

A Comprehensive Strategy Framework in the Adoption of Green Technology in Waste Management in Industries: A Case Study of Afghanistan

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DOI: <https://doi.org/10.47772/IJRISS.2026.1014MG0095>

Received: 02 May 2026; Accepted: 09 May 2026; Published: 16 May 2026

ABSTRACT

In Afghanistan, industrial waste has significantly increased due to industrial development, posing a threat to the health and welfare of the people, soil and water resources while degrading ecosystems. Where regulation and infrastructure are loose and substandard, green technologies, such as advanced recycling facilities, cleaner production processes, energy recovery systems and effective pollution abatement techniques, can help to minimize environmental damage and encourage a circular economy approach. This study builds a new theory and empirically tests an integrated framework of the Technology–Organization–Environment (TOE) theory and sustainability transition theory. The study combines survey data of 153 stakeholders in the industry and semi-structured interviews with managers, policy makers, and environmental experts. The results of the partial least squares structural equation modeling (PLS-SEM) show that environmental awareness is the strongest predictor of green technology adoption intention ($\beta = 0.357$, $p < 0.001$). In addition, economic feasibility ($\beta = 0.243$, $p = 0.007$) and institutional support ($\beta = 0.220$, $p = 0.006$) have a significant positive direct effect, while technological readiness has a non-significant direct effect ($\beta = 0.053$, $p = 0.504$). Qualitative analysis suggests that the finding is not significant due to misalignment between technologies available and operational realities, skill gaps in several sectors, and chronic infrastructure gaps. The model could account for 54.3% of the variance in the adoption intention ($R^2 = 0.543$) and had good predictive power ($Q^2 = 0.503$). This indicates that in low resource settings, particularly post-conflict, managerial awareness and institutional enablers are more important than the technical availability. The framework not only strengthens knowledge and understanding of technology adoption and sustainability transitions, but also helps to guide policy makers, industry actors, and international organizations in working toward better industrial waste management in an Afghanistan and other developing contexts.

Keywords: Green technology adoption; Industrial waste management; TOE framework; Sustainability transitions; Environmental awareness; PLS-SEM; Mixed-methods research; Afghanistan

INTRODUCTION

Effective industrial waste management has become one of the most pressing environmental challenges in developing countries. In Afghanistan, years of reconstruction and expansion in construction, manufacturing, mining, and related industries have led to a sharp increase in waste generation. At the same time, environmental regulations are poorly enforced, supporting infrastructure is limited, and technical expertise remains scarce. Toxic waste materials continue to leach into soil and water bodies, threatening human health and ecological integrity.

Green technologies offer a viable solution by enabling waste reduction, resource recovery, cleaner production, and energy generation from waste, while also delivering potential economic benefits. However, decisions to adopt such technologies are complex and influenced by technological availability, organizational resources, financial constraints, institutional frameworks, and managerial attitudes toward environmental risk.

This study pursues three main objectives:

Identify the key drivers of green technology adoption intention for industrial waste management in Afghanistan using mixed-methods primary data.

- Develop and validate an integrated conceptual framework that merges the TOE model with sustainability transition theory to account for both firm-level and system-level dynamics.
- Provide context-specific, actionable recommendations for stakeholders operating in fragile, low-resource environments.

Existing research on green technology adoption in fragile and post-conflict states remains limited. Moreover, self-reported survey data alone may suffer from response bias, especially when assessing sensitive issues such as regulatory compliance and institutional performance. This paper addresses these gaps by integrating quantitative survey data with qualitative interviews to triangulate findings, contextualize non-significant relationships, and enhance the robustness of results.

LITERATURE REVIEW

Green Technology in Industrial Waste Management

Green technology in waste management focuses on waste reduction, resource recovery, circularity, and pollution prevention. Empirical studies identify economic viability, regulatory pressure, top management commitment, and stakeholder awareness as key drivers of adoption (Geels, 2002; Horbach, 2008; Seuring & Müller, 2008; Khan, 2021; Shahzad et al., 2022). In developing countries, adoption is often hindered by financial constraints, skill shortages, weak policy enforcement, and inadequate infrastructure—barriers that are further intensified in post-conflict settings.

