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Designing and Testing a Technology Development Model Based on Environmental Ethics Using a Mixed-Methods Approach

ABSTRACT

The present study was conducted with the aim of designing and testing a technology development model based on environmental ethics using a mixed-methods approach. In terms of purpose, this study is applied in nature, and in terms of data, it employed an exploratory mixed design combining qualitative and quantitative approaches. In the qualitative phase, the statistical population consisted of key informants in the field of research at the Department of Environment of Tehran Province. Using snowball sampling, interviews were conducted with 11 participants until theoretical saturation was achieved. In the quantitative phase, the population comprised all male and female managers and employees of the Department of Environment of Tehran Province (N = 1350). According to Krejcie and Morgan's sample size table, a sample size of 298 was determined, and stratified random sampling was used. With an additional 10% to compensate for potential attrition, 302 questionnaires were collected. For data collection, library and field methods were used in the qualitative phase, while a researcher-made questionnaire was used as the field method in the quantitative phase. To assess the credibility of the qualitative instrument, three triangulation strategies were used: methodological triangulation (71%), investigator triangulation (77%), and participant triangulation (83%). In the quantitative phase, face and content validity were assessed, and reliability was determined using Cronbach's alpha, which indicated acceptable validity and reliability. Data analysis in the qualitative phase was performed using theoretical coding, while in the quantitative phase, confirmatory factor analysis was employed. The results showed that the technology development model based on environmental ethics consisted of 133 open codes (indicators), 26 axial codes (components), and 6 factors (dimensions). The causal factors included 4 axial codes (components) and 20 open codes (indicators); the contextual factors included 5 axial codes (components) and 30 open codes (indicators); the intervening factors included 5 axial codes (components) and 24 open codes (indicators); the strategies factor included 7 axial codes (components) and 34 open codes (indicators); and the consequences factor included 5 axial codes (components) and 25 open codes (indicators). Ultimately, the model fit indices, along with factor loadings and significance coefficients, indicated an acceptable model fit.

Keywords: Development, Technology, Environmental Ethics, Department of Environment

Introduction

In the contemporary era, the rapid advancement of technology has transformed almost every aspect of human life, yet this technological surge has raised profound ethical concerns about its impact on the natural environment. The discipline of environmental ethics has emerged as a crucial framework for evaluating the moral dimensions of human interactions with nature, aiming to guide technological development in a way that safeguards ecological integrity while sustaining human progress [1]. Environmental ethics emphasizes principles such as stewardship, sustainability, and justice for both present and future generations, offering a normative foundation to assess the consequences of technological activities [2]. The urgency

of integrating environmental ethics into technological development is underscored by escalating ecological crises—climate change, biodiversity loss, and resource depletion—that are inextricably linked to industrial and technological systems [3].

Scholars argue that sustainable technology must be embedded within ethical frameworks that acknowledge environmental limits and responsibilities. According to [4], ethics can function both as an enabler and as a constraint in technology development, influencing decisions about innovation pathways, resource allocation, and the acceptance of emerging technologies. Similarly, [5] highlights that proactive ethical oversight is essential throughout the life cycle of technological innovation, from design to implementation, ensuring that environmental consequences are foreseen and mitigated. This perspective aligns with the notion that ethical reflection should not be an afterthought but an integral component of technological innovation systems [6].

In this regard, several scholars within Iran have explored the foundations of environmental ethics from cultural, religious, and philosophical standpoints, arguing that technological progress devoid of ethical grounding risks exacerbating environmental degradation. For example, [7] emphasize that Islamic philosophical traditions contain robust principles of environmental ethics, which can guide responsible technological development. Building on this, [8] delves into the cosmological underpinnings of environmental ethics in the thought of Sadr al-Muta'allihin, asserting that his metaphysical view of nature as an interconnected whole demands a moral duty of care toward the environment. Moreover, [9] demonstrates that Islamic doctrine contains implicit yet strong commitments to environmental stewardship, while [10] highlights how scholars like Mesbah Yazdi have contributed to formulating a distinctly Islamic theory of environmental ethics.

These religious-philosophical contributions resonate with global debates on the moral responsibilities of technology developers. According to [11], integrating ethical accountability and sustainability concerns into technological design processes can bridge the gap between innovation and environmental responsibility. Furthermore, [12] notes that even fields traditionally focused on design and aesthetics, such as landscape architecture, have begun embedding environmental ethics to mitigate the ecological impacts of technological interventions in natural spaces. This broader paradigm shift reflects a growing consensus that technological development must align with ethical imperatives to protect ecosystems while fostering innovation.

Within the Iranian context, however, the institutionalization of environmental ethics in technology sectors has faced persistent challenges. Studies such as [13] reveal that ethical considerations often remain peripheral in technology policymaking, partly due to the dominance of instrumental and profit-driven logics. Likewise, [14] warns that modernity's ethical challenges have undermined environmental rights discourses, creating tensions between economic development objectives and ecological protection. These tensions are further exacerbated by weak regulatory frameworks and enforcement mechanisms, as emphasized by [15], who identifies institutional deficiencies as key factors contributing to environmental violations in urban contexts like Herat.

Conversely, embedding environmental ethics in organizational practices has shown positive outcomes for both ecological and economic performance. [16] found that fostering environmental ethics within manufacturing companies enhances green citizenship behavior and strengthens environmental performance metrics. Similarly, [17] proposed a market-oriented model incorporating social responsibility as an ethical dimension, arguing that ethical commitments can coexist with competitive business strategies. This aligns with [18], who demonstrated that organizations committed to environmental ethics positively

influence customer behavioral intentions, suggesting that ethical positioning may even confer reputational and market advantages.

Nevertheless, the operationalization of environmental ethics in technological systems requires a coherent conceptual and institutional framework. [6] emphasizes that national innovation systems must incorporate ethical governance structures to ensure the responsible evolution of technology sectors. [19] further argues that ethical and value-based foundations should be explicitly embedded in the design and simulation of technological systems to prevent ethical considerations from being sidelined. Such an approach can foster proactive ethical thinking among engineers, managers, and policymakers, ensuring that technology serves environmental as well as economic objectives.

