

## ORIGINAL RESEARCH ARTICLE

# Economic performance analysis of construction waste recycling and utilization in Shaanxi: Perspectives from construction and recycling sectors

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*Received: March 17, 2025; Revised: June 16, 2025; Accepted: July 1, 2025; Published online: July 18, 2025*

**Abstract:** China currently faces challenges related to the high volume of construction waste and its low utilization rate, which have varying impacts on resources and the environment. This study focuses on Shaanxi province in China and conducted online interviews with 12 respondents, comprising four representatives each from construction companies, recycling enterprises, and government departments. The research aims to explore the actual economic performance of recycling and utilization processes. Interview outlines were tailored to the professional attributes of the participants, revealing key issues: construction companies highlighted costs associated with the sorting process, recycling companies reported on the underdeveloped market for recycled products, and the government representatives identified challenges in the continuity and specificity of support policies. Based on these findings, this study proposes several recommendations to enhance the economic performance of recycling-related industries in the sample region and to improve recycling rates and resource utilization.

**Keywords:** Economic performance; Recycling and utilization; Construction waste; Shaanxi province

## 1. Introduction

Shaanxi province, located in inland China, has experienced rapid economic growth in recent years. The rate of urbanization has increased significantly from 51.57% to 65.16% between 2012 and 2023, with the construction industry serving as a cornerstone of the region's economy. During this period, the total area of buildings under construction has steadily grown to 396.71 km<sup>2</sup>.<sup>1</sup> Concurrently, the volume of construction waste generated in the province has remained alarmingly high. In 2023, the total output of construction waste in the province reached 141.93 million tons, with

construction waste accounting for over 40% of the total.<sup>2</sup> More critically, <50% of construction waste was recycled and utilized at the national level, posing a threat to the region's limited land resources amidst rapid urban development.<sup>3</sup> This practice also has led to the waste of potentially recyclable materials, contradicting China's current government mandates for sustainable development in the construction industry.

In the existing literature on construction waste management, the effectiveness of management in a given region is typically assessed by the recycling rate.<sup>4,5</sup> The Shaanxi provincial government, as early as 2008, introduced the "Regulations on Urban

Construction Waste Management,” which established specific requirements for the recycling and utilization of construction waste.<sup>6</sup> In recent years, several policies and regulations have been introduced to enhance recycling efficiency and promote the circular economy. In 2023, Xi’an recorded the highest utilization rate in the province, with a comprehensive utilization rate of around 50%, while other cities remained below 20%.<sup>7</sup> In contrast, countries such as Japan, Singapore, Australia, and Germany have achieved a recycling and secondary utilization rate of over 90% for construction waste.<sup>8,9</sup> This data clearly highlights two important points: the feasibility of recycling construction waste and the significant room for improvement in Shaanxi.

In numerous studies aimed at improving China’s construction waste recycling rate, the costs and economic challenges faced by construction and recycling units have been identified as the most significant barriers to a smooth recycling process.<sup>10,11</sup> In addition, many studies have proposed government financial subsidies and incentives as key measures to enhance recycling rates.<sup>12,13</sup> Furthermore, there is often a direct correlation between recycling rates and the economic development levels of different regions or countries. For instance, recycling rates in developed countries tend to be higher than those in developing nations.<sup>14,15</sup> This highlights the critical importance of costs and economic performance for construction and recycling entities in the recycling process. Therefore, to improve the current state of construction waste recycling in Shaanxi, it is essential to focus on the costs and economic benefits associated with these two sectors.

Previous research on construction waste management in China has primarily focused on the economic performance of recycling enterprises, emphasizing the perspective of waste recipients and recycled product producers.<sup>16,17</sup> These studies often overlook the economic interactions between stakeholders, particularly the dual role of construction companies as generators of waste and potential consumers of recycled products. Moreover, while government support mechanisms are frequently discussed in theory, they are seldom examined empirically through multi-stakeholder perspectives within a specific regional context.

In this regard, this study introduces a novel stakeholder triad analysis (construction companies, recycling enterprises, and government bodies) to investigate economic performance and inter-dependencies within a single provincial case – Shaanxi. This triadic approach has not been comprehensively applied in existing research, especially using qualitative field data from

all three sectors. Therefore, the study contributes by addressing this understudied intersection and by providing grounded insights to improve integrated policy and operational efficiency.

To realize the objective, this study represents the first empirical effort in Shaanxi to combine qualitative interviews across all three sectors, aiming to uncover the economic bottlenecks and systemic inefficiencies in construction waste recycling. The investigation focuses on the following key questions:

- (i) How do construction companies perform in terms of economic benefits and cost control?
- (ii) How do recycling enterprises perform in terms of economic benefits and market demand?
- (iii) What resources and technical support does the government provide to promote recycling and reuse?

By investigating and analyzing these questions within Shaanxi, this study seeks to enhance the understanding of the economic challenges faced by construction companies and recycling enterprises. In addition, it aims to provide valuable insights to support government decision-making in designing supportive policies.

