DIGITAL TRANSFORMATION AND ADMINISTRATION INNOVATION

Citation: Hosseini, S. F., Motamedi, M., Darvish Motavali, M. H., & Movahedi, M. M. (2025). Identification of Factors and Components of Environmentally Ethical Technology Development: A Qualitative Study Using Grounded Theory. *Digital Transformation and Administration Innovation,* 3(4), 1-13.

Received date: 2025-03-13 Revised date: 2025-08-03 Accepted date: 2025-08-13 Published date: 2025-10-10

Identification of Factors and Components of Environmentally Ethical Technology Development: A Qualitative Study Using Grounded Theory

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Abstract

The present article was conducted with the aim of identifying the factors and components of environmentally ethical technology development. In terms of purpose, the research is applied; in terms of data, it is qualitative; and in terms of implementation method, it was conducted using the systematic grounded theory approach. The statistical population consisted of key informants in the field of research within the Tehran Province Department of Environment, and interviews were conducted with 11 individuals using the snowball sampling method until theoretical saturation was achieved. Data were collected through both library research (documents and records) and field research (semi-structured interviews). To assess the validity of the research instrument, three triangulation methods were used: methodological triangulation (71%), investigator triangulation (77%), and participant triangulation (83%), indicating that the instrument had acceptable validity. Data analysis was performed using theoretical coding (based on the paradigm model of grounded theory). The coding results showed that environmentally ethical technology development consisted of 133 open codes (indicators), 26 axial codes (components), and 6 selective codes (dimensions).

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

1. Introduction

The accelerating pace of technological advancement in the twenty-first century has fundamentally reshaped human interaction with the environment, creating both unprecedented opportunities and severe ethical dilemmas. Emerging technologies have transformed industrial processes, communication systems, and societal infrastructures, but their environmental implications remain a pressing concern. As societies face escalating climate change, biodiversity loss, and resource depletion, integrating environmental ethics into the design, deployment, and governance of technologies has become a critical imperative (Randall, 2025). Ethical considerations are no longer peripheral to technological progress; instead, they are central to ensuring that innovation aligns with principles of sustainability, justice, and ecological stewardship (White,

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2015). This paradigm shift requires rethinking traditional economic, social, and political frameworks to accommodate the moral responsibilities associated with technological systems (Bacon, 2016).

The ethical assessment of technology is inherently interdisciplinary, drawing on philosophy, engineering, environmental science, and social theory. Classical perspectives, such as those articulated in *The New Organon*, emphasize the systematic pursuit of knowledge while cautioning against the misuse of scientific discovery for harmful ends (Bacon, 2016). In contemporary discourse, scholars argue that technological artefacts are not neutral tools but embody moral values that influence human action (Van de Poel & Kroes, 2014; Verbeek, 2011). This view challenges the deterministic notion that technology evolves independently of human intention (Seghatoleslami et al., 2011) and instead frames technology as a product of deliberate design choices infused with ethical and cultural assumptions (Manders-Huits, 2011).

In the environmental domain, the interplay between technology and ethics becomes particularly salient. Technologies have the capacity to mitigate environmental harms through renewable energy systems, pollution control mechanisms, and resource-efficient production methods, yet they can also exacerbate ecological crises if guided solely by market incentives (Khaleghi, 2015). Ethical evaluation, therefore, must address not only the technical performance of innovations but also their broader societal and ecological consequences (Ahani amineh & Boorghani Farahani, 2015). Environmental ethics provides a normative framework for determining how human actions, mediated by technology, should respect the intrinsic value of nature (Fanaei & Behrouzi, 2017). Within this framework, principles such as intergenerational justice, precautionary responsibility, and respect for ecological integrity are pivotal (Haghkhah et al., 2017).

Environmental ethics has gained increasing prominence in both policy and academic discourse, reflecting a recognition that sustainable development cannot be achieved through technical efficiency alone (Carlsson & Rönnblom, 2022). Policy frameworks in regions such as the European Union have undergone transformations from focusing solely on technological innovation to incorporating ethical governance mechanisms that ensure alignment with societal values (Carlsson & Rönnblom, 2022). This evolution underscores the necessity of integrating moral reasoning into science and technology policy-making (Rasekh et al., 2016). Furthermore, ethical governance of technology requires active participation from diverse stakeholders, including governments, industries, academic institutions, and civil society organizations (Horst et al., 2007).

In the Iranian context, the institutionalization of environmental ethics in technological development faces distinct challenges and opportunities. Studies indicate that environmental ethics among various professional groups, including agricultural students (Bandari et al., 2019) and rural communities (Mahboobi & Ramazani, 2011), are shaped by a combination of cultural norms, educational exposure, and economic conditions. Engineering education in Iran has been criticized for insufficient integration of environmental ethics into curricula (Hosseinloo, 2020; Mohammad Oghli Reyhan & Alizadeh, 2018), despite the acknowledged role of engineering decisions in shaping environmental outcomes (Mena, 2019). The absence of comprehensive ethical training in engineering fields can lead to a narrow focus on technical problem-solving without adequate consideration of ecological consequences (Mokhtari, 2019).