Legal frameworks also play a pivotal role in institutionalizing ethical norms in technology-related activities. [20] stresses that environmental protection must be rooted in binding legal orders, while [21] shows how performance assessment methods, such as fuzzy evaluation in green supply chains, can operationalize ethical principles within corporate processes. Moreover, [22] demonstrates that structured decision-making methods (e.g., Delphi method) can help prioritize environmentally sustainable industries in regional development, linking ethical responsibility to local economic planning.

Philosophically, there is a need to bridge the often fragmented ethical discourses on technology and environment. [23] highlights the complex bioethical interactions between philosophy and theology, suggesting that ethical deliberation on environmental issues must be both interdisciplinary and transcultural. [24] adds that clean technology initiatives must be guided by ethical values from their inception to ensure long-term environmental sustainability. This aligns with the proposition of [25], who argues that care ethics—which prioritize relational responsibility and long-term well-being—can help organizations confront their environmental harms, especially in sectors like healthcare where technological intensity is high.

This multidimensional body of scholarship suggests that designing and implementing a technology development model grounded in environmental ethics requires a synthesis of philosophical principles, organizational practices, legal mandates, and cultural values. Yet, as [26] point out, efforts to integrate religion, ethics, and environmental responsibility often encounter resistance from entrenched economic and political structures, which privilege short-term gains over long-term sustainability. Overcoming these barriers demands a systemic approach that embeds ethical reflection at all levels of technological decision-making—from strategic planning and resource allocation to operational management and community engagement.

In sum, while the theoretical and empirical literature confirms the critical importance of environmental ethics in steering technological development toward sustainability, there remains a lack of integrative models that operationalize these principles within institutional and managerial contexts. Existing research provides important building blocks—from ethical-philosophical foundations [7-10] to organizational practices [16-18] and regulatory frameworks [20, 21]—but they have yet to be combined into a cohesive model capable of guiding ethical technological innovation in practice. The present study therefore aims to design and empirically test a comprehensive model of technology development based on environmental ethics, employing a mixed-method approach to integrate conceptual, institutional, and managerial dimensions.

Methodology

In terms of purpose, this research is applied; in terms of data, it is exploratory mixed-method and combines qualitative and quantitative approaches; and in terms of implementation method, it was conducted using two approaches: the systematic grounded theory method and the cross-sectional survey method.

In the qualitative section, the statistical population consisted of key informants in the field of research at the Department of Environment of Tehran Province, who were selected using snowball sampling. In the quantitative section, the population consisted of all male and female managers and employees of the Department of Environment of Tehran Province (N = 1350). Based on Krejcie and Morgan's sample size table, a sample size of 298 was determined, and stratified random sampling was used. By adding 10% to account for potential attrition, 302 questionnaires were collected.

For collecting qualitative data, library and field methods were used, while for quantitative data, field methods (a researcher-made questionnaire) were employed. In the qualitative part, both library and field methods were used to collect data. In the library phase, as the first step, the library method was used to familiarize the researcher with basic concepts and theoretical foundations and to review previous studies on technology development based on environmental ethics. By reviewing documents and sources such as books, articles, dissertations, and databases, the theoretical foundations and research background were extracted.

In the field phase, as the second step, data were collected through the field method, using semi-structured interviews. In other words, in the qualitative part of the present study, a semi-structured and exploratory interview instrument was used. To conduct the semi-structured interviews, the researcher prepared a protocol, and the interviews were conducted based on that protocol. Initially, the semi-structured interview questions were designed based on the concepts and codes obtained from the library review. In the next step, the interview questions were aligned with the research questions following the systematic grounded theory approach. Furthermore, the questions were designed in an open-ended format to avoid leading the interviewees' responses.

Subsequently, all interviews were manually transcribed, and the researcher analyzed them. After conducting three interviews, the researcher began extracting codes and then continued conducting further interviews. Occasionally, in addition to the main research questions, the researcher also asked supplementary and probing questions to better understand the interviewees' experiences. The duration of each interview was set at approximately 30 to 45 minutes, although in some cases this varied. The interviews stopped at number 11, and interviews 12, 13, and 14 did not provide new findings, leading the researcher to conclude that theoretical saturation had been reached. Finally, the researcher re-read all the interviews and reviewed and refined the extracted codes.

To assess the credibility of the qualitative instrument, three triangulation strategies were used: methodological triangulation (71%), investigator triangulation (77%), and participant triangulation (83%). In the quantitative part, face and content validity were evaluated, and reliability was assessed using Cronbach's alpha, which indicated acceptable validity and reliability. Data analysis in the qualitative section was performed using theoretical coding, and in the quantitative section, confirmatory factor analysis (CFA) was used.

Findings and Results

After analyzing the data and answering the sub-questions of the research, the factors and categories constituting the technology development model based on environmental ethics were identified. The model consisted of 26 axial codes and 133 open codes within the six components of Strauss and Corbin's paradigmatic model, and was determined as follows:

Core Category: Technology development based on environmental ethics

Causal Conditions (4 axial codes and 20 open codes):

- Natural, technological, and scientific conditions: 4 open codes
- Economic factors: 5 open codes
- Cultural factors: 7 open codes
- Laws and regulations: 4 open codes

Contextual Conditions (5 axial codes and 30 open codes):

- Technical equipment and infrastructure: 8 open codes
- Incentives and support: 6 open codes
- Consideration of cultural aspects: 6 open codes
- Resource management: 5 open codes
- Responsibility: 5 open codes

Intervening Conditions (5 axial codes and 24 open codes):

- Structural and managerial weaknesses: 4 open codes
- Policy-making and legal weaknesses: 6 open codes
- Technological weaknesses: 4 open codes
- Lack of public awareness: 5 open codes
- Financial-economic factors: 5 open codes

Strategies (7 axial codes and 34 open codes):

- Providing incentives: 6 open codes
- Creating strategic plans: 5 open codes
- Training and raising awareness: 4 open codes
- Planning and monitoring: 6 open codes
- Drafting laws and regulations: 5 open codes
- Strengthening values and beliefs: 3 open codes
- Developing research infrastructure: 4 open codes

Consequences (5 axial codes and 25 open codes):

- Enhancing responsibility: 5 open codes
- Independence and sustainable employment: 5 open codes
- Natural resource productivity: 4 open codes
- Environmental protection: 5 open codes
- Public health and safety: 6 open codes

Table 1.

