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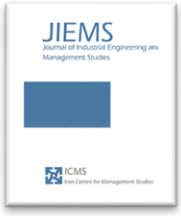

Developing a Digital Transparency Framework in Green Marketing of Brands Based on Digital Twins and Green Blockchain to Combat Greenwashing: A Grounded Theory Approach

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Abstract

The growing concern over greenwashing and declining consumer trust in environmental claims has highlighted the need for transparent and verifiable mechanisms in green marketing. This study aims to develop a digital transparency framework for green brand marketing based on Digital Twin and Green Blockchain technologies. The main objective is to design an integrated model that enables real-time environmental data generation, immutable verification, and credible signaling to enhance brand legitimacy and sustainability performance. Despite growing literature on green marketing and blockchain applications, a key research gap exists in the lack of a holistic framework that simultaneously integrates real-time data generation and tamper-proof verification for proactive greenwashing prevention.This research adopts a qualitative approach using grounded theory methodology (Corbin and Strauss). Data were collected through semi-structured interviews with 16 experts in green marketing, digital technologies, and sustainable branding. Data analysis was conducted through open, axial, and selective coding, leading to the identification of six core categories: causal conditions, contextual conditions, intervening conditions, strategies, consequence, and the central phenomenon. Findings indicate that stakeholder pressure, regulatory requirements, and technological maturity drive adoption, while cost, security concerns, and organizational resistance act as barriers. The proposed framework integrates Digital Twin and Green Blockchain to provide real-time, verifiable environmental data, thereby reducing greenwashing and strengthening consumer trust. The results demonstrate that digital transparency is not only a sustainability tool but also a strategic marketing advantage that enhances brand credibility and competitive positioning.

Keywords: Green Marketing, Greenwashing, Digital Twin, Green Blockchain, Digital Transparency.

Paper Type: Original Research

1. Introduction

The escalating global concern regarding environmental degradation and climate change has profoundly reshaped consumer behavior and corporate strategic imperatives, catalyzing the widespread adoption of green marketing (OnGreenMarketing, 2006). At its core, green marketing involves the promotion of products and services by emphasizing their environmental benefits, aiming to resonate with an increasingly eco-conscious consumer base (OnGreenMarketing, 2006). This paradigm shift reflects a surging demand for sustainable practices and products, compelling organizations to integrate environmental considerations into their brand development and communication frameworks (Putri, 2025). However, the proliferation of environmental claims has been mirrored by the rise of "greenwashing"—a deceptive practice in which firms mislead consumers regarding the ecological benefits of their products or corporate policies (Al-Ababneh, 2025; Judijanto, 2025). Greenwashing systematically erodes consumer trust, undermines substantive sustainability initiatives, and poses fundamental challenges to the credibility of the green marketing landscape (Judijanto, 2025). The scholarly and practical significance of mitigating greenwashing and enhancing transparency within green marketing is undeniable. From an operational perspective, firms disseminating misleading environmental claims face substantial reputational risks and stringent legal penalties (Judijanto, 2025). Consequently, the development of innovative solutions capable of providing immutable and verifiable evidence of environmental performance is of critical importance for both advancing academic discourse in marketing and sustainability and facilitating practical industrial application (Putri, 2025). In the digital era, the