## 2. Methodology

### 2.1. Research approach

This study investigated the economic performance of construction companies, recycling enterprises, and government management departments in the recycling and waste utilization process, identifying areas for improvement to enhance economic feasibility. Given the study’s focus on the economic behaviors and actions of the three stakeholders in the recycling and reuse process, qualitative research was deemed more suitable for addressing these objectives. As Lim<sup>18</sup> suggested, qualitative research enables researchers to explore and understand complex problems and phenomena more deeply.

Therefore, this study adopted a qualitative analysis approach, specifically the semi-structured interview method, to examine the economic performance of construction companies, construction waste recycling enterprises, and government departments in recycling and waste utilization processes. To gain deeper insights into the multi-actor economic behaviors, thematic analysis was applied in this research. This method has been widely used in many qualitative research studies to systematically organize and describe data in rich detail. Moreover, it often goes beyond description to interpret various aspects of the research topic.<sup>19</sup>

## 2.2. Data sources

To ensure that participants possessed sufficient industry experience and knowledge to address the interview questions, they were required to be currently engaged in construction waste management within Shaanxi and have at least 15 years of relevant experience. A sample size of 4 – 30 participants is generally sufficient to meet the research objectives in a case study with comparative analysis.<sup>20</sup> Thus, this study included a total of 12 participants and divided into three groups based on occupation, with four individuals in each group.

Potential participants were invited through email or phone. Once identified, they were provided with the interview outline to familiarize themselves with the content, facilitating a smoother interview process. Participants were also informed about the confidentiality of the interviews and that the content would be used solely for academic research purposes. The interviews were conducted online between December 2024 and January 2025, with the responses recorded in textual format.

## 2.3. Interview design

Given the distinct roles of the interviewees in construction waste recycling, resource utilization of construction waste, and policy design, the interview content was tailored to reflect their professional attributes, aiming to uncover their specific economic performances. The full set of interview questions is provided in Appendix A. For the construction units, the questions mainly focused on three aspects, including cost control processes, their impact on the economic performance of the project, and the overall economic benefits. For the recycling units, the questions centered on market development for recycled materials and the economic performance throughout the recycling process. For government departments, the focus was on the resources or technical support provided and plans to enhance construction waste utilization.

## 2.4. Data analysis

After organizing the content of the interviews into a textual format, the data were subjected to thematic categorization and comparative analysis. Previous research shows that thematic categorization and comparative analysis are commonly employed for summarizing and analyzing interview data.<sup>21,22</sup> These methods effectively integrate interview content by categories, uncover underlying issues, and provide multi-perspective solutions to address them. As Neale highlighted, when investigating the perspectives of

multiple professions on a specific issue, the advantages of these methods become particularly pronounced.<sup>23</sup>

This study followed four main steps to analyze the qualitative data, as shown in [Figure 1](#). First, all online interviews were transcribed verbatim into textual format, followed by repeated close reading to ensure thorough immersion in the data. At the same time, key interview excerpts were organized and included in Appendix B. Subsequently, systematic coding was applied to the transcripts, focusing specifically on economic performance, challenges, and participant roles across the three distinct stakeholder groups. Third, preliminary codes were then categorized into coherent themes, ensuring internal consistency while deliberately highlighting connections and divergent perspectives among respondents. Finally, a comparative analysis of inter-group contradictions regarding shared economic themes in construction waste recycling was conducted, yielding deeper insights into the economic dimensions of the process.

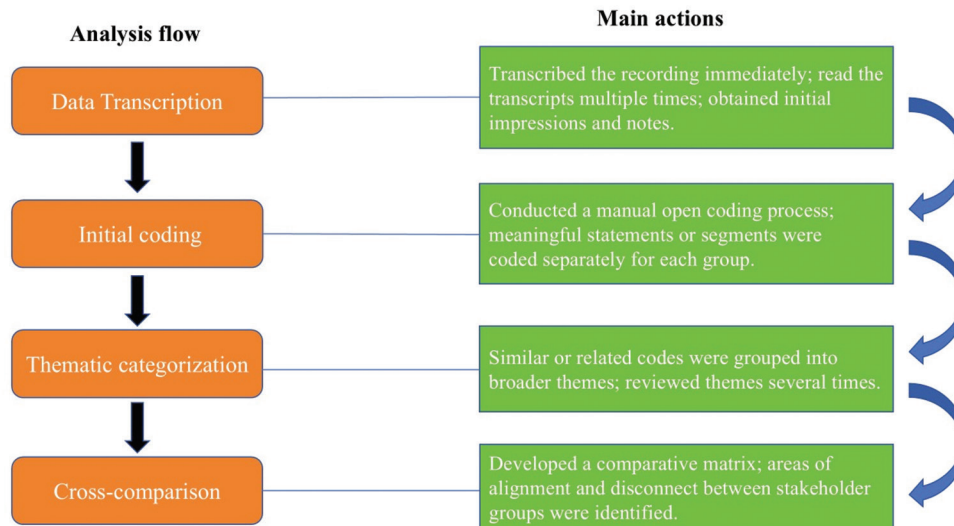
## 3. Results and discussion

### 3.1. Respondents' information

The information regarding the interviewees is summarized in [Table 1](#). All 12 participants have over 15 years of work experience. Among the four participants from the construction units, two have prior experience working in design firms. The four participants from the recycling units specialized in different types of waste recovery and processing. Finally, all four government officials representing various administrative departments are involved in construction waste management. This diverse and experienced group of participants ensured a comprehensive coverage of the various aspects of construction waste management. Their insights provided robust support for subsequent research and policy-making in this domain.