Addressing environmental ethics in technology requires an understanding of both micro-level behavioral factors and macro-level structural influences. At the individual level, moral awareness, value orientation, and cultural background significantly influence ethical decision-making (Hasanpour et al., 2017). At the organizational level, leadership commitment to ethical principles, institutional policies, and competitive value frameworks play crucial roles in embedding environmental ethics within operational practices (Haghkhah et al., 2017). Moreover, systemic challenges—such as weak regulatory enforcement, limited public awareness, and insufficient stakeholder collaboration—can undermine efforts to develop environmentally responsible technologies (Hemmati & Shobeiri, 2016).

Globally, the emergence of artificial intelligence (AI), biotechnology, and other transformative innovations has prompted renewed attention to ethical governance (Kazim & Soares Koshiyam, 2021). Scholars emphasize that AI ethics, for example, must extend beyond issues of bias and privacy to address environmental impacts, such as energy consumption in data centers and e-waste generation (Kazim & Soares Koshiyam, 2021). Similarly, the convergence of science and technology in areas like nanotechnology and genetic engineering raises complex ethical questions about unintended ecological effects

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(Khanahmadi et al., 2016). In this context, environmental ethics serves as a guiding framework to anticipate, assess, and manage the risks associated with novel technological applications (Rahimi et al., 2021).

From a philosophical standpoint, environmental ethics intersects with theories of responsibility and justice. Act utilitarian perspectives advocate for actions that maximize environmental well-being while minimizing harm (White, 2015), whereas deontological approaches stress the inherent duty to protect nature regardless of economic cost (Ahani amineh & Boorghani Farahani, 2015). The challenge lies in operationalizing these ethical commitments within the technological innovation process, where economic, political, and social pressures often compete with ecological priorities (Saleh Ahmadi, 2011). Integrating ethics into technology design requires explicit articulation of moral values during the early stages of innovation (Manders-Huits, 2011) and continuous reflection on their implications as technologies evolve (Verbeek, 2011).

Practical strategies for embedding environmental ethics into technology development include regulatory frameworks, market-based incentives, stakeholder engagement, and educational reform (Dashtaki et al., 2021). Regulatory measures, when effectively enforced, can set minimum environmental performance standards and deter harmful practices (Seghatoleslami et al., 2011). Economic instruments, such as green taxation and subsidies for sustainable technologies, can align financial incentives with ethical objectives (Khaleghi, 2015). Public participation mechanisms enhance the legitimacy and responsiveness of technological governance, ensuring that diverse perspectives inform decision-making (Horst et al., 2007).

Educational initiatives are equally essential in fostering a culture of environmental responsibility among future technologists. Curricula that integrate environmental ethics, sustainability principles, and interdisciplinary problem-solving skills can equip students to address complex socio-ecological challenges (Hosseinloo, 2020; Mohammad Oghli Reyhan & Alizadeh, 2018). Ethical competence in technology professionals not only improves individual decision-making but also strengthens institutional capacity to pursue sustainable innovation (Mena, 2019). Research indicates that promoting environmental values and norms within educational and professional settings positively correlates with ethical behavior in environmental contexts (Dehghan et al., 2018).

Despite these advances, significant gaps remain in the literature and practice of environmentally ethical technology development. Many existing studies focus on specific sectors or technologies, lacking comprehensive models that integrate causal, contextual, and intervening factors influencing ethical outcomes (Dashtaki et al., 2021; Rahimi et al., 2021). Additionally, there is a need for empirical frameworks that capture the complex interactions between cultural, regulatory, technological, and economic variables (Bandari et al., 2019). This complexity is heightened in developing countries, where resource constraints, policy instability, and competing development priorities can hinder ethical integration (Hemmati & Shobeiri, 2016).

Given these challenges, grounded theory offers a suitable methodological approach to systematically identify and categorize the factors shaping environmentally ethical technology development. By engaging with diverse stakeholders and analyzing their perspectives, such an approach can reveal underlying patterns, contextual dependencies, and strategic pathways for embedding environmental ethics into technology systems (Randall, 2025). The current study applies grounded theory to identify causal conditions, contextual influences, intervening variables, strategies, and outcomes associated with environmentally ethical technology development, with the aim of contributing both to theoretical understanding and practical policy-making.