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expansion of online platforms and social media has simultaneously broadened the reach of green marketing and exacerbated the potential for greenwashing (Budiarti, 2026). While consumers have become more informed, the inherent complexity of digital marketing tactics and various cognitive biases continue to impede the effective identification of deceptive claims (Eze, 2025; Ramdhani, 2025). This milieu necessitates robust mechanisms to ensure the transparency and authenticity of brands' environmental disclosures. Digital Twin (DT) technology has emerged as a formidable tool for enhancing transparency, as it provides a virtual synchronized representation of a physical object, process, or system, enabling real-time monitoring and data acquisition (Tao, 2019). Within green marketing, Digital Twins offer unprecedented visibility into product lifecycles, manufacturing processes, and supply chains, allowing for the precise recording and tracking of environmental performance metrics (Fitriawijaya, 2024). Complementing this, Green Blockchain provides a decentralized and immutable ledger system that secures and validates environmental data. Characterized by inherent transparency, data security, and resistance to tampering, this technology facilitates the authentication of green claims throughout the product's journey from origin to end-consumer (Al-Ababneh, 2025) The convergence of Digital Twin and Green Blockchain technologies establishes the foundation for a comprehensive Digital Transparency Framework. While the Digital Twin provides real-time data and operational insights, Blockchain ensures the integrity, security, and verifiability of that information (Ferone, 2025). This synergy fosters a secure and transparent ecosystem where environmental claims are not merely asserted but are continuously monitored, recorded, and validated. Although previous studies have made significant contributions to understanding greenwashing and the role of emerging digital technologies, several important gaps remain. Existing research on blockchain has mainly focused on improving traceability, data integrity, and supply chain transparency, while studies on Digital Twin have primarily emphasized operational optimization, real-time monitoring, and lifecycle management. These streams of research have largely evolved independently, with limited attempts to integrate both technologies into a unified framework for green marketing. Furthermore, most previous studies have concentrated on detecting greenwashing after misleading claims have been made rather than preventing deceptive practices proactively through continuous verification mechanisms. Existing literature also provides limited insight into how real-time environmental data generated by Digital Twins can be securely verified and communicated to consumers through blockchain-based infrastructures. In addition, few qualitative studies have explored this issue from the perspectives of experts involved in green marketing, sustainability, and digital technologies. Therefore, there remains a clear theoretical and practical need for a comprehensive framework that integrates real-time environmental data generation, immutable verification, and transparent stakeholder communication. Addressing this gap, the present study develops a Digital Transparency Framework using Grounded Theory to explain how Digital Twin and Green Blockchain technologies can jointly prevent greenwashing and strengthen consumer trust in green marketing. Given the existing research gap concerning integrated digital frameworks for combating greenwashing at the brand level, this study aims to develop a Digital Transparency Framework based on Digital Twin and Green Blockchain technologies. Utilizing a Grounded Theory approach, this research seeks to provide immutable and verifiable evidence of the environmental performance of products and processes, thereby reinforcing consumer trust and enhancing corporate accountability (Budhathoki, 2023; Armağan, 2014). This research underscores the imperative of transparency in green marketing as a deterrent to greenwashing. By proposing an innovative, integrated digital framework, this study addresses the current scholarly lacuna in combining emerging technologies for the validation of environmental claims. Ultimately, it addresses the fundamental research question: "How can a transparent and reliable system be established to verify the green claims of brands? Although previous studies have examined Digital Twin and Green Blockchain technologies from technological, operational, or supply chain perspectives, little is known about how these technologies can be integrated to establish digital transparency and proactively prevent greenwashing in green marketing. This research therefore addresses an exploratory research problem for which no comprehensive theoretical framework currently exists. Accordingly, the objective of this study is not to test existing hypotheses or validate an established theory, but to develop a conceptual framework grounded in empirical evidence obtained from experts in green marketing, sustainability, and digital technologies. Given this research objective, the Grounded Theory methodology was considered the most appropriate methodological approach because it enables the systematic generation of theory directly from empirical data through iterative coding and constant comparison. Following the Corbin and Strauss approach, this methodology facilitates the identification of key concepts, their relationships, and the underlying processes that explain how Digital Twin and Green Blockchain technologies jointly contribute to digital transparency, greenwashing prevention, and consumer trust. Therefore, the selection of Grounded Theory establishes a coherent alignment between the research problem, the study objective, and the methodological approach adopted for developing the proposed framework.

2. Theoretical Foundation and Literature Review

The theoretical foundations of this research are grounded in key theories that explain the phenomenon of greenwashing, the importance of transparency in green marketing, and the role of emerging technologies in building trust. A thorough understanding of these theoretical perspectives is essential for developing a comprehensive digital transparency framework (Forliano, 2025). Accordingly, this study draws upon two complementary theoretical lenses—Legitimacy Theory and Signaling Theory—to explain both the motivations underlying greenwashing and the mechanisms through which digital technologies can enhance the credibility of environmental claims. Legitimacy Theory posits that organizations must operate within prevailing societal norms and values to maintain public acceptance and ensure their long-term survival (Seele, 2017). Legitimacy, defined as the generalized perception that an organization's activities are appropriate and desirable within socially constructed systems of norms and beliefs, represents a critical organizational asset (Delmas, 2011). In the context of green marketing, firms frequently adopt environmental initiatives and sustainability communications to obtain or preserve legitimacy among stakeholders (Putri, 2025). However, organizations may pursue legitimacy either through substantive environmental improvements or through symbolic actions. Greenwashing emerges when companies attempt to gain legitimacy by disseminating misleading or exaggerated environmental information without implementing corresponding operational changes (Delmas, 2011). Although such practices may temporarily enhance perceived legitimacy, they ultimately undermine stakeholder trust and organizational credibility once the discrepancy between claims and actual performance becomes evident (Lestari, 2025). A major strength of Legitimacy Theory lies in its ability to explain why organizations invest heavily in environmental communication and why some firms resort to greenwashing as a strategy for managing stakeholder perceptions (Forliano, 2025). The theory also emphasizes the influence of social expectations and stakeholder pressure in shaping corporate behavior and disclosure practices. Nevertheless, its explanatory power is limited regarding the practical mechanisms through which transparency can generate authentic legitimacy, particularly within digitally connected business environments. Furthermore, the theory pays relatively little attention to the role of emerging digital technologies in verifying environmental information and enabling stakeholders to independently evaluate corporate sustainability claims (Judijanto, 2025; Agustin, 2025). The present research extends the application of Legitimacy Theory by proposing a digital transparency framework that enables organizations to achieve authentic rather than symbolic legitimacy (Abdallah-Ou-Moussa, 2026). Through the complementary integration of Digital Twin and Green Blockchain technologies, firms can continuously generate, verify, and transparently disclose reliable environmental performance information. Digital Twin technology facilitates real-time monitoring of environmental performance, while Green Blockchain securely records these data in an immutable and transparent manner. Consequently, stakeholders are empowered to independently verify corporate environmental claims, thereby reinforcing organizational legitimacy through demonstrable sustainability performance rather than promotional communication alone (Owusu-Berko, 2025). Signaling Theory explains how information is communicated under conditions of information asymmetry, where one party (the sender, such as a company) possesses information that is unavailable to another party (the receiver, such as a consumer) (Al-Ababneh, 2025). Within the context of green marketing, companies' environmental claims function as market signals intended to demonstrate their commitment to sustainability. However, greenwashing transforms these claims into "cheap talk" or unreliable signals because organizations can communicate environmental responsibility without making substantial investments or implementing meaningful environmental improvements (Ramdhani, 2025). According to Signaling Theory, signals become credible only when they are costly, verifiable, and difficult for organizations to imitate or manipulate. A primary strength of Signaling Theory is its ability to explain why consumers often remain skeptical of corporate environmental claims and why credible verification mechanisms are essential for reducing uncertainty in sustainable markets (Ramdhani, 2025). The theory also highlights the importance of minimizing information asymmetry between companies and consumers, thereby enabling more informed purchasing decisions and strengthening trust in sustainability communications. Nevertheless, the theory provides limited insight into the technological and infrastructural mechanisms required to generate credible signals in digital environments. In particular, it does not adequately explain how emerging technologies can continuously produce, verify, and communicate trustworthy sustainability information or capture the broader network effects of digital transparency across multiple stakeholder groups (Nagesh, 2025). The present study addresses these limitations by integrating Digital Twin and Green Blockchain technologies into a unified digital transparency framework that transforms environmental claims into credible and verifiable market signals (Oleh, 2025). Digital Twin technology continuously generates measurable, real-time environmental performance data, creating evidence-based sustainability signals that are difficult to fabricate. Green Blockchain subsequently records these