Results of Kolmogorov–Smirnov test

Significance Level	Degrees of Freedom	K-S
0.649	301	3.15

In the quantitative part of the study, to generalize the results to the population from which the data were drawn, Confirmatory Factor Analysis (CFA) was used, and the results are presented below.

Figure 1.

Standardized values for the causal factors

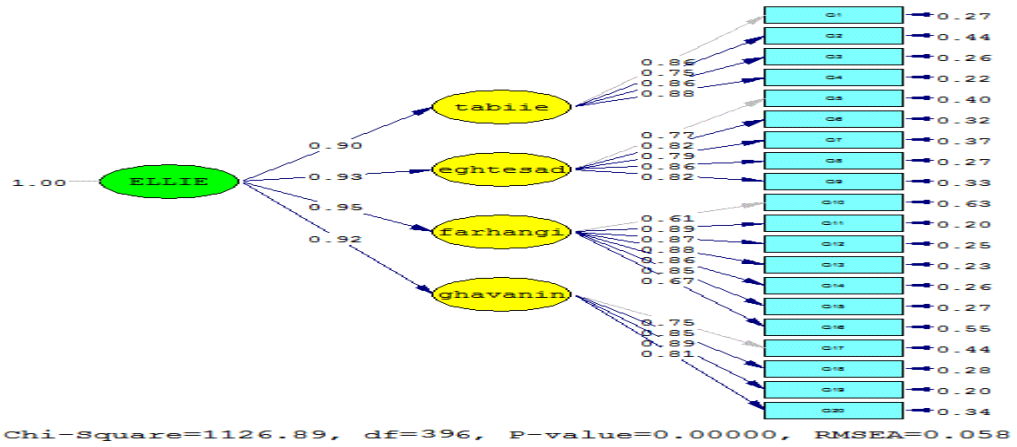


Figure 2.

Significance values (t-value coefficients) for the causal factors

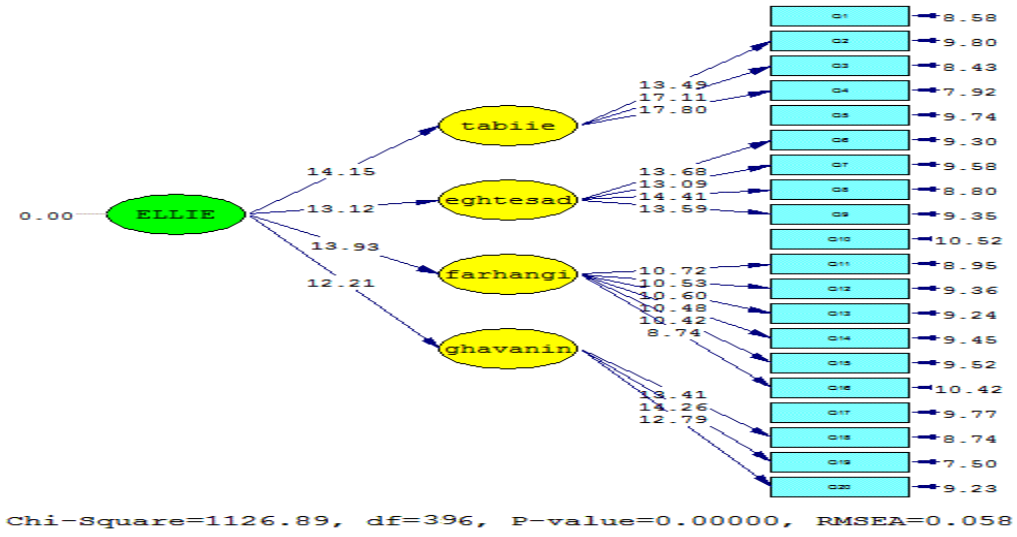


Table 2.

Goodness-of-fit indices for the causal factors

Index	Acceptable Range	Obtained Value
X^2	–	1126.89
df	–	396
X^2/df	< 3	2.85
RMSEA	< 0.08	0.058

CFI	> 0.90	0.95
IFI	> 0.90	0.94
RFI	> 0.90	0.93
GFI	> 0.90	0.92
AGFI	> 0.90	0.91

Figure 3.

Standardized values for the contextual factors

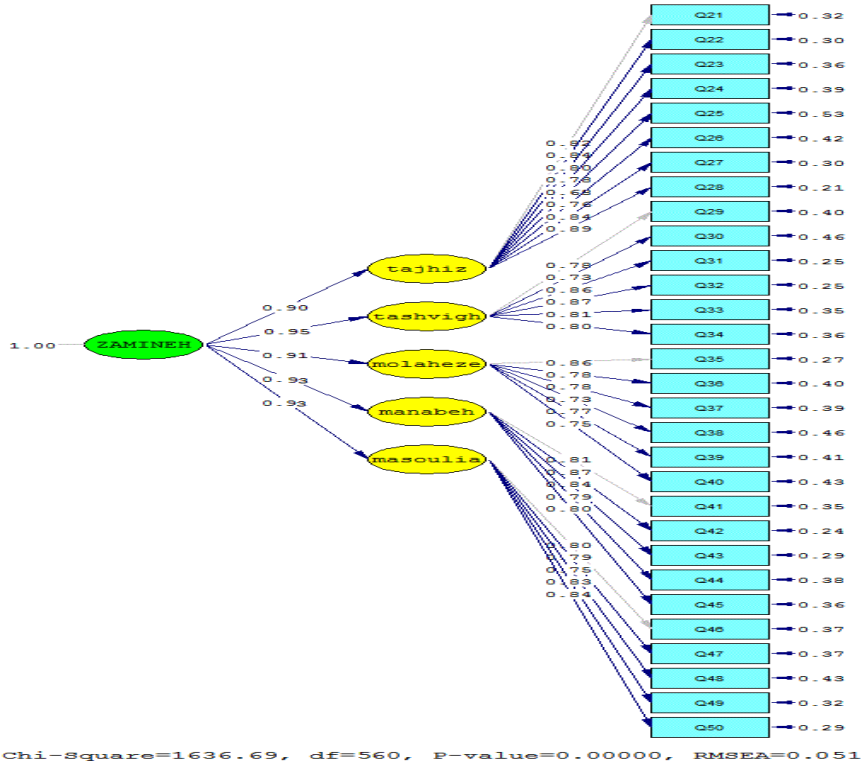


Figure 4.