2. Methods and Materials

In terms of purpose, the research is applied; in terms of data, it follows a qualitative approach; and in terms of implementation method, it was conducted using the systematic grounded theory approach. The statistical population consisted of key informants in the research field within the Tehran Province Department of Environment. Eleven individuals were selected and interviewed using the snowball sampling method until theoretical saturation was achieved. Data collection was carried out through both library research and fieldwork. The research instrument involved both library-based and field-based methods for data gathering. Based on the open and axial codes (components and indicators) obtained in the qualitative section, data consisting of 133 open

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codes and 26 axial codes (components) were coded and categorized into six main factors. To assess the validity of the instrument, three triangulation methods were applied: methodological triangulation (71%), investigator triangulation (77%), and participant triangulation (83%). The results indicated acceptable validity and reliability. Therefore, data analysis was conducted using open, axial, and selective coding methods.

3. Findings and Results

Research Question: What are the factors and components of environmentally ethical technology development from the perspective of grounded theory?

Table 1. Key Concepts (Initial Open Codes) Extracted from Interviews with Experts

Row	Initial Open Codes	Interviewee Code
1	Development of environmentally friendly technologies	P6
2	Impact of countries' scientific and technical level on technology development	P7
3	Level of scientific and technological advancement in the country	P8, P9
4	Market demand for sustainable products and services	P4, P1
5	Healthy, stable, and competitive production environment	P9
6	Economic stability and calmness	P3, P9
7	Access of economic actors and development authorities to modern technologies	P4, P5
8	Consideration of natural resources in economic development	P5, P3
9	Government support for green employment	P4, P8
10	Understanding of environmental economics	P1
11	Economic investment in technologies	P9
12	Making the environment an important public demand and discourse	P10, P11
13	The role of education as the most fundamental cultural institution	P9
14	Preparation and consideration of environmental appendices for green technologies	P2, P11
15	Importance of adhering to environmental standards	P4, P6
16	Observance of environmental ethics in technology design and development	P3
17	Considering cultural, social, and economic issues when introducing new technologies to societies	P4, P5, P8, P9
18	Proper public awareness regarding the importance of green technologies	P2
19	Environmental laws and regulations	P7, P3
20	National governance, such as enacting and implementing strict laws	P6, P8
21	Consideration of consumer rights and production transparency	P2, P9
22	Establishment of mandatory ethical and environmental standards	P10
23	Acceleration in transforming environmental policies, laws, and support policies	P10
24	Demographic impacts	P8, P4
25	Geographical and natural factors	P7, P11
26	Increase in climate change	P1, P2, P6
27	New data processing models with minimal energy consumption	P8
28	Energy-oriented and environmentally friendly technologies	P4, P8
29	Implementation of green machine learning models	P3
30	Use of recycled and renewable materials in hardware and digital equipment production	P1, P3, P4, P7
31	Waste reduction strategies and energy optimization in various industries	P2
32	Infrastructure and resources needed for technology development	P4
33	Online control and monitoring systems for pollutant measurement	P9
34	Use of modern technologies to reduce energy consumption	P4, P8
35	Establishment of educational and awareness-raising infrastructures	P3, P9, P3
36	Availability of information and communication technology infrastructure	P7
37	Emergence of supportive events such as incentive systems for the green industry	P7
38	Creation of supportive platforms, including green tax exemptions in organizations and companies	P11, P5
39	Legal and regulatory support	P2, P3, P8, P10
40	Governmental financial rewards and support	P7, P1
41	Government support for sustainable and green technologies	P5
42	Free scientific and cultural platforms for innovation and invention development	P7
43	Facilitating the presentation of innovative ideas and supporting technological innovations	P3, P11
44	Government support for research and development in green and environmental technologies	P11, P3
45	Need for financial and technical support for innovative ideas and green technologies	P10
46	Attention to ethics in technology design, decision-making, and usage	P10
47	Consideration of low/no environmental damage technologies	P8, P4