data on an immutable and transparent ledger, ensuring their integrity, traceability, and resistance to manipulation (Charfi, 2025). Through this technological integration, the framework substantially reduces information asymmetry, enhances the credibility of corporate environmental disclosures, and strengthens consumer trust in green claims, thereby directly supporting efforts to combat greenwashing (Budiarti, 2026). Although Legitimacy Theory and Signaling Theory approach organizational behavior from different perspectives, they provide complementary explanations for understanding and addressing greenwashing (Judijanto, 2025). Legitimacy Theory explains why organizations seek public acceptance and why some firms may employ greenwashing to maintain or enhance their legitimacy. In contrast, Signaling Theory explains how stakeholders evaluate the credibility of corporate environmental claims under conditions of information asymmetry and why verifiable signals are essential for building trust. The proposed Digital Transparency Framework integrates the strengths of both theoretical perspectives by enabling organizations to achieve authentic legitimacy through credible environmental communication. Digital Twin technology continuously generates objective, real-time environmental performance data, while Green Blockchain ensures that these data are securely recorded, immutable, and transparently accessible to stakeholders. Together, these complementary technologies transform sustainability claims from symbolic assertions into verifiable evidence of environmental performance (Eze, 2025). Consequently, organizations are better positioned to demonstrate genuine environmental responsibility, reduce information asymmetry, strengthen stakeholder trust, and discourage greenwashing practices. By aligning organizational legitimacy with credible market signals, the proposed framework contributes to the development of a more transparent, accountable, and sustainable marketplace (Marcatajo, 2022). The relationship between the adopted theories and the proposed framework extends beyond mere theoretical justification and provides an analytical explanation of the relationships among the framework's components. Legitimacy Theory explains the underlying motivation for organizations to adopt digital transparency by suggesting that firms seek to achieve and maintain social legitimacy through credible environmental performance rather than symbolic sustainability claims. Accordingly, the causal conditions identified in this study—such as stakeholder pressure, regulatory requirements, and market demand for transparency—represent the institutional forces that motivate organizations to pursue legitimate environmental practices. In contrast, Signaling Theory explains the mechanism through which this legitimacy is communicated to external stakeholders. Within the proposed framework, Digital Twin continuously generates objective environmental performance data, while Green Blockchain transforms these data into credible, verifiable, and tamper-resistant market signals that reduce information asymmetry and strengthen stakeholder trust. The interaction of these technologies therefore operationalizes the signaling process by converting actual environmental performance into trustworthy sustainability information. Together, Legitimacy Theory explains why organizations adopt the framework, whereas Signaling Theory explains how the framework creates credible communication between organizations and stakeholders. The integration of these complementary theoretical perspectives provides the analytical foundation of the proposed Digital Transparency Framework and explains the causal relationships linking technological capabilities, organizational drivers, transparency strategies, and greenwashing prevention. Prior research has extensively examined green marketing, greenwashing, and the application of emerging digital technologies to improve transparency, consistently highlighting the widespread nature of greenwashing and its detrimental effects on consumer trust, corporate credibility, and market integrity (Delmas, 2011; Ramdhani, 2025; Judijanto, 2025; Rosari, 2025). Existing studies have identified a variety of greenwashing practices and demonstrated how misleading environmental claims influence consumer perceptions and purchasing decisions. These findings emphasize the urgent need for effective mechanisms capable of verifying corporate environmental claims. Nevertheless, much of the existing literature has concentrated on detecting greenwashing after misleading claims have already been communicated rather than developing proactive approaches that prevent deceptive practices through integrated technological solutions (Priyadarshi, 2025; Judijanto, 2025). The emergence of blockchain technology has generated considerable scholarly interest because of its potential to enhance supply chain transparency, product traceability, and sustainability reporting (Al-Ababneh, 2025). Previous studies have shown that blockchain's immutable ledger can securely record information related to ethical sourcing, carbon emissions, waste management, and other sustainability indicators, thereby strengthening stakeholder confidence in environmental disclosures (Wei, 2025). However, a recurring limitation of this body of research is its primary emphasis on data recording and verification while paying comparatively less attention to the generation of accurate, real-time environmental performance data. Consequently, many studies remain constrained by the so-called "oracle problem," whereby blockchain guarantees data integrity only after information has been entered into the system and therefore depends on the reliability and completeness of external data sources (Nicolau, 2026). Similarly, Digital Twin technology has been widely investigated for its capabilities in real-time monitoring, simulation, and optimization of physical assets and operational processes,