### 3.2. Perspectives of construction units

In this section, the questions were designed to gain insight into cost control and economic benefits from the perspective of project managers involved in waste reduction and recycling participation. By exploring the feasibility reflected in the economic aspect of these processes, the findings can inform the formulation of economic subsidies and incentive policies, thereby guiding future directions. Based on the responses from the four interviewees, four key themes were identified, and the corresponding theme-coding table is presented in [Table 2](#).



**Figure 1. Overview of the analysis workflow**

Among the four interviewees, three clearly stated that they gained economic benefits from participating in the recycling process. These benefits mainly stemmed from reduced spending on raw materials and landfill fees, with such cost savings being particularly significant in larger projects. The fourth interviewee also addressed this issue, noting that for medium-sized or smaller construction projects, the upfront investment in equipment and labor greatly reduces the economic returns from recycling activities. He stated, “In our project, the scale is small, and the management level is average. Although recycling can reduce waste disposal costs, the increased upfront investment and labor costs are relatively higher, and these costs far exceed the savings, so the effect is not very significant.” This finding is consistent with the study by Ann *et al.*, which also showed that the cost-effectiveness of recycling varies significantly with project size for construction companies.<sup>24</sup>

When discussing barriers to recycling, all four interviewees mentioned similar challenges. These included a lack of sorting equipment and technical support, high labor costs for manual sorting, an underdeveloped market for recycled products, and limited land availability. These factors contributed to high processing costs and were considered major risk factors for construction companies attempting to profit from recycling.<sup>23</sup> Furthermore, a weak recycling market makes it difficult to directly utilize or resell many materials, significantly reducing recycling efficiency. In addition, storage space limitations pose challenges for optimal sorting and temporary storage.<sup>24,25</sup>

Based on these insights, the interviewees discussed the types of support and improvement strategies they believe are needed. They primarily emphasized the need for increased investment in new equipment and technologies, such as the introduction of automated sorting systems to reduce labor costs. They also suggested enhancing workers’ awareness and skills in waste sorting and reuse and establishing an effective circular waste system to ensure that market demand aligns with the supply of recycled products.

Overall, the economic benefits of recycling have demonstrated the feasibility to some extent, but these benefits are closely linked to factors such as project scale, management level, market integration, and policy support. All four interviewees expressed a strong desire for government support and assistance. Therefore, at the policy level, the government could consider offering differentiated subsidies and incentive policies for projects of varying scales, particularly in areas such as recycling facilities, technical training, and market expansion. Such measures would help enterprises achieve greater economic benefits in waste reduction and recycling processes. Ultimately, these measures would not only encourage more businesses to engage in recycling but also accelerate the overall development of the construction waste management industry.

### 3.3. Perspectives of recycling units

In this section, respondents were asked to discuss the current demand for recycled materials and the actual economic performance of recycling enterprises. Through an in-depth exploration of these issues, we

**Table 1. Participants' information**

Code	Occupation	Working experience	Duty range
C1	Construction unit	20 years	On-site construction management, with design institute working experience
C2	Construction unit	16 years	On-site construction management
C3	Construction unit	21 years	On-site construction management, with working experience in a design institute
C4	Construction unit	20 years	On-site construction management
R1	Recycling unit	23 years	Focus on the recycling of concrete, bricks, and aggregates
R2	Recycling unit	27 years	Focus on the recycling of metals and timber
R3	Recycling unit	20 years	Focus on the recycling of concrete waste
R4	Recycling unit	18 years	Focus on the recycling of hazardous waste
G1	Government department	20 years	Department of Environmental Protection
G2	Government department	22 years	Department of Housing and Urban Development
G3	Government department	25 years	Department of Housing and Urban Development
G4	Government department	22 years	Department of finance

gained insights into the current state and potential of the recycled materials market in the sample region, while identifying key factors affecting the economic benefits of recycling enterprises. This analysis provided a basis for improving the economic viability of construction waste management. Based on the responses from the four interviewees, four themes were identified, with the corresponding theme-coding shown in [Table 3](#).

All recyclers generally acknowledged that the current market demand for recycled products is increasing,

**Table 2. Theme-coding of the construction unit**

Theme	Code
Perceived economic benefits	Saving costs on materials
	Saving costs on the disposal method
Barriers	Lack of equipment for sorting
	High labor cost
	Recycled product market imbalance
Support needs	Storage constraints
	More advanced sorting equipment is needed
	Qualified workforce welcomed
Improvement strategies	Equipment investment
	Well-planned training for the workforce
	Logistics optimization
	Recycling market development

**Table 3. Theme-coding of the recycling unit**

Theme	Code
Perceived economic benefits	Subsidy-based profit
	Low return (high process fee and low selling price)
Barriers	Quality problems
	Market imbalanced
	Operation cost large
	Supervision loopholes
Support needs	Third-party certification
	Mandatory usage policy
Improvement strategies	Innovation for low-value material
	Increasing recycled product quality control
	Introducing government demand
	Improving regulation enforcement (illegal dumping)

especially in government-led or public construction projects. However, demand varied across different materials. For instance, R1–R3 clearly indicated that infrastructure and prefabricated construction projects have a high demand for recycled products. On the other hand, R2 and R4 stated that materials such as recycled coatings containing hazardous substances and waste wood have virtually no secondary use market. The findings also revealed that while metal and waste aggregate recycling can generate considerable returns, the recycling of waste wood yields minimal benefits or even losses. The details can be seen in Appendix B.