Technology–Organization–Environment (TOE) Framework

The TOE framework (Tornatzky & Fleischer, 1990) conceptualizes technology adoption as a function of three interrelated contexts:

Technological context: relative advantage, compatibility, availability of skills and infrastructure.

Organizational context: firm resources, top management support, firm size, and strategic orientation.

Environmental context: regulations, incentives, institutional support, and competitive pressure.

The TOE framework has been widely applied to green innovation and sustainability research in emerging economies (Hwang et al., 2016; Liu et al., 2024; Mehmood et al., 2026).

Sustainability Transition Theory and Integration with TOE

Sustainability transition theory, particularly the Multi-Level Perspective (MLP) (Geels, 2002, 2011), conceptualizes societal transitions toward sustainability as interactions between:

Niches: innovative technologies and practices.

Regimes: established rules, norms, and practices.

Landscape: macroeconomic, political, and cultural context.

MLP complements TOE by adding a system-level perspective, which is critical in fragile states where political instability, donor dependence, and weak institutions strongly shape firm-level decisions. Integrating MLP with TOE enables a holistic analysis of green technology adoption that bridges micro-level firm behavior and macro-level systemic constraints.

Hypotheses and Conceptual Framework

Model Overview

The proposed framework extends the traditional TOE model by incorporating environmental awareness as a distinct motivational construct informed by sustainability transition theory. The model posits four direct predictors of green technology adoption intention (AI) in industrial waste management:

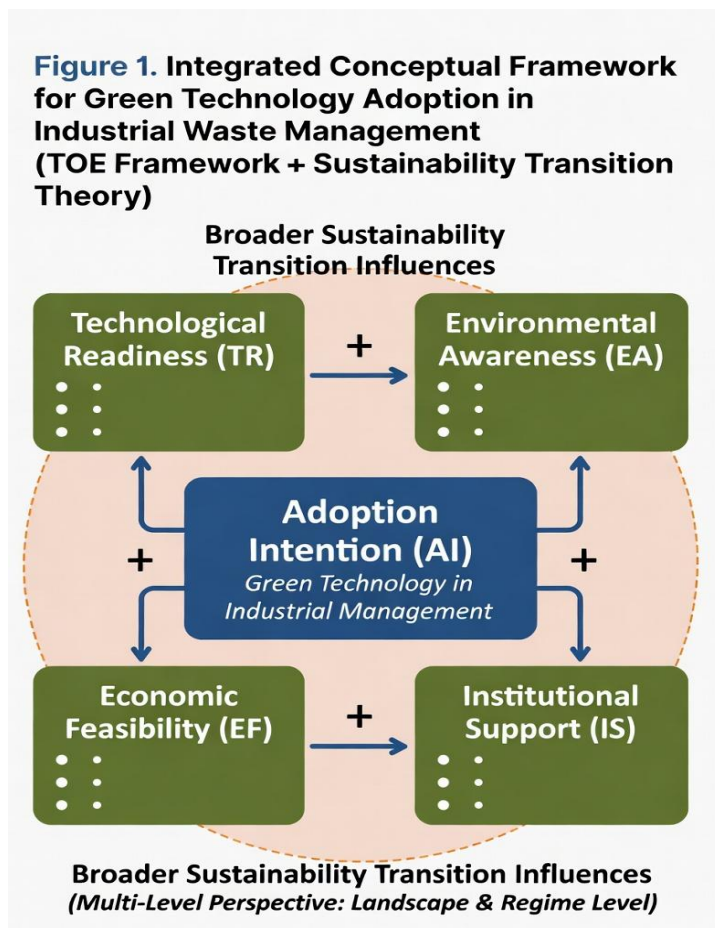
Technological Readiness (TR): availability, compatibility, and required skills for green waste technologies.