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48	Impact of family upbringing and institutionalization of teachings	P7, P11
49	Achieving correct understanding of the importance of respecting the right to life and natural resources	P2, P3, P9, P11
50	Application of eco-friendly technologies and equipment	P1, P3, P8, P10
51	Acceptance of technologies through culture and public attitudes toward the environment	P8
52	Collaboration among universities, private sectors, media, and governmental bodies to facilitate environmental ethics development	P5, P6
53	Research in the field of developing new green and sustainable materials and technologies	P11
54	Prevention of environmental degradation, including limiting natural resource use, reducing pollution, and sustainable resource management	P8
55	Optimal resource management through proper and measured use of natural resources	P5
56	Financial resources required for green technology development	P3, P2
57	Human resources and specialists with high technical knowledge	P1, P2, P4, P9
58	Increasing public awareness of environmental problems and growing interest in environmentally sustainable products and services	P4
59	Environmental impact assessment of technologies prior to use	P2, P5, P11, P7
60	Changing attitudes and social acceptance of green technologies	P4, P2
61	Compliance with environmental responsibilities and standards	P8
62	Attention to optimal use of natural resources without excessive exploitation	P4, P6, P2
63	Creation of educational infrastructure from childhood to adulthood	P1, P5
64	Enhancing the social role and responsibility of people and institutions	P11
65	Political and economic interests	P1, P10, P16
66	Prevention by some governments and major companies from adopting green technology due to economic and political interests	P2
67	Inefficient management of resources and technologies	P3, P1, P5
68	Lack of strict monitoring over standard implementation	P1, P2, P4
69	Absence of effective supervisory structures for evaluating and implementing environmental standards	P4, P7
70	Need for financial resources, specialized human capital, and suitable infrastructure	P9
71	Creating scientific and technical capacities and enhancing expertise	P4, P8
72	Absence of tax incentives	P1
73	Lack of strict laws	P3
74	Weak policy-making	P3
75	Lack of clear legal frameworks for sustainable and ethical technologies	P6, P11
76	Lack of international cooperation in regulating green technologies	P3
77	Insufficient supportive laws and executive guidelines for advancing environmental technologies	P7
78	Accurate understanding of technologies and techniques to improve environmental conditions	P3, P5, P10
79	Insufficient equipment and infrastructure for producing, storing, and distributing renewable energy	P1, P9
80	Accessibility challenges and delays in technology transfer to developing countries	P9
81	Technical and technological barriers	P10
82	Incomplete maturity of sustainable and green technologies	P4
83	Lack of accurate public and organizational awareness about the environmental impact of digital products, reducing social pressure on companies	P4, P7
84	Strict resistance from economic actors and governments toward changing to new technologies	P1
85	Lack of formal and media-based training and misunderstanding of green technology benefits	P8
86	Resistance from organizations and employees toward changes due to unfamiliarity with new technologies and high investment requirements	P7
87	Non-compliance with ethical standards in practices	P1, P11
88	Lack of ethical content in environmental contexts	P6, P3, P6
89	High costs of developing and implementing environmentally friendly modern technologies	P3
90	Low willingness of technology companies to invest due to high infrastructure modification costs	P5
91	Lack of financial support	P5
92	No economic incentives for high-consumption industries	P4, P10, P2
93	Lower costs of using polluting energy sources compared to renewable energies	P3, P2
94	Economic challenges and insufficient investment in green technologies	P1, P2, P4, P9
95	Profit-centered focus while ignoring environmental considerations	P1, P6, P6
96	Scarcity of natural resources and need for new technologies	P2, P9, P6
97	Scarcity and over-extraction of natural resources causing damage	P7, P10
98	Scarcity and unavailability of resources and raw materials for green technologies due to overuse of natural resources	P4, P9
99	Limitations of natural resources	P4, P8
100	Economic incentives and support for green businesses and startups	P1
101	Reduction of taxes for companies using renewable resources and sustainable technologies	P3
102	Provision of low-interest loans for projects related to green artificial intelligence, electronic recycling, and energy management	P5, P1