Table 3 summarizes the themes and codes from this section (Section 3.3). The main challenge lies in the low intrinsic value of recycled materials combined with high processing or sorting costs, resulting in poor economic viability.<sup>26</sup> Subsequently, recycling units often incur losses and face significant economic pressure. Although these units help the government mitigate environmental impacts, they often do not receive corresponding economic compensation.<sup>27</sup> Respondents explicitly stated that the current selling price of recycled concrete products is 10 – 20% lower than that of raw materials, further limiting profit margins. As a result, the income of recycling units is largely driven by government subsidies, making economic sustainability a key issue restricting the development of recycling enterprises. This situation is also regarded as a key economic issue restricting the development of recycling units.<sup>28</sup>

Regarding the obstacles, the main problems include a lack of trust in the quality of recycled products, low pricing due to intense competition, and high disposal costs leading to illegal dumping, which in turn causes instability in waste sources. This was clearly reflected in R4's statement, "The market demand for certain toxic wastes is low, the profits are minimal, and due to weak regulations, most contractors resort to illegal dumping to avoid disposal costs, further limiting the profits." Therefore, ensuring a stable source of waste has also become an important means to secure the economic foundation of recycling companies.<sup>29</sup>

Finally, the recycler respondents discussed key areas for improvement, primarily aimed at promoting a healthy and virtuous market cycle. These included certifications of recycled product quality, minimum usage quotas (for both public and private construction), and expansion of product applications. As the Retail Industry Leaders Association points out, promoting the development of high-strength recycled materials and setting mandatory usage ratios in construction projects will help eliminate bias and ensure healthy market development and operation.<sup>30</sup> The interviewees also emphasized the need to strengthen regulatory enforcement to reduce illegal dumping at the end of the chain and ensure a stable supply of recyclable waste.

In summary, the market-oriented pathway for construction waste recycling in the current sample region still requires further exploration. A dual approach of policy and market-driven forces, coupled with the deep integration of technology and application, will be the core direction for promoting recycling and utilization in the future. Implementing these measures can provide actionable strategies for recycling enterprises in Shaanxi

to better adapt to market demands, improve the market acceptance of recycled materials, and enhance their economic viability.

### 3.4. Perspectives of government departments

In this section, interviewees were invited to discuss, from the perspective of government departments, the efforts made to allocate resources and provide technical support for construction waste management, as well as areas requiring improvement. This section emphasizes the government's role in offering economic support (resources and technical support) as a functional authority. The interviews in this section aimed to offer a comprehensive understanding of the government's current support within the sample region, while identifying shortcomings and areas for improvement. These insights will help guide future strategies to enhance the effectiveness of construction waste management initiatives.

By analyzing the theme-coding table of the government department, as shown in Table 4, several key findings emerge. First, government departments have undertaken a series of supportive initiatives to promote the recycling of construction waste. These included assisting in the formulation of more specific recycling and classification guidelines, providing education and training, offering special financial support, subsidizing the costs of dedicated recycling vehicles, and supporting the construction of recycling centers. In addition, to strengthen the supervision of the recycling process, several projects have introduced new technologies such

**Table 4. Theme-coding of the government department**

Theme	Code
Supporting solutions	Technology pilot
	Different forms of subsidy
	Specific training and documentation
Barriers	Limited policy coverage and coordination
	Cumbersome funding application
	Small and medium-sized enterprises are overlooked
Support needs	Multilevel subsidy mechanism
	Reform administration
	Collaboration strengthening
Improvement strategies	Develop a procurement standard
	Tough enforcement of the regulation
	Certification and education for trust-building

as intelligent construction waste identification, sorting systems, and geographic information system-based tracking of transport vehicles.

When discussing the difficulties and challenges faced by the government, respondents highlighted issues such as limited policy coverage and poor communication among stakeholders. Several interviewees mentioned problems, including low enterprise participation in government-led training programs, complex subsidy application procedures resulting in low application willingness and difficulty in fund allocation, and the lack of attention to small and medium-sized enterprises. This aligns with previous studies, which noted that the current subsidies tend to focus on large projects and major enterprises, while small and medium-sized enterprises receive little support, resulting in unbalanced development within the recycling market.<sup>31</sup>

Based on these findings, the respondents discussed the types of support they deemed necessary. This mainly includes continued financial investment from higher-level authorities and enhanced information exchange and coordination among departments. Moreover, simplifying the subsidy application process, setting up dedicated funds for small-scale enterprises, and implementing high-level government-led cross-departmental integration actions to avoid the duplication of resources (human and financial) have also been mentioned in several Chinese reports.<sup>32</sup>

Regarding future improvement strategies, the respondents highlighted three main points. First, the government should take the lead in developing and promoting green public procurement standards for recycled materials and scaling up successful pilot projects. Second, enforcement must be strengthened, such as through strict penalties for illegal dumping, to ensure that the recycling industry becomes a profit-generating sector rather than a regulatory burden. Finally, efforts should be made to enhance public awareness and certification systems to build trust in recycled products. In addition, one interviewee raised a point not coded but noted in other studies on improving the economic viability of recycling: subsidy coverage should be comprehensive, with part of the funding shifted from end-stage treatment (recycling) to earlier stages, such as source reduction and waste product usage.<sup>33</sup> This could serve as an important recommendation for future government policy development.