including applications related to environmental sustainability (Fitriawijaya, 2024). Previous research demonstrates that Digital Twins provide unprecedented visibility into operational performance and environmental impacts, enabling organizations to improve decision-making and resource efficiency. However, these studies have primarily focused on internal operational improvements and product lifecycle management, with comparatively limited attention devoted to communicating real-time environmental information to external stakeholders in a transparent, credible, and easily verifiable manner capable of reducing marketing deception (Alsaggaf, 2025). As a result, an important gap remains between the generation of environmental performance data and its effective communication to consumers and other stakeholders. Building upon these limitations, the present research proposes a holistic Digital Transparency Framework that integrates the complementary strengths of Digital Twin and Green Blockchain technologies. Although previous studies have separately demonstrated the benefits of blockchain for ensuring data integrity and Digital Twin technology for generating real-time environmental information, few studies have systematically integrated these technologies into a unified framework specifically designed to prevent greenwashing within brand marketing (Budiarti, 2026). The proposed framework enables the continuous generation of accurate environmental performance data through Digital Twin technology while simultaneously ensuring secure, immutable, and transparent verification and dissemination of these data through Green Blockchain (Budiarti, 2026). By combining these complementary capabilities, the framework offers a novel theoretical and practical approach for strengthening transparency, enhancing consumer trust, and supporting authentic green marketing while proactively reducing opportunities for greenwashing.

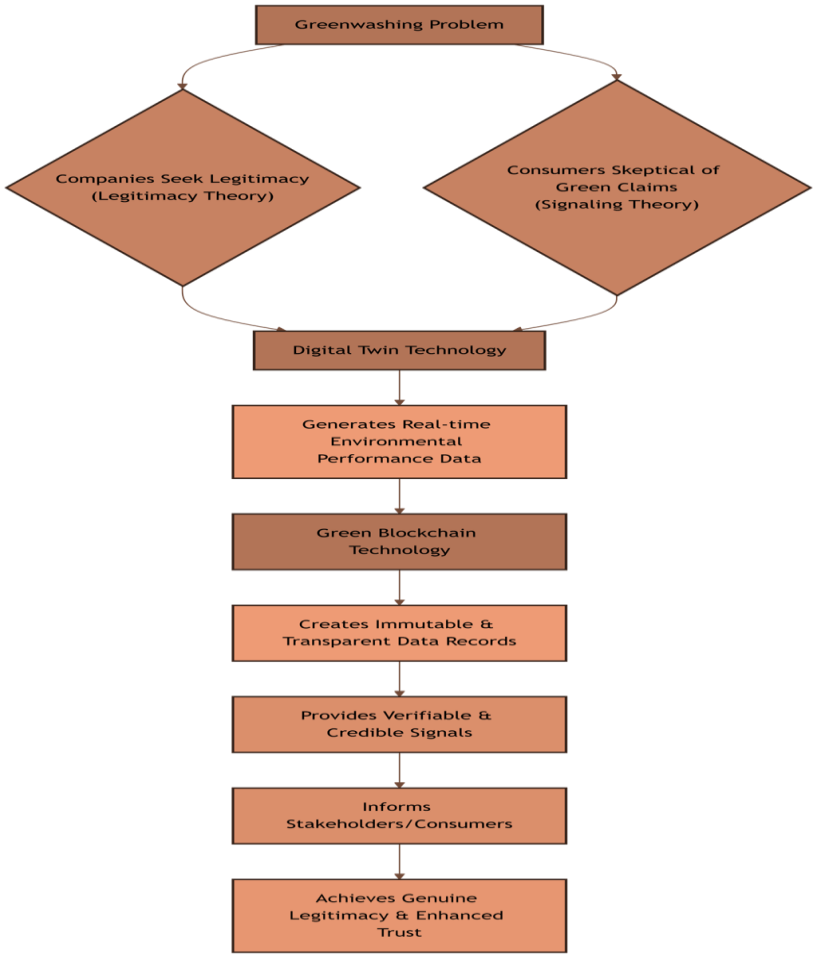

Figure 1. Integration of digital twin and green blockchain technologies

Source: Taken from research literature

This flowchart illustrates how the integration of Digital Twin and Green Blockchain technologies addresses the challenges of greenwashing by leveraging Legitimacy Theory and Signaling Theory. Greenwashing, driven by companies seeking legitimacy and consumer skepticism towards green claims, is tackled by Digital Twin generating real-time environmental performance data. This data is then recorded by Green Blockchain, creating immutable

and transparent records, which in turn provide verifiable and credible signals to stakeholders and consumers, ultimately leading to genuine legitimacy and enhanced trust