Significance values (t-value coefficients) for the contextual factors

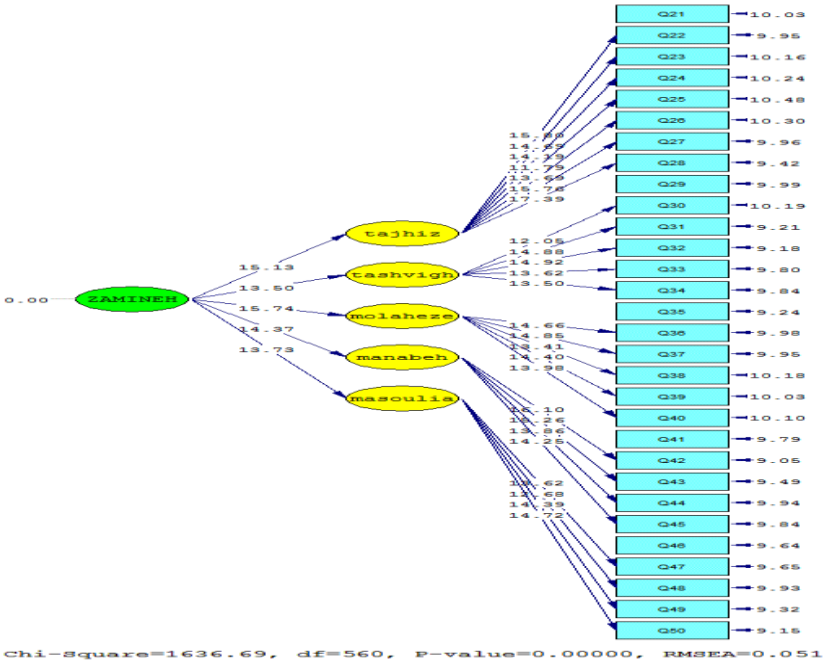


Table 3.

Goodness-of-fit indices for the contextual factors

Index	Acceptable Range	Obtained Value
X^2	–	1636.69
df	–	560
X^2/df	< 3	2.92
RMSEA	< 0.08	0.051
CFI	> 0.90	0.94
IFI	> 0.90	0.93
RFI	> 0.90	0.92
GFI	> 0.90	0.92
AGFI	> 0.90	0.90

Figure 5.

Standardized values for the intervening factors

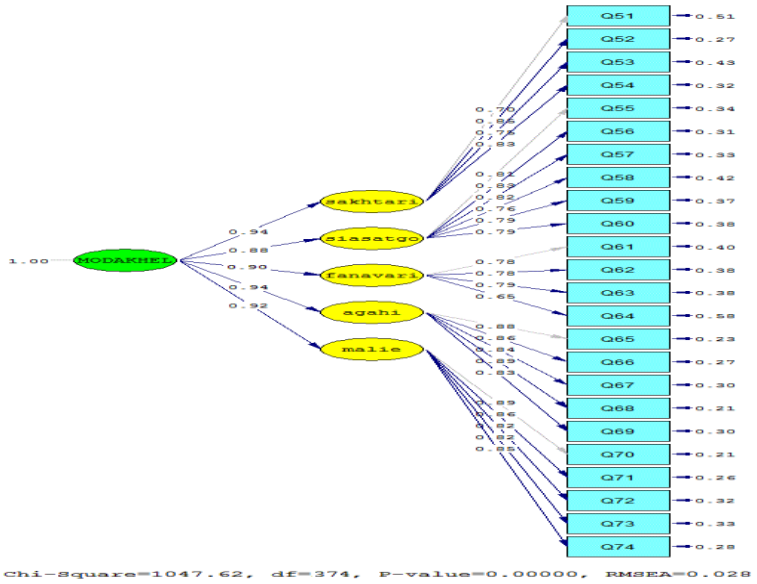


Figure 6.

Significance values (t-value coefficients) for the intervening factors

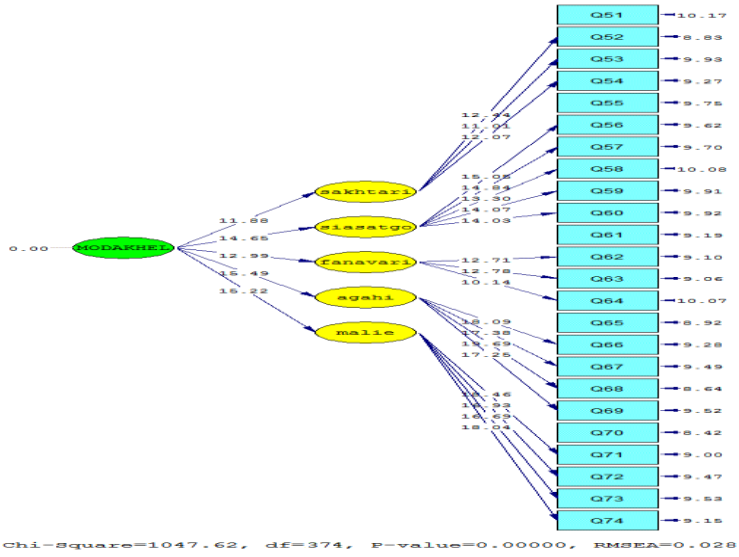


Table 4.