Overall, government departments have achieved certain successes in resource support and the promotion of new technologies, yet there remains room for improvement in terms of adaptability, promotion depth,

and policy implementation efficiency. By optimizing resource allocation, reducing technology costs, enhancing enterprise cooperation, and strengthening interdepartmental collaboration, the overall efficiency and effectiveness of construction waste management are expected to improve significantly.

### 3.5. Cross-stakeholder comparative analysis

The previous three subsections discussed different aspects of economic performance related to recycling. This subsection aims to integrate the perspectives of the three stakeholder groups, using the theme-coding table to identify their shared understandings and contradictions. Based on the stakeholder theory, the analysis explores the challenges encountered in the cooperation process and potential directions for improvement.

#### 3.5.1. Consensus (*benefits and constraints*)

All parties acknowledged that under certain conditions, recycling activities provide economic value. Construction units reported reductions in material costs and disposal expenses, while recycling units expressed strong confidence in the long-term establishment of the market and its economic prospects. Throughout this process, government-issued support policies were seen as enhancing the economic benefits for both groups. At the same time, all stakeholders agreed on the systemic constraints affecting economic viability. These include increased costs due to sorting and processing technologies, low recycling efficiency, underdeveloped markets, poor acceptance of recycled products, and limited price competitiveness. In terms of policy support, all three groups emphasized the critical role of strong government intervention in improving economic outcomes, such as through various forms of subsidies, infrastructure investment, and tax incentives. This finding is also supported by earlier research,<sup>34</sup> which stated that the government can be seen as a “bridge” enabling effective circulation between construction and recycling units.

#### 3.5.2. Divergences (*profit cycle and responsibility distribution*)

Although there is a general consensus among the three parties regarding the benefits and constraints of recycling, a deeper analysis revealed fundamental contradictions in terms of economic gains.

The first contradiction lies in the length of the profit cycle. As mentioned in other studies, construction units prioritize short-term cost control and expect immediate returns when participating in recycling processes.

In contrast, recycling units focus more on long-term operational feasibility, where a stable supply of waste and sustained market demand are deemed crucial.<sup>35</sup> Consequently, when short-term profits are not evident, contractors tend to withdraw from recycling efforts, disrupting the commercial recycling process.

The second contradiction concerns unclear responsibility distribution. Interview findings reveal a clear pattern of blame-shifting among stakeholders, resulting in a circular offset of responsibilities. According to a previous study, the absence of clear primary responsibility is one of the main reasons why recycling fails to generate economic benefits.<sup>36</sup> For instance, construction units rely on external parties (recycling companies or the government) for equipment, technology, and training support. Recycling companies depend on the government to set mandatory usage quotas for recycled products and enforce policies to secure raw material supply and resolve sales difficulties. Although the government has introduced various support programs, limitations in coverage and implementation have been evident.

The third contradiction highlights the inconsistency between policy design and execution, which often results in low efficiency in policy outcomes.<sup>37</sup> Although the government has invested in subsidies, technical guidance, and training programs, construction and recycling parties often display negative attitudes in different aspects, such as complex access procedures, insufficiently detailed guidelines, and low participation rates. This reveals a gap between policy design and on-the-ground implementation. Addressing this issue should become a key direction for reforming municipal government support policies.

### 3.5.3. Future coordination for stakeholders

This study indicates that without coordinated efforts, the economic value of recycling among stakeholders will remain largely unrealized. Both interviews and literature highlight that value realization depends not only on improvements in technology or policy but also requires collaborative participation, shared responsibility, and common incentives among stakeholders.<sup>38</sup>

An analysis of the roles within the recycling value chain reveals that each stakeholder holds a critical yet incomplete position, and an effective connection among them is essential:

- (i) Construction units determine the quality and stability of waste material flows through on-site sorting, labor management, and project planning.
- (ii) Recycling enterprises convert waste into marketable

products, with their economic sustainability depending on stable supply and demand.