Table 1. Previous studies and innovation of the current research

Author (Year)	Main Focus of the Research	Novelty of the Present Research (Digital Transparency Framework with Digital Twin and Green Blockchain)	Research Gap Filled
Delmas (2011)	Examination of greenwashing and its detrimental effects on consumer trust and market integrity	Active prevention of greenwashing through the generation and verification of real-time and transparent data	Sole focus on detecting greenwashing rather than proactive prevention using integrated technology
Putri (2025)	Identification of various greenwashing tactics and their impact on consumer perception	Provision of credible and verifiable signals for green claims by reducing information asymmetry	Lack of a preventive, technology-driven solution to counter deceptive tactics
Judijanto (2025, 2025b)	Pervasive nature of greenwashing and the need for mechanisms to verify environmental claims	Holistic integration of the two technologies for real-time data generation and immutable recording	Focus on post-hoc detection rather than active and systematic prevention
Ramdhani (2025)	Consumer skepticism toward green claims and the need for credible signals	Creation of "costly" and verifiable signals using Digital Twin + Green Blockchain	Lack of attention to technical tools for generating and transmitting credible signals
Al-Ababneh (2025)	Application of blockchain for supply chain transparency and sustainability traceability	Solving the "oracle problem" by combining Digital Twin (precise data generation) and blockchain (immutable recording)	Focus solely on data recording without addressing the issue of generating real-time and accurate data
Wei (2025)	Building stakeholder trust through blockchain's immutable ledger	Creating broader trust via direct marketing transparency to consumers through an integrated framework	Limitation to internal supply chain; lack of focus on green marketing and consumers
Fitriawijaya (2024)	Simulation and optimization of processes and environmental impacts using Digital Twin	Translation of complex Digital Twin data into digestible and verifiable information for the market and consumers	Lack of emphasis on external and marketing applications; focus on product lifecycle management
Nicolau (2026)	The oracle problem in blockchain and limitations in communicating Digital Twin data to external stakeholders	Filling the oracle gap and externalizing data through a comprehensive greenwashing prevention framework	Identification of the problem without providing an integrated technology-based solution
Rosari (2025)	Examination of various aspects of greenwashing and emerging technologies	Comprehensive preventive approach by combining the two technologies for authentic green marketing	Lack of systematic integration of technologies to specifically target greenwashing in marketing
Present Research (Eze 2025; Budiarti 2026;	—	Holistic digital transparency framework: real-time data generation (Digital Twin) + immutable recording and transparency (Green Blockchain) for greenwashing prevention	Filling all the above gaps: combination of precise data production + credible recording + external transparency + active prevention of greenwashing

A critical review of the recent literature reveals that existing studies have addressed only isolated aspects of digital transparency in green marketing. Research on Green Blockchain has predominantly focused on data immutability, traceability, and supply chain transparency, whereas studies on Digital Twin have mainly emphasized operational monitoring, lifecycle management, and sustainability optimization. Although these studies have generated valuable insights, they largely examine these technologies independently and provide limited explanation of how they can function together to establish a comprehensive digital transparency mechanism for preventing greenwashing. Furthermore, prior research has generally adopted technical, quantitative, or conceptual perspectives, paying relatively little attention to the underlying organizational processes through which digital transparency emerges and creates stakeholder trust. Consequently, the interaction between technological capabilities, organizational conditions, stakeholder pressures, and transparency strategies remains insufficiently understood. The present study addresses this theoretical gap by developing an empirically grounded conceptual framework that integrates Digital Twin and Green Blockchain through the Grounded Theory methodology. In doing so, this research extends the existing literature beyond technology adoption by explaining the dynamic relationships among technological, organizational, and marketing factors that collectively contribute to proactive greenwashing prevention and credible green marketing.

3. Research Methodology

The present study is fundamental (basic) in purpose and qualitative in nature and method, conducted using the grounded theory approach as developed by Corbin and Strauss. This approach was deemed highly suitable for developing a conceptual framework in emerging domains—such as the application of Digital Twin and Green Blockchain technologies in green brand marketing and combating greenwashing—due to its systematic, process-oriented structure and the use of the paradigm model to explain relationships among causal conditions, contextual conditions, intervening conditions, action/interaction strategies, and consequences.