Goodness-of-fit indices for the intervening factors

Index	Acceptable Range	Obtained Value
X^2	–	1047.62
df	–	374
X^2/df	< 3	2.80
RMSEA	< 0.08	0.028
CFI	> 0.90	0.94
IFI	> 0.90	0.93
RFI	> 0.90	0.93
GFI	> 0.90	0.92
AGFI	> 0.90	0.90

Figure 7.

Standardized values for the strategies factor

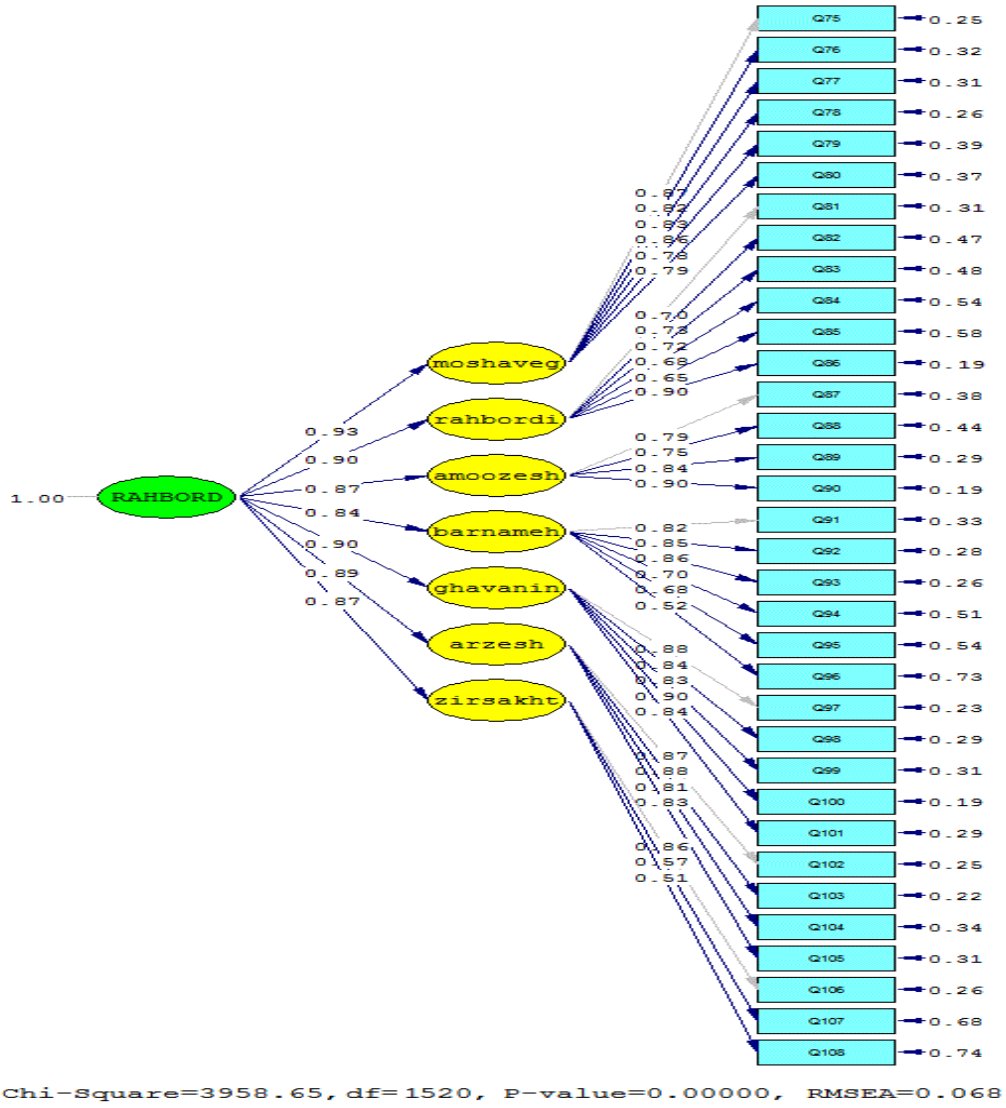


Figure 8.