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103	Development of government guaranteed purchase programs from green technology companies	P4, P8
104	Support for circular economy and sustainable design in digital industries	P1
105	Improvement of international relations and promotion of international cooperation on global environmental agreements	P3
106	Support for citizen innovation in developing green technologies	P3
107	Optimization of data centers to reduce energy consumption through natural cooling and renewable energy use	P5
108	Design of low-power machine learning algorithms to reduce carbon footprint	P6, P8
109	Intelligent resource and energy management to control energy consumption	P7, P11
110	Investment in green AI projects for environmental protection	P6, P7
111	Creation of green industrial networks to share innovations in green technologies	P16
112	Creation of a network for presenting technological ideas aimed at environmental preservation	P1, P9, P4
113	Investment in R&D to improve environmental technologies and other modern technologies for conserving natural resources	P3, P5
114	Use of bio-based materials and electronic recycling	P1, P2, P5
115	Smart agriculture to reduce water consumption and increase productivity	P5
116	Development and commercialization of new innovations in sustainable materials and processes	P1, P2, P4
117	Role of media and communication tools in the green technology field	P4, P8
118	Promotion and advertising of environmental ethics	P5, P9
119	Public training and guidance for business stakeholders	P1, P7
120	Public awareness campaigns about consumption of environmentally friendly products	P1, P9
121	Public and intra-organizational education and cultural promotion	P3
122	Public cultural promotion and education on environmental impacts in the process of ethical technology development	P3, P5, P10
123	Increasing public awareness of environmental threats	P4
124	Promoting environmental ethics discourse and institutionalizing it in public opinion	P9
125	Preventive and remedial measures against environmental degradation	P4, P8
126	Institutionalizing the culture of environmental preservation in future generations	P3, P9, P3
127	Support for innovative and effective ideas in environmental preservation	P4, P8
128	Use of monitoring systems to assess environmental behaviors in industries	P1
129	Establishment of user feedback systems on technology development considering environmental ethical compliance	P3
130	Effective monitoring of standard compliance	P1, P7
131	Mitigation of international sanctions and pressures on companies active in this field	P3
132	Establishment and enforcement of strict environmental laws	P6, P11
133	Establishment of mandatory pollutant reduction standards for digital and technology industries	P3
134	Establishment of legal frameworks for supply chain transparency in technologies	P7
135	Imposition of heavy penalties on polluting manufacturers	P3, P5, P10
136	Development of ethical frameworks and standards in technology and industry development	P10
137	Development of laws to protect user privacy in environmental technologies	P3
138	Change in consumer behavior and obligating or encouraging companies to develop products with new technologies	P8
139	Creation of a green culture in industries and businesses by establishing corporate social responsibility obligations	P7
140	Use of media to encourage the public to reduce consumption	P1, P11
141	Acceleration in developing environmentally friendly technologies	P6, P3, P6
142	Enhancement of research and scientific and international cooperation	P4, P5, P8, P9
143	Research and innovation in green technologies and their development	P4, P6, P2
144	Funding university research in low-consumption and sustainable technologies	P3
145	Institutionalization of social responsibility culture among all people	P4, P7
146	Increasing organizational and corporate responsibility toward the environment	P8
147	Cultural promotion of responsible consumption	P2, P9
148	Lifestyle changes	P1, P5
149	Creation of more environmentally aware and responsible communities	P7
150	Raising public awareness on environmental issues and consequences	P1, P10, P16
151	Development of a green economy and creation of sustainable businesses and new economic opportunities	P2
152	Creation of sustainable and green employment	P9
153	Improvement of economic conditions	P1, P2, P4
154	Development of green industries	P6, P11
155	Increasing resource efficiency by reducing energy and raw material consumption	P1
156	Creation of clean technologies through renewable energy development	P11
157	Reduction in consumption of polluting fuels	P7, P3
158	Increased efficiency in the use of natural resources and reduction of waste	P3
159	Reduction of air, water, and soil pollution through sustainable technologies	P3, P1, P5
160	Preservation of biodiversity	P7, P3
161	Reduction of ecological damage and protection of ecosystems	P6, P8
162	Enhancement of environmental security	P1, P11
163	Improvement of environmental quality	P1, P2, P5

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164	Environmental justice and equal access to natural resources	P16
165	Preservation and improvement of public health	P6, P7
166	Improvement of air quality and ecosystems	P8
167	Well-being and security for future generations	P7
168	Reduction of dependence on imported advanced technologies and equipment	P2
169	Technological independence of the country	P4, P7
170	Development of modern domestic technologies while reducing dependence on foreign resources	P3
171	Reduction of pollution caused by fossil fuels	P1, P9, P4
172	Reduction in consumption	P6, P3, P6
173	Industrial production with minimal environmental damage	P9
174	Preservation of natural resources	P10, P11
175	Strengthening social welfare and vitality	P9
176	Achieving a cleaner and healthier world	P2, P11
177	Improving people's quality of life	P4, P6

Table 2: Open and Axial Codes Obtained from the Delphi Method

Row	Factors	Axial Codes	Open Codes
1	Causal Factors	Natural, Technological, and Scientific Conditions	Development of environmentally friendly technologies
2			Impact of countries' scientific and technical level on technology development
3			Demographic impacts
4			Increase in climate change
5		Economic Factors	Healthy, stable, and competitive production environment
6			Access of economic actors and development authorities to modern technologies
7			Consideration of natural resources in economic development
8			Understanding of environmental economics
9			Economic investment in technologies
10		Cultural Factors	Making the environment an important public demand and discourse
11			The role of education as the most fundamental cultural institution
12			Preparation and consideration of environmental appendices for green technologies
13			Observance of environmental ethics in technology design and development
14			Considering cultural, social, and economic issues when introducing new technologies to societies
15			Market demand for sustainable products and services
16			Proper public awareness regarding the importance of green technologies
17		Laws and Regulations	Environmental laws and regulations
18			National governance through the enactment and implementation of strict environmental policies and laws
19			Consideration of consumer rights and production transparency
20			Establishment of mandatory ethical and environmental standards
21	Contextual Factors	Technical Equipment and Infrastructure	Energy-oriented and environmentally friendly technologies
22			Implementation of green machine learning models
23			Use of recycled and renewable materials in hardware and digital equipment production
24			Waste reduction strategies and energy optimization in various industries
25			Online control and monitoring systems for pollutant measurement
26			Use of modern technologies and models to reduce energy consumption
27			Establishment of educational and awareness-raising infrastructures
28			Availability of information and communication technology infrastructure
29		Encouragement and Support	Creation of supportive and incentive platforms, including green tax exemptions in organizations and companies
30			Legal and regulatory support
31			Governmental financial rewards and support for sustainable and green technologies
32			Free scientific and cultural platforms for innovation and invention development
33			Facilitating the presentation of innovative ideas and supporting technological innovations
34			Government support for research and development in green and environmental technologies
35		Consideration of Cultural Aspects	Attention to ethics in technology design, decision-making, and usage
36			Consideration of low/no environmental damage technologies
37			Impact of family upbringing and institutionalization of teachings