The statistical population comprised 23 experts and knowledgeable informants from fields related to green marketing, sustainable digital technologies, supply chain transparency, and anti-greenwashing efforts. Participants

were divided into two main groups: (1) faculty members from prestigious Iranian universities, including the University of Tehran, Shahid Beheshti University, Semnan University, Mazandaran University, Qom University, and Ilam University, specializing in marketing management, industrial management, and closely related disciplines (e.g., business management and technology management); and (2) senior managers and experts in green marketing and sustainable branding from active companies and organizations, specialists in Digital Twin and Green Blockchain technologies (particularly in sustainability and ESG applications), consultants in corporate social responsibility and anti-greenwashing, researchers in digital transparency and green supply chains, and entrepreneurs and managers of knowledge-based firms active in green technologies and environmental reporting.Selection criteria for participants included a minimum of 5 years of professional, research, or consulting experience in green marketing, sustainable digital technologies, or brand environmental claim management; in-depth theoretical or practical knowledge of Digital Twin, Green Blockchain, greenwashing, and transparency in marketing; and a record of publishing relevant scholarly articles or implementing practical projects in digital technologies for sustainability or anti-greenwashing initiatives. Purposive sampling was employed to ensure access to individuals with rich, pertinent expertise, with sampling continuing until theoretical saturation was achieved. Saturation occurred after conducting 16 semi-structured interviews.

The primary data collection tool was the semi-structured interview. The research questions guiding the interviews were as follows:

1. What key causal factors motivate stakeholders (consumers, brand managers, investors, regulatory bodies) to adopt and utilize Digital Twin and Green Blockchain in green brand marketing?
2. What contextual conditions influence the design and implementation of a digital transparency framework based on Digital Twin and Green Blockchain for combating greenwashing?
3. What intervening conditions (barriers or challenges) affect the adoption, implementation, and effectiveness of this framework in green brand marketing?
4. What action/interaction strategies, leveraging Digital Twin and Green Blockchain, can enhance transparency in green claims and reduce greenwashing?
5. What are the consequences of adopting this digital transparency framework—based on the two technologies—for brand credibility, consumer trust, sustainability performance, and transformation of the green market?
6. How do the interactions among causal conditions, contextual conditions, intervening conditions, strategies, and consequences contribute to formulating a comprehensive conceptual framework for countering greenwashing in green brand marketing?

In addition to the interviews, supplementary data were analyzed from relevant documents, including ESG reports, case studies of Digital Twin and Green Blockchain projects, and anti-greenwashing standards. Interviews were conducted in person or online via secure platforms, recorded with participants' informed consent, and lasted between 50 and 80 minutes each. To enhance data credibility, simultaneous note-taking occurred, and a summary of key points was prepared immediately after each interview. Ethical principles were strictly observed: participants were fully informed prior to interviews about the study objectives, data usage, confidentiality, and their rights (including the right to withdraw at any time without consequence). Identifying information was replaced with anonymous codes, audio files and notes were stored securely, and participant identities were fully protected. Data analysis was conducted following the systematic grounded theory procedures proposed by Corbin and Strauss. The analysis progressed through three interrelated coding stages: open coding, axial coding, and selective coding, accompanied by the constant comparative method and analytical memoing. In the open coding stage, interview transcripts were examined line by line. Meaningful segments of data were conceptualized and labeled as open codes. Codes were generated inductively from the participants' statements rather than being imposed a priori. Similar codes were continuously compared and grouped into preliminary concepts. In the axial coding stage, the open codes were reorganized around the paradigm model. Relationships among categories were systematically examined, and the data were structured into causal conditions, contextual conditions, intervening conditions, action/interaction strategies, and consequences. This process enabled the identification of the core categories and their interconnections. In the selective coding stage, the central phenomenon—Integrated Digital Transparency Framework—was identified and systematically related to all other categories. The emerging theoretical model was refined through iterative comparison until theoretical saturation was reached. Theoretical saturation was