Significance values (t-value coefficients) for the strategies factor

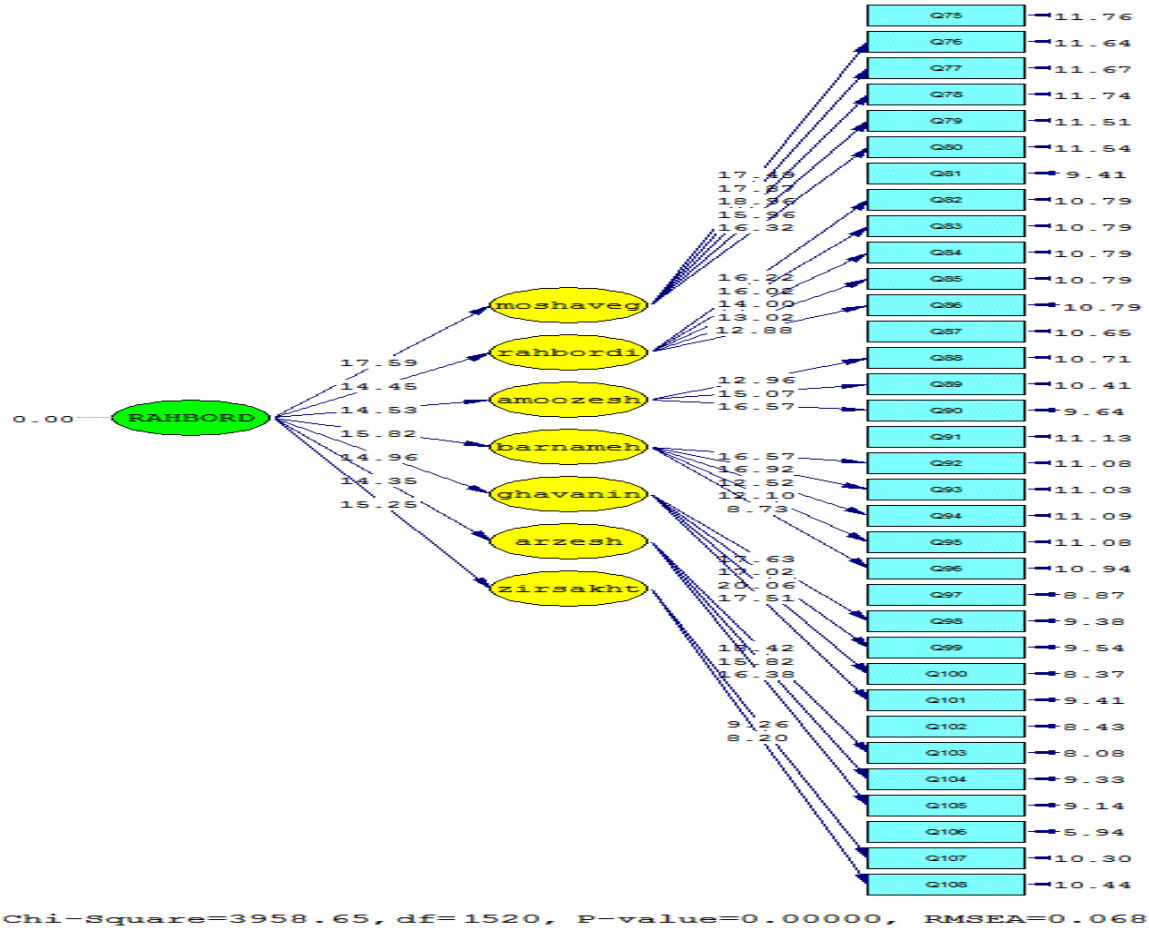


Table 5.

Goodness-of-fit indices for the strategies factor

Index	Acceptable Range	Obtained Value
X^2	–	3958.65
df	–	1520
X^2/df	< 3	2.60
RMSEA	< 0.08	0.068
CFI	> 0.90	0.95
IFI	> 0.90	0.94
RFI	> 0.90	0.93
GFI	> 0.90	0.92
AGFI	> 0.90	0.91

Figure 9.

Standardized values for the consequences factor

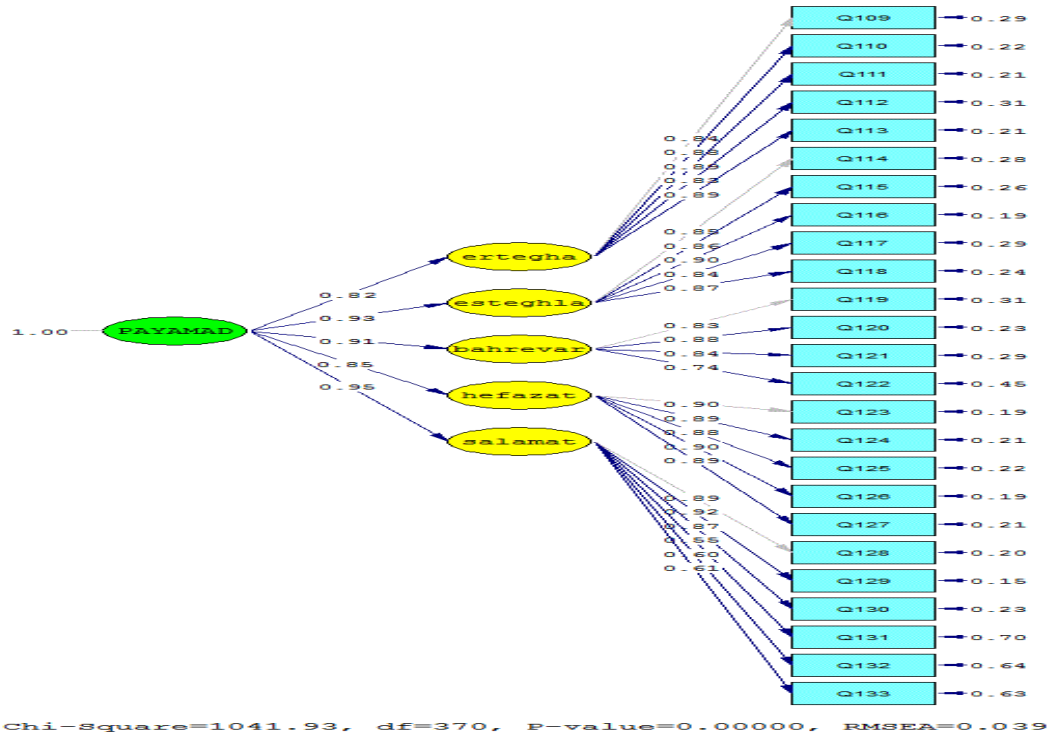


Table 6.