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38			Achieving correct understanding of the importance of respecting the right to life and natural resources
39			Acceptance of technologies through culture and public attitudes toward the environment
40			Collaboration among universities, private sectors, media, and governmental bodies to facilitate environmental ethics development
41		Resource Management	Research in developing new green and sustainable materials and technologies
42			Prevention of environmental degradation, including limiting natural resource use, reducing pollution, and sustainable resource management
43			Optimal resource management through proper and measured use of natural resources
44			Provision and allocation of financial resources needed for green technology development
45			Attention to human resources and specialists with high technical knowledge in technology development
46		Responsibility	Increasing public awareness of environmental problems and encouraging people to use environmentally sustainable products
47			Environmental impact assessment of technologies prior to use
48			Changing attitudes and social acceptance of green technologies
49			Compliance with environmental responsibilities and standards
50			Enhancing the social role and responsibility of people and institutions
51	Intervening Factors	Structural and Managerial Weakness	Political and economic interests of individuals, governments, organizations, and companies, and prevention of green technology adoption
52			Inefficient management of resources and technologies
53			Lack of effective supervisory structures for evaluating and implementing environmental standards
54			Lack of financial resources, specialized human capital, and suitable infrastructure
55		Weak Policy-Making and Legal Gaps	Lack of scientific and technical capacities for increasing the knowledge and expertise of stakeholders and industries
56			Absence/shortage of strict laws
57			Weak policy-making in developing environmentally ethical technologies
58			Lack of clear legal frameworks for sustainable and ethical technologies
59			Lack of international cooperation in regulating green technologies
60			Insufficient supportive and incentive laws and executive guidelines for advancing environmental technologies
61	Intervening Factors	Technological Weakness	Inadequate understanding of technologies and techniques for improving environmental conditions
62			Insufficient equipment and infrastructure for producing, storing, and distributing renewable energy
63			Limited accessibility and delays in technology transfer to developing countries
64			Incomplete maturity of sustainable and green technologies
65		Lack of Public Awareness	Lack of accurate public and organizational knowledge about the environmental impact of digital products, reducing social pressure on companies
66			Strict resistance by economic actors and governments to adopting and introducing new technologies
67			Lack of formal and media-based training and misunderstanding of the benefits of green technologies
68			Failure to observe environmental ethical standards in the use of required products and services
69			Shortage of environmental ethics-related content in technology fields
70		Financial–Economic Factors	High costs of developing and implementing environmentally friendly modern technologies
71			Low willingness of technology companies to invest due to high costs of infrastructure modification
72			Lack of financial support and investment in green technologies
73			Lack of economic incentives for high-consumption industries and profit-oriented focus
74			Lower costs of using polluting energy sources compared to renewable energies
75	Strategies	Providing Incentives	Economic incentives and support for green businesses and startups
76			Reduction of taxes for companies using renewable resources and sustainable technologies
77			Development of government guaranteed purchase programs from green technology companies
78			Support for circular economy and sustainable design in digital industries
79			Improvement of international relations and encouragement of international cooperation on global environmental agreements
80			Support for citizen innovation in developing green technologies and environmental protection
81		Developing Strategic Plans	Implementation of environmentally ethical technological projects, such as designing low-power machine learning algorithms, electronic recycling, smart agriculture, and optimization of data centers