Economic Feasibility (EF): perceived cost–benefit balance, upfront investment, long-term savings, and financial sustainability.

Institutional Support (IS): regulatory clarity, enforcement, incentives, and policy guidance.

Environmental Awareness (EA): recognition of waste-related environmental hazards and strategic benefits of green solutions.

Figure 1. Integrated Conceptual Framework for Green Technology Adoption in Industrial Waste Management (TOE + Sustainability Transition Theory)



Hypotheses

H1: Technological readiness has a positive effect on green technology adoption intention.

H2: Economic feasibility has a positive effect on green technology adoption intention.

H3: Institutional support has a positive effect on green technology adoption intention.

H4: Environmental awareness has a positive effect on green technology adoption intention.

METHODOLOGY

This study employs an explanatory mixed-methods design: quantitative survey data test the structural model; qualitative semi-structured interviews contextualize results, address self-report bias, and explain the non-significant technological readiness effect.

Survey Design and Sample

The questionnaire was developed in Persian/Dari, adapted from validated TOE and green innovation scales, and culturally contextualized for Afghanistan. All constructs were measured with four reflective items on a 5-point Likert scale (1 = strongly disagree; 5 = strongly agree). Surveys were distributed to managers, engineers, environmental officers, and industry stakeholders in construction, manufacturing, and mining sectors.

Distributed: 158

Valid responses: 153

Valid response rate: 96.8%

Although modest, the sample is justified by severe data collection constraints in Afghanistan.

Qualitative Data Collection

To mitigate response bias and deepen interpretation, 20 semi-structured interviews (30–45 minutes each) were conducted with purposively selected stakeholders:

- 8 industry managers (construction, manufacturing, mining)
- 6 government policymakers (environment, industry affairs)
- 6 environmental NGO experts

Interviews focused on barriers to adoption, infrastructure gaps, skill shortages, regulatory consistency, and environmental attitudes. Interviews were transcribed verbatim and analyzed via thematic analysis.

Measurement Validation Procedures

The study follows rigorous scale development and validation:

- Items adapted from peer-reviewed TOE and green innovation studies.
- Forward–back translation into Dari/Persian.
- Pilot testing with 10 industry stakeholders; ambiguous items revised.
- Reliability: Cronbach’s alpha, composite reliability (CR).
- Convergent validity: average variance extracted (AVE).
- Discriminant validity: Heterotrait–Monotrait (HTMT) ratios.

Data Analysis

Quantitative: PLS-SEM via SmartPLS 4; 5,000 bootstrap resamples; assessment of path coefficients, p-values, R^2 , Q^2 , and VIF.

Qualitative: NVivo-based inductive thematic analysis; coding focused on infrastructure, skills, finance, regulation, and awareness themes.

RESULTS

Measurement Model

Table 1. Reliability and Convergent Validity

Construct	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Technological Readiness (TR)	0.82	0.83	0.62
Economic Feasibility (EF)	0.79	0.80	0.57
Institutional Support (IS)	0.81	0.82	0.60
Environmental Awareness (EA)	0.85	0.86	0.68
Adoption Intention (AI)	0.87	0.88	0.71

All constructs exceed recommended thresholds ($\alpha > 0.70$, $CR > 0.70$, $AVE > 0.50$), indicating good reliability and convergent validity.

Discriminant Validity

All HTMT ratios < 0.85 (max = 0.79 for IS–EA), supporting satisfactory discriminant validity.