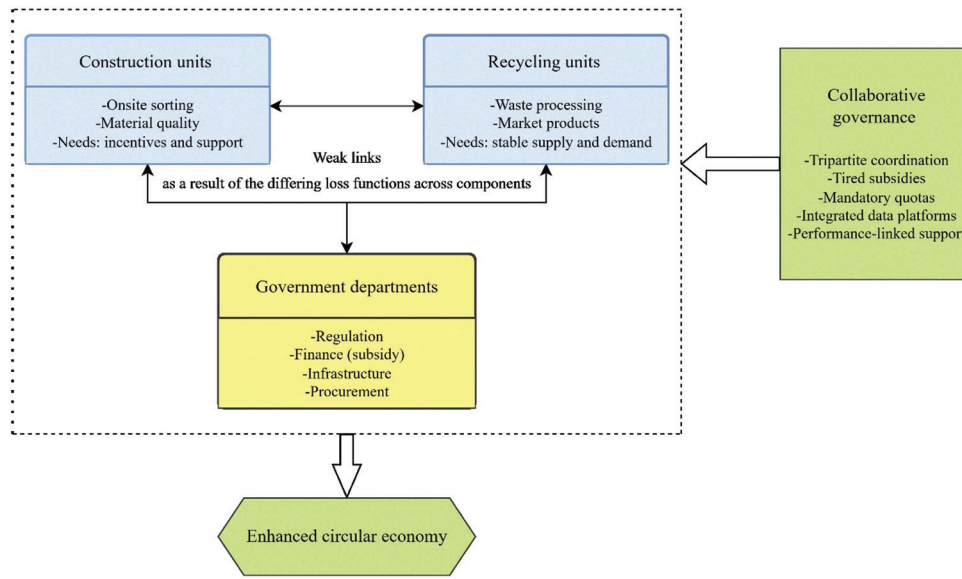
- (iii) Government departments shape the business environment through regulatory enforcement, financial instruments, infrastructure investment, and public procurement policies.

However, this study reveals that the aforementioned functions remain fragmented. Construction units have not received sufficient economic incentives or technical support for sorting, while recycling enterprises are more affected by unstable raw material supplies and poor market and policy coordination. Although various government measures exist, their effectiveness is limited, often weakened through layers of implementation, and lacks timely and effective feedback mechanisms. This fragmented situation has been repeatedly highlighted in waste governance studies, where the lack of coordination among stakeholders and imbalanced risk-sharing weakens policy effectiveness and hinders market development.<sup>39,40</sup> More directly, these issues result in market imbalance and a non-circular economy.

To address these challenges and ensure a smoother, economically sustainable recycling process, it is essential to establish a collaborative governance model between enterprises and the government. Measures to enhance coordination, such as tiered subsidies, joint infrastructure investment, and the establishment of integrated governance committees, have been suggested in many previous studies.<sup>41,42</sup> Specific approaches have also been discussed in earlier sections, including providing targeted support for construction units (such as tax rebates and priority approvals), mandating public projects to procure recycled materials with proper quotas, and offering performance-based subsidies to recycling enterprises to support innovation. Government departments should transition to roles as integrated platform builders, enabling real-time data sharing, cross-departmental cooperation, and inclusive consultations. Through these actions, and under a shared framework of tripartite coordination, a circular economy becomes achievable, as illustrated in [Figure 2](#).

These models have shown positive results in other countries with well-developed circular economies. For example, the Netherlands has established tripartite partnerships among contractors, recyclers, and government departments through coordinated incentives, subsidies, and monitoring systems.<sup>43</sup> In China, the “14<sup>th</sup> 5-year Plan for the Construction Industry” also outlines a similar development direction, emphasizing coordinated governance of solid waste between related

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**Figure 2. Approaches supporting the realization of a waste recycling economy**

stakeholders, as well as digital traceability and support for small and medium-sized enterprises.<sup>44</sup> This again highlights the importance of constructing a stakeholder community where coordinated efforts play a key role in achieving the economic benefits of construction waste recycling.

In summary, a cross-comparative analysis shows that the economic performance of construction waste recycling depends not only on market mechanisms or technical conditions but also fundamentally on relational governance. Specifically, it requires alignment of stakeholder roles, capabilities, responsibility awareness, and layered policy frameworks. Future policy design should integrate these aspects, strengthen collaborative mechanisms, and transform the construction waste recycling process into measurable economic returns.

## 4. Conclusion

This study, from the perspective of the stakeholder theory, explores the economic performance of construction waste recycling in Shaanxi. The findings reveal that both construction units and recycling enterprises acknowledge the economic value generated by waste recycling. However, their potential is constrained by factors such as project scale, technological equipment, and market conditions. Although government departments do not directly participate in economic activities, they play a crucial role in shaping outcomes. The effectiveness of government support and supervision mechanisms determines whether the government acts as a facilitator or an obstacle in the recycling process.

Through thematic coding analysis of interviews with three key stakeholder groups, the following conclusions were drawn:

- (i) Construction units can achieve economic benefits in large-scale projects with well-established management, but in small-scale projects, high upfront costs and limited recycling channels result in financial feasibility challenges.
- (ii) For recycling enterprises, the immature market for recycled materials places them in a fragile business environment. Their profitability is highly dependent on external policy support.
- (iii) Government departments have made progress in areas such as funding, regulatory systems, and pilot projects for technology and training. However, issues such as the absence of coordination mechanisms and inadequate policy layering have limited their ability to effectively guide and support stakeholders' economic gains.

These findings are consistent with international research on construction and demolition waste recycling, which emphasizes that technological maturity, policy coordination, and stakeholder alignment are key factors determining economic feasibility. Through the establishment and analysis of the stakeholder theoretical framework in this study, common interests and conflicts among parties are identified, thereby explaining why economic value is difficult to realize evenly across the system.