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82			Intelligent management of resources and energy to control energy consumption
83			Creation of green industrial networks to share innovations in the field of green technologies
84			Creation of a network for presenting technological ideas aimed at environmental preservation
85			Investment in research and development to improve environmental technologies and other modern technologies for conserving natural resources
86			Development and commercialization of new innovations in sustainable materials and processes
87		Education and Awareness-Raising	Role of media and communication tools in the green technology field
88			Public awareness campaigns about consumption of environmentally friendly products
89			Public, organizational, and business stakeholder education and cultural promotion in the process of developing environmentally ethical technologies
90			Promotion, advertising, and training related to environmental ethics in response to environmental threats
91		Planning and Monitoring	Promoting environmental ethics discourse and institutionalizing it in public opinion
92			Preventive and remedial measures against environmental degradation
93			Institutionalizing the culture of environmental preservation in future generations
94			Use of monitoring systems to assess environmental behaviors in industries and compliance with standards
95			Establishment of user feedback systems on technology development considering environmental ethical compliance
96			Mitigation of international sanctions and pressures on companies active in this field
97		Drafting Laws and Regulations	Establishment and enforcement of strict environmental laws
98			Establishment of mandatory pollutant reduction standards for digital and technology industries
99			Establishment of legal frameworks for supply chain transparency in technologies
100			Imposition of heavy penalties on polluting manufacturers
101			Development of ethical frameworks and standards in technology and industry development
102		Strengthening Values and Beliefs	Change in consumer behavior and obligating or encouraging companies to develop products with new technologies
103			Creation of a green culture in industries and businesses by establishing corporate social responsibility obligations
104			Use of media to encourage the public to reduce consumption
105		Developing Research Infrastructure	Acceleration in developing environmentally friendly technologies
106			Enhancement of research and scientific and international cooperation
107			Research and innovation in green technologies and their development
108			Funding university research in low-consumption and sustainable technologies
109	Outcomes	Enhancing Responsibility	Institutionalization of social responsibility culture among all people
110			Increasing organizational and corporate responsibility toward the environment
111			Lifestyle changes and responsible consumption
112			Creation of more environmentally aware and responsible communities
113			Raising public awareness on environmental issues and consequences
114		Independence and Sustainable Employment	Creation of sustainable businesses and new business opportunities
115			Creation of sustainable and green employment based on modern technologies
116			Improvement of economic conditions
117			Development of green industries
118			Development of modern domestic technologies and reduction of dependence on imported technologies and equipment
119		Natural Resource Efficiency	Increasing resource efficiency by reducing energy and raw material consumption
120			Creation of clean technologies through renewable energy development
121			Reduction in consumption of polluting fuels
122			Increased efficiency in the use of natural resources and reduction of waste
123		Environmental Protection	Preservation of biodiversity and natural resources
124			Reduction of ecological damage and protection of ecosystems
125			Enhancement of environmental security
126			Improvement of environmental quality
127			Industrial production with minimal environmental damage
128		Community Health and Safety	Environmental justice and equal access to natural resources
129			Preservation and improvement of public health
130			Improvement of air, food, and ecosystem quality

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131	Well-being and security for future generations
132	Strengthening social welfare and vitality
133	Improving people's quality of life

Therefore, after analyzing the data and answering the research questions, the factors and components constituting environmentally ethical technology development were identified, comprising 26 axial codes and 133 open codes categorized into six main factors.

4. Discussion and Conclusion

The findings of this study identified a comprehensive set of causal, contextual, and intervening factors, along with strategic actions and outcomes, that together define the structure of environmentally ethical technology development. Using grounded theory and Delphi methodology, the research produced 133 open codes organized into 26 axial codes within six major factors. The causal factors revealed that natural, technological, scientific, economic, cultural, and regulatory conditions directly influence the capacity of organizations and societies to adopt and integrate environmentally responsible technologies. These include both structural determinants, such as the level of scientific and technological advancement, and dynamic drivers, such as market demand for sustainable products and public discourse on environmental protection.

The results demonstrate that contextual factors—particularly technical infrastructure, financial incentives, cultural considerations, resource management, and responsibility mechanisms—serve as enabling or constraining environments for ethical technological development. These findings are consistent with the view that the socio-technical context shapes the ethical trajectory of innovation (Van de Poel & Kroes, 2014), underscoring that technologies are embedded in complex institutional, cultural, and economic systems (Verbeek, 2011). For instance, the presence of robust information and communication infrastructure, coupled with active government support for research and development in green technologies, creates a fertile ground for integrating environmental ethics into the innovation process (Rahimi et al., 2021).

Intervening factors emerged as a significant barrier category, comprising structural and managerial weaknesses, policy and legal gaps, technological immaturity, limited public awareness, and adverse financial–economic conditions. These align with previous studies that identify institutional weaknesses, lack of stringent regulations, and insufficient public engagement as recurring obstacles to embedding ethical principles into technological systems (Khaleghi, 2015; Seghatoleslami et al., 2011). Moreover, findings indicate that resistance from economic actors and governments, high costs of infrastructure transition, and the absence of effective supervisory mechanisms can significantly delay the implementation of sustainable technologies. This resonates with the argument that without coherent governance structures, market incentives often override environmental considerations (Ahani amineh & Boorghani Farahani, 2015).

The strategies identified in the model address these barriers through multi-pronged approaches: providing economic incentives, developing strategic plans, enhancing education and awareness, improving planning and monitoring, drafting effective laws and regulations, strengthening environmental values and beliefs, and building research infrastructure. The inclusion of targeted incentive programs—such as tax reductions for companies using renewable resources and mandatory pollutant reduction standards—echoes policy shifts in the European Union toward integrating ethics in digital and green technology governance (Carlsson & Rönnblom, 2022). Furthermore, embedding environmental values within organizational cultures and public behavior supports the notion that ethical change requires both top-down regulatory action and bottom-up cultural transformation (Hasanpour et al., 2017).