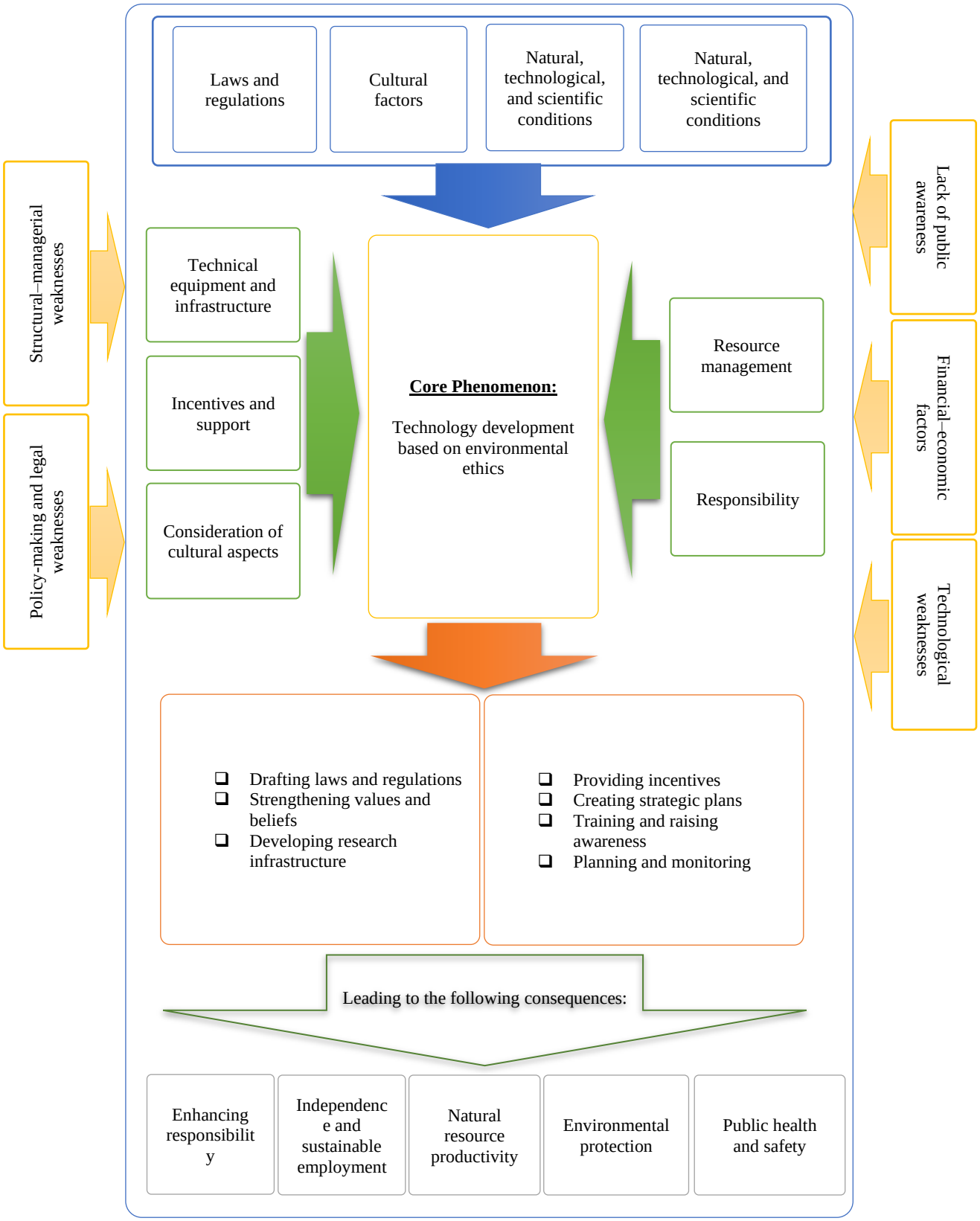
Goodness-of-Fit Indices of the General Research Model

Index	Acceptable Range	Obtained Value
X^2	–	7286.53
df	–	2529
X^2/df	< 3	2.88
Root Mean Square Error of Approximation (RMSEA)	< 0.08	0.045
Comparative Fit Index (CFI)	> 0.90	0.95
Incremental Fit Index (IFI)	> 0.90	0.94
Relative Fit Index (RFI)	> 0.90	0.93
Goodness of Fit Index (GFI)	> 0.90	0.92
Adjusted Goodness of Fit Index (AGFI)	> 0.90	0.91

To determine the overall model fit, the goodness-of-fit indices available in LISREL were used. According to the results in the table, the ratio of chi-square to degrees of freedom is 2.88. The value of the Root Mean Square Error of Approximation (RMSEA) is 0.045, which is considered an acceptable level of model fit. Other fit indices, such as the Goodness of Fit Index (GFI) and Adjusted Goodness of Fit Index (AGFI), as well as other indicators, have values above 0.90, which are regarded as desirable indicators of model fit.

Figure 10.

The technology development model based on environmental ethics using a mixed-method approach



Discussion and Conclusion

The findings of this study led to the design and validation of a technology development model based on environmental ethics using a mixed-method approach, which incorporated six major dimensions: causal conditions, contextual conditions, intervening conditions, strategies, consequences, and the core phenomenon of "technology development grounded in environmental ethics." This model was developed through qualitative grounded theory analysis and then validated via confirmatory factor analysis, which demonstrated acceptable fit indices across all dimensions. The results showed that the causal factors included natural, technological, and scientific conditions, economic factors, cultural factors, and laws and regulations. Contextual factors included technical equipment and infrastructure, incentives and support, consideration of cultural aspects, resource management, and responsibility. Intervening conditions encompassed structural-managerial weaknesses, policy and legal weaknesses, technological weaknesses, financial-economic constraints, and lack of public awareness. Strategic factors included providing incentives, creating strategic plans, training and raising awareness, planning and monitoring, drafting laws and regulations, strengthening values and beliefs, and developing research infrastructure. Finally, the model indicated that these processes collectively contribute to consequences such as enhancing responsibility, achieving independence and sustainable employment, improving natural resource productivity, protecting the environment, and promoting public health and safety.

These findings strongly support the theoretical proposition that ethical considerations are not peripheral but rather foundational to sustainable technology development. As [1] argued, environmental ethics provides the normative framework within which economic and technological actions must be evaluated to ensure their long-term sustainability. The causal dimension identified in this study—particularly the emphasis on natural, technological, and scientific conditions—reflects this normative orientation by situating technological development within the boundaries of ecological systems and scientific accountability. Similarly, [2] contends that environmental problems are fundamentally normative in nature, and thus technological systems must be guided by ethical norms to avoid further ecological harm.

The incorporation of cultural factors and laws and regulations within the causal dimension aligns with earlier work by [8], who demonstrated that the metaphysical and cosmological worldview of Sadr al-Muta'allihin supports the moral duty of protecting the environment as part of a holistic ethical vision. This perspective indicates that cultural worldviews can shape ethical orientations toward technology. Moreover, [9] identified implicit ethical commitments toward the environment in Islamic doctrine, suggesting that culturally grounded ethical values can serve as catalysts for the integration of environmental ethics in technological systems. The inclusion of laws and regulations also confirms the assertion of [20] that environmental protection must be institutionalized through binding legal frameworks to become operational in practice.

The contextual factors identified in the model, such as technical infrastructure, incentives, cultural considerations, and resource management, further validate the notion that ethical implementation requires supportive institutional and material environments. [6] emphasized that the success of national innovation systems depends on the integration of ethical governance structures, which include both institutional incentives and infrastructural capacities. This aligns with the findings of [17], who highlighted that ethical and social responsibility considerations can be operationalized in market-oriented technological models through appropriate resource allocation and incentive structures. Additionally, the model's identification of "responsibility" as a contextual factor echoes [18], who showed that organizational commitment to

environmental ethics enhances not only internal responsibility but also positively influences customer behavioral intentions, thereby reinforcing the organizational legitimacy of ethical practices.