Overall, this study employed semi-structured interviews to examine the economic development

potential and limitations of construction waste recycling in Shaanxi. The results indicate that while economic benefits theoretically exist for both construction and recycling units, they are highly dependent on factors such as the level of cooperation, accuracy of policies, access to and support for equipment and technology, and the market development. Addressing issues such as responsibility sharing and risk distribution among the three parties may improve the economic performance of both construction units and recycling enterprises. Although this study employed coding, comparative analysis, and literature verification to investigate the related mechanisms and enrich interview data and conclusions, the limitation of a single qualitative research approach affects the generalizability of the findings. Future research should adopt a mixed-methods approach, incorporating quantitative surveys to capture specific economic performance metrics across different enterprise scales, alongside policy analysis that examines actual government support measures. Comparative studies with other regions, supported by concrete data, would further deepen understanding of how to enhance the efficiency of government economic and technological policy support and improve the economic benefits of stakeholders.

### Acknowledgments

None.

### Funding

None.

### Conflict of interest

The authors declare that they have no competing interests.

### Author contributions

*Conceptualization:* Han Liu

*Formal analysis:* All authors

*Investigation:* Han Liu

*Methodology:* Han Liu

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*Writing – original draft:* Han Liu

*Writing – review & editing:* All authors

### Ethics approval and consent to participate

This study involved human participants. Ethical approval was granted by UCSI University, Malaysia

(Reference code: IEC-2024-FETBE-0002). Informed consent was obtained from all participants before their involvement in the research. Participants were provided with written and verbal explanations of the study's purpose, procedures, potential risks, benefits, and their right to withdraw at any time without consequence.

### Consent for publication

All participants provided written informed consent for their anonymized data to be published in this study.

### Availability of data

All data analyzed have been presented in the paper.

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## Appendix

### Appendix A. Interview questions

The interview questions were separated into three sections based on different occupational backgrounds. The details are as follows:

#### 1. Construction units

As direct producers of construction waste and consumers of recycled materials, the primary questions for construction units were:

##### 1.1. How is cost control managed during the implementation of waste reduction and recycling processes?

- (i) How does it affect overall costs?
- (ii) How is it controlled?
- (iii) How important is it?

##### 1.2. Have these measures impacted the economic performance of the company?

- (i) What are the effects?
- (ii) Are there areas for improvement?
- (iii) How can improvements be made, and what should be prioritized?

##### 1.3. Does participation in the recycling and utilization of construction waste bring economic benefits to the company?

- (i) What are the main costs?
- (ii) How do these compare to the costs of landfill disposal or illegal dumping?
- (iii) Have recycled products reduced costs?
- (iv) Are they being adopted? Why or why not?

#### 2. Recycling units

As receivers of construction waste and producers of recycled products, the primary questions for recycling units were

##### 2.1. What is the current market demand for recycled construction materials?

- (i) Is the market stable and balanced?
- (ii) Does it affect the profitability of recycling units?

##### 2.2. Does recycling and utilizing construction waste generate economic benefits for the company?

- (i) What are the main costs?
- (ii) How do they ensure profitability?
- (iii) What are the primary expenses?

#### 3. Government departments

As facilitators and supporters in the recycling process, the primary questions for government departments were:

##### 3.1. Does the government provide resources or technical support to help construction and recycling units improve waste reduction and recycling rates?

- (i) In what ways?
- (ii) How is support provided?
- (iii) How well is it received?
- (iv) What are the outcomes?

### 3.2. Are there plans to introduce or promote new technologies or models to enhance the reuse of construction waste?

- (i) What are these technologies?
- (ii) How do they differ from previous ones?
- (iii) What are their advancements?
- (iv) How effective are they?
- (v) Are they suitable for current conditions?

#### Appendix B. Interview outcomes summary

**Table A1. The economic benefits of the construction waste management from different perspectives**

Code	Economic benefit	Manifestation	Cost composition	Control measures	Improvement directions	Desired support units
C1	Yes	Reduced raw material purchase costs and waste disposal fees	Waste collection, sorting, and transportation	Cost control during the budgeting phase and regularly evaluating the utilization rate of recycled materials	Introduce automated sorting equipment and optimize transportation routes	Government departments, recycling unit
C2	Yes	Lower waste disposal costs	Labor costs, machinery rental, and waste transportation expenses	Set up dedicated waste sorting areas on-site, reducing transportation costs	Enhance professional skills, especially in the technical application of waste sorting and reuse	Government department, transportation companies
C3	Yes	Long-term savings on raw material expenses	Recycling equipment, transportation, and secondary processing costs	Establish long-term partnerships with equipment suppliers to obtain discounted prices	Develop tiered treatment plans for different types of waste	Equipment suppliers
C4	No	Initial investment and labor costs are relatively higher, exceeding the savings	Specialized sorting equipment, transportation expenses, and site management fees	Consider recycling and processing only when cost accounting meets the required conditions	Promote industry-wide optimization of recycling technologies and increase financial support	Government department

**Table A2. The market demand for the recycled product and the recycling company's economic performance in the sample region**