Outcomes of environmentally ethical technology development, as identified in this study, extend beyond ecological benefits to include enhanced social responsibility, independence and sustainable employment, improved natural resource efficiency, environmental protection, and community health and safety. These multifaceted impacts reinforce the proposition that environmental ethics in technology is not only about reducing harm but also about generating broader societal and economic value (Randall, 2025). For example, fostering sustainable employment and developing domestic technological capabilities can simultaneously address environmental and socio-economic objectives, aligning with the principles of just and inclusive transitions (White, 2015).

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The finding that ethical technology development requires a confluence of scientific–technical capacity, cultural awareness, and regulatory enforcement parallels earlier work emphasizing the need for integrated models of environmental ethics in public policy (Fanaei & Behrouzi, 2017; Haghkhah et al., 2017). Specifically, the recognition of cultural and educational influences reflects evidence that environmental values are strongly mediated by societal norms and educational exposure (Bandari et al., 2019; Mahboobi & Ramazani, 2011). Educational integration is a particularly salient outcome of this research, supporting arguments that environmental ethics must be embedded into curricula at all levels to ensure long-term cultural change (Hosseinloo, 2020; Mohammad Oghli Reyhan & Alizadeh, 2018).

The role of economic and political interests as intervening factors also aligns with prior findings on the influence of power dynamics in technological decision-making (Khanahmadi et al., 2016; Saleh Ahmadi, 2011). In some cases, such interests manifest as active resistance to the adoption of environmentally friendly technologies due to perceived short-term costs, despite long-term benefits. This tension is further compounded by technological determinism pressures (Seghatoleslami et al., 2011), where stakeholders may believe that environmental harms are unavoidable consequences of technological progress, thereby reducing motivation for ethical intervention. The present study challenges this view by demonstrating that deliberate strategic actions—particularly those targeting public awareness and policy reform—can shift the technological trajectory toward sustainability.

Moreover, the identification of insufficient public awareness as a major intervening factor supports existing literature on the importance of risk perception, trust, and personal experience in shaping acceptance of environmental technologies (Horst et al., 2007). Public engagement campaigns and participatory governance can enhance legitimacy and acceptance, fostering behavioral shifts necessary for technology adoption. These behavioral elements are consistent with moral theories that emphasize responsibility not only at the institutional level but also within individual consumption and production choices (Ahani amineh & Boorghani Farahani, 2015; Bacon, 2016).

The strategic emphasis on research and innovation infrastructure reflects the growing recognition that technological solutions to environmental challenges require ongoing scientific advancement and cross-sector collaboration (Mena, 2019; Mokhtari, 2019). This includes investing in low-energy machine learning models, bio-based materials, and circular economy applications, which correspond to the “design for values” approach in technology ethics (Manders-Huits, 2011). By embedding ethical considerations into the design process, organizations can proactively prevent environmental harms rather than reacting to them post-deployment.

Finally, the outcomes identified in this study—ranging from ecological preservation to societal well-being—support the view that environmentally ethical technology development embodies a holistic vision of progress, one that balances innovation with justice, responsibility, and sustainability (Van de Poel & Kroes, 2014; Verbeek, 2011). The grounded theory model developed here offers a structured framework for understanding these dynamics, integrating causal and contextual factors with practical strategies to produce measurable environmental and societal benefits.

While the study provides a comprehensive framework for environmentally ethical technology development, several limitations must be acknowledged. First, the research relied on interviews with a limited number of key informants within the Tehran Province Department of Environment, which may restrict the generalizability of the findings to other regions or sectors. Second, the use of qualitative methods, while offering depth and context, inherently limits the statistical validation of the proposed model. Third, the rapidly evolving nature of technology and environmental policy means that some identified factors may change in relevance or form over time, necessitating ongoing updates to the model.

Future research could expand the scope of this study by incorporating a larger and more diverse sample of stakeholders, including representatives from industry, academia, and non-governmental organizations. Quantitative validation of the grounded theory model through survey-based methods would strengthen its applicability and reliability. Comparative studies across different cultural or regulatory contexts could also provide insights into the universality or specificity of the identified factors. Additionally, longitudinal research tracking the implementation of identified strategies could offer valuable evidence on their effectiveness in achieving sustainable technology outcomes.

Practitioners can apply the findings of this study by integrating environmental ethics into the earliest stages of technology design and decision-making, ensuring that moral values are embedded alongside technical specifications. Policymakers should

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consider adopting multi-level strategies that combine regulatory enforcement, economic incentives, and public education to foster widespread adoption of environmentally responsible technologies. Organizations should invest in building research infrastructure and promoting cross-sector collaboration to develop innovative solutions that align with both environmental and socio-economic goals. Embedding environmental ethics in professional training and organizational culture will further enhance long-term sustainability outcomes.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all who helped us through this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

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