campaigns—conducted in September, November, and March—corresponded to key academic phases: initial settlement, mid-semester accumulation, and end-of-year disposal. This alignment con-tributed to consistent waste availability across cycles, reducing variability in collection volumes and improving operational predictability.

The quantitative results also reveal important system-level constraints. While di-rect efficiency metrics such as ERCE (0.471 notebooks/kg) and CVRR (Rs. 47.06/kg) are clearly measurable, system-level metrics such as Waste Recovery Rate (WRR) and Stakeholder Participation Rate (SPR) are dependent on external baselines that were not fully observable in the pilot context. WRR, for instance, could not be normalized against total institutional waste generation due to the absence of baseline waste audits. Simi-larly, SPR is influenced by undefined denominators such as total eligible population across institutions, limiting its interpretability as a comparative metric.

Despite these limitations, the framework suggested consistent operational performance across all three deployment cycles with zero structural modifications, indicating strong procedural robustness. The repeatability of outcomes across cycles suggests that the system design is resilient to temporal and operational variation within similar institutional contexts.

Another key insight is the role of decentralized coordination in sustaining participa-tion levels. The engagement of student ambassadors as localized coordinators contributed significantly to achieving 3,320 participants without centralized enforcement mechanisms. This indicates that peer-driven participation models may be more effective than admin-istrative top-down approaches in institutional circular economy systems.

However, the pilot also highlights constraints on generalizability. The implementation was limited to two schools within a single urban region, and therefore the observed efficiency metrics may not directly translate to institutions with different administrative structures or waste management infrastructures. Additionally, the absence of longitudinal tracking limits the ability to assess sustained behavioral or environmental impact beyond the immediate operational cycles.

Overall, the quantitative evidence suggests that ICRRF functions effectively as a socio-technical integration framework rather than merely a waste collection mechanism. Its primary contribution lies in structurally coupling measurable environmental recovery (1.7 tonnes), economic value generation (Rs. 80,000), and educational impact delivery (800 notebooks) within a single repeatable system.

6 Related Work

The Circular Economy (CE) has emerged as a prominent framework for improving re-source efficiency through waste reduction, resource recovery, and closed-loop material flows [1, 2]. Subsequent studies have expanded CE from conceptual definitions to prac-tical implementation across manufacturing, business models, and sustainability systems [3, 4, 5, 6, 7].

Higher Education Institutions (HEIs) have increasingly been recognized as suitable environments for demonstrating CE principles due to their diverse infrastructure, op-erational complexity, and educational role. Mendoza *et al.* proposed a methodological framework for CE implementation in universities, while later studies examined the contri-bution of university assets, governance, and stakeholder participation in supporting circu-lar transitions [8, 9]. Existing research has largely focused on recycling behaviour, waste segregation, and sustainable waste management

practices within campuses [10, 11, 12, 13]. In parallel, CE has also been linked to broader sustainability objectives, particularly the United Nations Sustainable Development Goals (SDGs), highlighting its environmental, economic, and social benefits [14].

Despite these advances, current literature primarily addresses isolated aspects of cir-cularity such as waste management, policy, or business models. Limited work integrates real-time resource monitoring, predictive analytics, optimization, and quantitative circu-larity assessment into a unified decision-support framework for HEIs. To address this gap, the proposed Integrated Circular Resource Recovery Framework (ICRRF) combines IoT-enabled data acquisition, machine learning-based prediction, optimization algorithms, and circularity metrics to support data-driven Circular Economy implementation on uni-versity campuses.

7 Conclusion

This paper presented the Institutional Circular Resource Recovery Framework (ICRRF), a socio-technical operational architecture designed to integrate institutional waste re-covery with educational resource generation through a closed-loop circular system. The framework formalizes the interaction between waste-generating institutions, certified re-cycling systems, and educational distribution networks into a unified and repeatable operational structure.

The proposed framework was evaluated through a pilot implementation conducted by Divyadaan Foundation in Bengaluru, India, across three institutional collection cam-paigns between September 2025 and March 2026. The pilot suggested operational feasi-bility, with measurable execution across multiple deployment cycles, including consistent stakeholder participation, structured waste recovery, and successful conversion of recy-clable materials into educational resources.

The findings provide preliminary evidence that institutional environments may pro-vide a suitable foundation for circular economy systems because of their predictable waste generation patterns and centralized administrative structures. Furthermore, the pilot suggests that social impact objectives can be structurally embedded into recycling systems without altering underlying material recovery processes.

However, the study remains limited to a single-city, small-scale deployment and does not evaluate long-term educational or environmental outcomes. Future work should focus on scaling the framework across diverse institutional contexts, integrating residential and commercial waste streams more formally, and incorporating digital coordination systems for improved transparency and efficiency.

Overall, the primary contribution of this work lies in demonstrating that circular economy systems can be designed as integrated socio-technical architectures rather than isolated environmental interventions. The ICRRF provides a transferable reference model for linking resource recovery systems with structured social impact generation.

Ethics Statement

The pilot implementation relied exclusively on aggregated operational data collected during routine implementation activities. No personally identifiable information was col-lected from participants or beneficiaries, and no individual-level analyses were performed.

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