determined when no new significant codes or relationships emerged from additional interviews (after the 16th interview). Throughout the analysis, the constant comparative method was applied. Newly coded data were continuously compared with previously coded data to refine category properties and dimensions. Analytical memos were written concurrently to record conceptual insights, emerging relationships, and theoretical reflections. These memos guided the progressive development of the conceptual framework. To enhance the reliability of the coding process, two qualitative methodology experts independently reviewed the coding scheme and category structure. Discrepancies were discussed and resolved through consensus, resulting in a high level of inter-coder agreement. Member checking was also performed by sharing preliminary findings with selected participants to verify the accuracy of interpretations. This rigorous analytical process ensured that the final conceptual framework was firmly grounded in the empirical data and systematically explained the relationships among technological, organizational, and marketing factors in the development of digital transparency for combating greenwashing. To establish the credibility of the study, triangulation was employed. Data were collected from three primary sources: university faculty in marketing and industrial management, managers and consultants in green marketing and sustainable branding, and specialists/researchers in sustainable digital technologies (Digital Twin, Green Blockchain, and ESG transparency). This multi-source approach enabled the researcher to obtain comprehensive insights from diverse perspectives on developing a digital transparency framework using Digital Twin and Green Blockchain to combat greenwashing in green brand marketing. Collecting data from varied sources enhanced the depth, breadth, and multi-faceted analysis of findings. Additionally, existing theoretical and empirical literature on Digital Twin, Green Blockchain, greenwashing, and green marketing served as complementary sources, providing diverse viewpoints for a more holistic examination of the topic. To ensure the validity of findings, a member checking process was implemented. Following initial data analysis, summarized results were shared with a subset of participants (at least 6 individuals). The purpose was to verify the accuracy of the researcher's interpretations and the alignment of findings with participants' intended meanings. Participants provided feedback, and any discrepancies between the researcher's understanding and their actual views were identified and addressed. Based on this input, portions of the findings were revised for greater alignment. This procedure not only demonstrated acceptable validity but also ensured that results were logical, grounded in participants' real perspectives particularly regarding the roles of Digital Twin and Green Blockchain in fostering transparency and countering greenwashing and contributed to deeper, more robust insights. To assess the reliability of the research instrument, multiple strategies were adopted to confirm that the tools could yield valid and consistent results. A key focus was on the precise and clear definition of core concepts (e.g., greenwashing, green marketing, Digital Twin, Green Blockchain, digital transparency, genuine legitimacy, and credible signaling). This was especially critical in semi-structured interviews, the main data collection method. Ambiguity in terminology can undermine instrument reliability; thus, every effort was made to ensure concepts were understandable and straightforward for participants. Questions underwent repeated review for clarity and comprehensibility. A pilot study with 4 experts tested whether interviewees shared uniform interpretations of terms and concepts; probing questions such as “Does this concept mean what the researcher intends?” or “What does this phrase mean to you?” were used for evaluation. Attention was also given to the instrument's face and content validity; questions were designed to be motivating and engaging, using appropriate wording, logical structure, and a comfortable response environment to elicit richer, more accurate replies. Clear, professional instruments typically yield more precise and substantive responses. To ensure data stability and accurate interpretation of participants' statements, preliminary findings were shared with selected interviewees for verification of accuracy and alignment with their original intent. Feedback from this stage informed revisions and improvements. Furthermore, the coding process and category extraction were independently reviewed by two qualitative methodology experts to confirm inter-coder agreement and interpretive consistency. Collectively, these measures ensured that the research instruments and analytical processes exhibited high reliability and credibility, rendering the results trustworthy and reflective of field realities.

4. Data analysis and findings

In the present study, in order to develop a conceptual framework for digital transparency based on Digital Twin and Green Blockchain technologies in green brand marketing and combating greenwashing, semi-structured interviews were conducted with 16 experts and specialists from relevant fields. These participants included university professors specializing in green marketing, industrial management, business administration, and sustainable digital technologies; senior managers and experts in green marketing and sustainable branding from companies and organizations; specialists in Digital Twin and Green Blockchain technologies (particularly in sustainability and ESG applications); consultants in corporate social responsibility and anti-greenwashing strategies; and researchers

in digital transparency and green supply chains. Gender distribution: 70% of the interviewees were male and 30% were female. Age distribution: The maximum age among participants was 50 years. Three university professors (approximately 19%) were aged between 41 and 50 years, while the remaining 13 participants (approximately 81%) were aged between 30 and 40 years. This age profile reflects a combination of dynamic young professionals in emerging sustainable digital technologies alongside relatively younger yet experienced academics. Educational background: All university professors held doctoral degrees. Among the other participants (managers, experts, consultants, and technology specialists), approximately one-third held a bachelor's degree, one-third a master's degree, and one-third a doctoral degree. Overall, about 50% of the sample possessed a PhD, 30% a master's degree, and 20% a bachelor's degree. Relevant professional experience (in green marketing, sustainable digital technologies, supply chain transparency, or anti-greenwashing): Approximately 40% had less than 10 years, 40% had 10–15 years, and 20% had more than 15 years of experience. This diverse composition of participants—with an emphasis on younger specialists (30–40 years old) alongside experienced professors (up to 50 years) and a balanced gender distribution (30% female)—enabled a comprehensive, up-to-date, and multi-perspective examination of the role of Digital Twin and Green Blockchain technologies in creating genuine transparency, reducing greenwashing, and strengthening trust and legitimacy in green brand marketing.

Table 2. Descriptive statistics of the research

Characteristic	Category	Frequency	Percentage (%)
Gender	Male	11	68.8
	Female	5	31.3
Age Group	30–40 years	13	81.3
	41–50 years	3	18.8
Educational Level	Bachelor's degree	3	18.8
	Master's degree	5	31.3
	Doctoral degree (PhD)	8	50.0
Relevant Professional Experience	Less than 10 years	6	37.5
	10–15 years	7	43.8
	More than 15 years	3	18.8
Participant Type	University professors (all PhD)	6	37.5
	Industry managers/experts/consultants	10	62.5