Structural Model Results

Table 2. Path Coefficients and Hypothesis Testing

Path	Beta (β)	t-value	p-value	Decision
TR \rightarrow AI	0.053	0.668	0.504	Not supported
EF \rightarrow AI	0.243	2.697	0.007	Supported
IS \rightarrow AI	0.220	2.722	0.006	Supported
EA \rightarrow AI	0.357	3.467	0.001	Supported

$R^2 = 0.543$ (substantial explanatory power)

$Q^2 = 0.503$ (strong predictive relevance)

VIF = 1.64–2.02 (no severe collinearity)

Qualitative Findings: Explaining the Non-Significant Technological Readiness Effect

Thematic analysis identifies three key explanations for the non-significant TR–AI relationship:

Infrastructure–Technology Misalignment: Advanced green technologies require stable electricity, water, and maintenance networks that are largely absent. Even available technologies cannot operate reliably.

Sector-Specific Skill Deficits: Construction and mining lack trained technicians; manufacturing reports limited knowledge of green technology integration.

Motivation Precedes Technology: Stakeholders consistently emphasized that environmental awareness and financial security must come first. Without perceived risk and return, technical readiness is not a decisive factor.

DISCUSSION

Mixed-methods results confirm and extend the literature while revealing context-specific dynamics in Afghanistan.

Environmental awareness emerges as the strongest driver ($\beta = 0.357$, $p < 0.001$). Qualitative data show that managers with clear awareness of soil/water contamination and health risks are significantly more willing to adopt green solutions. This aligns with findings from Pakistan (Khan, 2021; Shahzad et al., 2022).

Economic feasibility ($\beta = 0.243$, $p = 0.007$) and institutional support ($\beta = 0.220$, $p = 0.006$) are significant. Firms require clear cost–benefit projections, incentives, and consistent policy. Weak enforcement and policy inconsistency reduce confidence—consistent with Asian green supply chain studies (Hwang et al., 2016; Liu et al., 2024).

Technological readiness is non-significant ($\beta = 0.053$, $p = 0.504$). This does not negate technology’s importance but reflects a post-conflict reality: technical availability matters little without foundational infrastructure, skilled labor, or motivational drivers. Unlike stable emerging markets, early sustainability transitions in fragile contexts prioritize awareness, finance, and institutions over technical readiness.

Integrating TOE with MLP highlights how landscape factors (instability, donor dependence) shape regime practices (weak governance) and niche adoption (green technology). Awareness and institutions act as gatekeepers enabling or blocking adoption.

Theoretical Contributions

Integrated Mixed-Methods TOE–MLP Framework: Validates a holistic model for fragile states, addressing single-method limitations.

Empirical Explanation of Non-Significant TR: Qualitative data resolve a critical interpretive gap in TOE research for post-conflict settings.

Rare Empirical Evidence from Afghanistan: Enables cross-contextual comparison with South and Central Asian studies.

Transparent Measurement Validation: Detailed scale development procedures improve replicability.

Practical Implications

Government: Strengthen enforcement; introduce grants/tax incentives; run industrial environmental awareness campaigns; invest in basic infrastructure (power, water).

Industry: Build internal environmental awareness; conduct sector-specific cost–benefit analyses; pilot small-scale green projects.

Donors/NGOs: Support context-appropriate pilot projects; provide blended finance; deliver sector-specific technical training; align with national reconstruction priorities.

Limitations and Future Research

Sample: Formal sector only; future studies should include informal waste actors.

Cross-sectional: Measures intention, not behavior; longitudinal mixed-methods recommended.

Context specificity: Cross-country comparison with other post-conflict states to test generalizability.

Sector deep dive: Construction vs. manufacturing vs. mining subsector analysis.

CONCLUSION

This study aims to develop and validate the framework of green technology adoption in the industrial waste management system with a mixed-methods approach and the combination of theories of transition towards sustainability and TOE. Results indicate that the factors that influence the adoption intention are environmental awareness, economic feasibility, and institutional support, with technological readiness being the least influential of the three, due to infrastructure lack, skill shortage, and mismatched technology. The study is both quantitative and qualitative, thus eliminating the problems of response and interpretation, with both theory and practice offering actionable insights. For Afghan and other fragile states, investing in awareness creation, incentives and building capacity are key to turning green intentions into environmental and economic benefits.

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