The intervening conditions revealed in this study—structural-managerial weaknesses, policy and legal gaps, technological deficiencies, financial constraints, and lack of public awareness—explain why ethical integration into technological development has often been slow or inconsistent. These findings are consistent with [15], who reported that institutional deficiencies are a major cause of environmental violations and failures in enforcement. Similarly, [13] found that technological decision-making in many organizations is dominated by instrumental rationality, leaving ethical concerns marginal. The identification of financial-economic constraints as intervening barriers also supports [14], who argued that the pursuit of economic growth often undermines environmental rights discourses and creates resistance to ethical integration.

Addressing these barriers requires well-designed strategies, which this study identified as providing incentives, creating strategic plans, training and raising awareness, planning and monitoring, drafting laws and regulations, strengthening values and beliefs, and developing research infrastructure. These strategies resonate with previous findings that ethical embedding must be proactive and multi-layered. [5] emphasized that ethical oversight should accompany all stages of technology development, from design to deployment, while [4] showed that ethical considerations can act as both enablers and constraints, shaping innovation trajectories and risk assessments. The emphasis on training and awareness also reflects [3], who demonstrated that educational tools like ecological footprint calculators can significantly increase environmental literacy and sustainable behaviors. Moreover, strengthening values and beliefs as a strategy echoes [10], who stressed the importance of embedding ethical worldviews, such as those articulated by Mesbah Yazdi, into the ethical architecture of environmental decision-making.

The model's consequences—enhanced responsibility, sustainable employment, natural resource productivity, environmental protection, and public health and safety—highlight the broader societal benefits of integrating environmental ethics into technological systems. These outcomes align with [16], who found that ethical commitments in organizations lead to improved environmental performance and green citizenship behaviors. They also support [19], who argued that embedding ethical values in technological systems improves long-term efficiency and societal acceptance. The link between ethical technology development and public well-being further reflects the notion of "care ethics" advanced by [25], who suggested that care-oriented ethical frameworks can help organizations address their environmental harms by prioritizing long-term collective well-being over short-term gains.

This study also reinforces the idea that environmental ethics must be deeply institutionalized across legal, organizational, and cultural domains to achieve transformative change. The inclusion of laws and regulations at multiple stages of the model supports [21], who demonstrated how ethical principles can be incorporated into operational frameworks through performance assessment methods in green supply chains. Furthermore, the call for strategic planning aligns with [22], who showed that structured decision-making tools such as the Delphi method can help prioritize environmentally sustainable industries. By combining strategic planning with ethical imperatives, organizations can institutionalize sustainability as a guiding principle rather than an optional add-on.

Additionally, the model's structure resonates with philosophical perspectives on the interdependence of ethics, technology, and environmental sustainability. [11] emphasized that ethical accountability must be integrated into the intentionality of technological design to achieve sustainability, while [23] highlighted the need for dialogue between

philosophy and theology to create coherent bioethical frameworks. This integrationist approach parallels [24], who argued that clean technology initiatives must be rooted in ethical considerations from inception to ensure their longevity and public trust. By situating ethical reasoning at the heart of technological systems, the model proposed in this study advances the interdisciplinary integration called for by these scholars.

Finally, the findings validate [26], who pointed out that efforts to integrate religion, ethics, and environmental responsibility often face structural resistance but are essential for achieving long-term sustainability. By empirically demonstrating how ethical, cultural, legal, and infrastructural factors interact to shape technology development outcomes, this study contributes a comprehensive and operationalizable framework to guide future technological policies and practices in alignment with environmental ethics.

Despite its contributions, this study has several limitations. First, it was geographically limited to the Department of Environment of Tehran Province, which may limit the generalizability of the findings to other organizational, cultural, or national contexts. Different regions may have varying institutional capacities, cultural orientations, and regulatory frameworks that influence the integration of environmental ethics into technological development. Second, the quantitative phase relied on self-reported questionnaire data, which may be affected by social desirability bias, especially regarding ethical attitudes and behaviors. Third, while the mixed-method design enhanced the robustness of the model, it did not include longitudinal data, making it difficult to assess the long-term effects of the proposed model on organizational and environmental outcomes. Additionally, the qualitative phase involved a relatively small number of interviews (n = 11), and although theoretical saturation was reached, broader stakeholder perspectives (e.g., private sector innovators, policy-makers, and civil society actors) could further enrich the model.

Future research should replicate and extend this model in diverse organizational and geographic contexts to enhance its external validity. Comparative studies across regions with different cultural and regulatory systems could clarify how contextual factors moderate the effectiveness of environmental ethics integration. Longitudinal studies are also recommended to assess the causal impact of implementing the proposed model on long-term technological innovation outcomes, environmental performance, and organizational change. Future research could also incorporate experimental or quasi-experimental designs to evaluate specific strategic interventions—such as training programs, incentive mechanisms, or legal reforms—on the adoption of ethical practices in technological development. Furthermore, future studies should include a broader range of stakeholders, including private sector firms, governmental agencies, non-governmental organizations, and local communities, to capture multi-level perspectives on ethical technology governance.

Practitioners and policymakers should consider institutionalizing environmental ethics as a core component of technological development strategies. Organizations should establish formal ethical oversight mechanisms, including dedicated ethics committees and sustainability offices, to monitor compliance and guide decision-making throughout the technology life cycle. Training and capacity-building initiatives should be implemented to raise environmental ethics literacy among engineers, managers, and employees. Policymakers should integrate ethical evaluation criteria into funding, licensing, and regulatory approval processes for new technologies. Finally, fostering a culture of responsibility, transparency, and long-term stewardship will be essential to ensure that technological innovation contributes positively to environmental sustainability and societal well-being.

Acknowledgments

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants. Written consent was obtained from all participants in the study.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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