Code	Market demand	Economic performance	Improvement direction
R1	Demand has grown in infrastructure projects such as roads and park pathways, but remains low in the real estate development sector	The selling price is about 10%–20% lower per ton compared to virgin materials. However, high costs for sorting, transportation, and crushing have compressed profit margins	Specifying minimum usage of recycled materials in the construction projects (public and private); enhancing third-party certification of recycled material performance to boost market confidence
R2	Demand for metal waste is general, but wood recycling and utilization face challenges	Metal recycling generates relatively good returns. In contrast, wood recycling incurs costs far exceeding its recovery value. This material lacks a clear market position	Establishing dedicated funds to support research and promotion of wood processing technologies; exploring broader application areas, such as converting wood into particleboard or fuel
R3	Mainly serve prefabricated component factories and infrastructure projects; customers are often concerned about the strength of recycled materials, especially in high-load construction projects; price sensitivity among customers has led to intense market competition	The selling price of recycled concrete is much lower than that of virgin materials; current profitability relies heavily on government subsidies.	There is a need to develop higher-performing, more stable products to dispel biases; the government should increase efforts to promote recycled materials in public and private construction projects.
R4	Demand for hazardous waste recycling is minimal; paint waste and contaminated wood have high treatment costs and limited applications for recycled products	Operations primarily depend on processing fees; many projects opt for illegal dumping or simple landfilling to avoid extra disposal costs	Cultivating market demand that transforms hazardous waste treatment from merely a responsibility into a profitable business; tighter penalties for prohibiting illegal disposal are needed

**Table A3. Economic support (resources and technology) from different government departments**

Code	Support progress	Category	Details
G1	Technical support	Content	Provided classification management manuals, waste treatment process guidelines, and organized training programs
		Measures	Allocated special funds; collaborated with universities to hold regular technical sharing sessions
		Acceptance level	Enterprises show interest in financial support, but participation rates in technical training remain low
		Effectiveness	Funding has preliminarily improved waste classification and treatment efficiency in some enterprises
	Advanced technology	Type	Introduced an intelligent waste classification recognition system
		Improvement	Significant improvements in automation and accuracy, reducing human errors and associated costs
		Effectiveness	The system demonstrated positive outcomes but requires further adjustments to align with real-world construction scenarios
		Adaptability	The applicability is relatively high, though equipment upgrade costs need to be considered.
G2	Technical support	Content	Provided dedicated vehicles for waste transportation and established construction waste sorting centers
		Measures	Offered free treatment services for properly classified construction waste and fuel subsidies for waste transportation companies
		Acceptance level	Construction units acknowledged that transportation support significantly reduced their burden, but remain hesitant about utilizing sorting centers
		Effectiveness	The coordination mechanism between transportation and sorting has shown initial success, though inadequate waste classification continues to limit its effectiveness
	Advanced technology	Type	Promoted precast production technology using recycled aggregates, such as processing waste concrete into bricks and curb stones
		Improvement	Significantly enhanced the strength and durability of recycled materials
		Effectiveness	Applied on a small scale in municipal projects, yielding stable results
		Adaptability	Highly applicable, but policy support is required to mitigate the economic risks for enterprises adopting the technology
G3	Technical support	Content	Required construction units to submit construction waste management plans during project approval processes and provided a data-sharing platform for recycling units
		Measures	Used approval authority to monitor construction units' compliance with classification responsibilities. Encouraged recycling units to develop new technologies through policy incentives and rewards
		Acceptance level	Construction units demonstrated strong compliance with approval requirements.
		Effectiveness	The initiative enhanced the standardization of construction waste management, though government departments lack complementary regulatory measures.
	Advanced technology	Type	Pilot promotion of an intelligent construction waste tracking system (Geographic Information System) to record the entire process from construction sites to processing facilities
		Improvement	Improved regulatory efficiency and transparency.

*(Cont'd...)*

**Table A3. (Continued)**

<b>Code</b>	<b>Support progress</b>	<b>Category</b>	<b>Details</b>
G4	Technical support	Effectiveness	Significantly reduced illegal dumping in pilot areas, though installation and maintenance costs remain high.
		Adaptability	Highly applicable, requiring continuous government investment and enterprise collaboration
		Content	Assisting construction companies with the installation of waste sorting bins and labeling; providing fuel subsidies and toll fee reductions for construction waste transportation companies; offering equipment upgrade subsidies, low-interest loans, and tax reduction policies to recycling companies to encourage investment in technology upgrades
		Measures	Implemented primarily through an application system, requiring companies to submit detailed fund utilization plans and performance reports, with proportional disbursement after approval
	Advanced technology	Acceptance level	Positive feedback on funding support, though some companies find the application process complex and time-consuming
		Effectiveness	Partially alleviated financial pressures on companies, but support for small enterprises remains insufficient.
		Type	Artificial intelligence-based waste recognition systems; large-scale construction waste processing; high-efficiency separation and pollutant treatment technologies
		Improvement	Previous fiscal support primarily focused on end-point treatment, while the current emphasis has shifted toward “source reduction” and “resource utilization”
		Effectiveness	The guiding role of fiscal subsidies is gradually becoming evident, with more enterprises attempting to adopt new technologies
		Adaptability	Applicability varies depending on enterprise scale and business type. Highly suitable for medium to large recycling companies, but small enterprises still require tailored, tiered support policies