Table 3. Sample interview transcript from experts

Open Code	Interview Excerpt
High awareness of young people about greenwashing on social media Demand from investors for real-time and accurate environmental performance reports Pressure from the Department of Environment and regulatory bodies for precise reporting	"Young people quickly spot greenwashing claims on Instagram and Telegram and boycott brands. Investors no longer accept annual reports; they want real-time live data. The Department of Environment is also pushing for accurate carbon reporting; without real-time technology, it's practically impossible."
Consumer expectations for verifiable green claims Growing demand from people for truly green products Brand managers' need for real differentiation from competitors	"People scan the QR code on the product and expect to see the real carbon and water footprint. Demand for genuinely green products has risen a lot. Brand managers can no longer just make claims; they need real data to stand out from competitors."
Relatively high initial cost for medium-sized companies Shortage of specialists familiar with both technologies Resistance from older managers to new technology	"The initial cost of setting up a Digital Twin is still high for medium-sized companies. Specialists who know both Digital Twin and green blockchain are hard to find. Older managers still think full transparency harms them and resist it."
Concern about disclosing confidential information on blockchain Fear of cyber-attacks on the Digital Twin system Challenge of complying with data protection regulations	"The biggest concern is leaking sensitive supply chain information on the blockchain. The Digital Twin system could be targeted by cyber-attacks. Complying with data protection rules when everything is transparent is a major challenge in itself."
Secure connection of Digital Twin to blockchain Building a simple dashboard for all stakeholders Use of artificial intelligence for automatic problem detection	"The best approach is a secure connection between Digital Twin and blockchain. A simple dashboard that all stakeholders can view is very important. Artificial intelligence automatically detects anomalies and prevents false claims."
Publishing real information on the brand's website and app Placing QR codes on products Real storytelling on social media	"We must publish real information directly on the brand's website and app. A QR code on every product linking to the blockchain is essential. Storytelling on social media should also be based on real data."
Increased repeat purchases from transparent brands Reduction in people's skepticism toward green claims Customers themselves become brand advocates	"Repeat purchases and loyalty to transparent brands increase significantly. People's skepticism about green claims almost disappears. Customers themselves become advocates and promote the brand organically on social networks."
Improved brand image in people's minds Reduced risk of crises and fines for the brand Better position for the brand in export markets	"The brand image changes from superficial green to a truly trustworthy brand. The risk of crises and fines drops a lot. Brands that implement this approach gain a much stronger position in export markets."

Table 4. Codes extracted from data analysis

Main Category	Axial Code	Open Codes (Open Codes)

Causal Conditions	Stakeholder Pressure for Genuine Transparency	High awareness among young people of greenwashing on social media Demand from investors for real-time and accurate environmental performance reports Pressure from the Department of Environment and regulatory bodies for precise reporting Consumer expectations for verifiable green claims Brand managers' need for real differentiation from competitors Requests from customers and shareholders to view real company data
	Legal and Policy Pressures	New requirements from the Department of Environment for carbon reporting Anti-greenwashing laws under consideration Government green economy policies supporting transparent technologies Mandatory environmental reporting for listed companies Government incentives for green knowledge-based companies Regulations from the Ministry of Industry for supply chain transparency
	Maturity of Digital Twin and Green Blockchain Technology	Reduction in Digital Twin implementation costs for companies Green blockchain with energy consumption suitable for current conditions Ability to connect sensors to Digital Twin Development of simple and reliable oracles National standards for using these technologies Capability to execute smart contracts on existing platforms
	Market Demand for Green Credibility	Growing consumer demand for genuinely green products Preference for brands that publish real information Intense competition among brands to gain green credibility Increased brand value through genuine transparency Demand from young generation for real green storytelling Pressure from large retailers for transparent suppliers
Intervening Conditions	Cost and Implementation Complexity	Relatively high initial cost for medium-sized companies Shortage of specialists familiar with both technologies Long setup time in traditional companies Resistance from older managers to new technology Equipment supply challenges due to restrictions Risk of project failure under economic conditions
	Security and Privacy Issues	Concern about disclosing confidential information on blockchain Fear of cyber attacks on the Digital Twin system Challenge of complying with data protection regulations Managers' worry about leaking competitive information Difficulty managing access for different stakeholders
	Organizational and Cultural Resistance	Managers' fear of revealing real environmental performance Traditional company culture of “say less” Lack of employee training to work with the new system Marketing department resistance to losing message control Conflict between short-term profit and long-term sustainability
Contextual Conditions	Digital and Technological Infrastructure	Expansion of internet and mobile coverage across the country Growth of knowledge-based companies in blockchain Possibility of using domestic and cloud servers Access to energy for running green technology Availability of ready APIs in companies
	Governmental and Institutional Support	Support from science and technology parks for green projects Innovation and Prosperity Fund for transparency technologies Ministry of Industry policies for green economy Collaboration between universities and industry Government environmental programs for transparency
	Organizational and Consumer Culture	Readiness of young generation for transparent technology Increased public awareness of environmental issues Willingness of young managers for transparency and social responsibility Growth of “conscious buying” culture
Core Phenomenon	Integrated Digital Transparency Framework	Real-time generation of company environmental performance data Immutable recording of green claims on blockchain Simple and accessible dashboard for people and customers Automatic execution of claim verification Solving data input problem through direct connection of both technologies Automatic and reliable reporting to the Department of Environment Building genuine trust between brand and customer
	Credible Signaling and Real Legitimacy	Converting real data into trustworthy signals Strengthening brand credibility through genuine transparency Reducing consumer skepticism Differentiating brand from competitors using technology Rebuilding public trust lost in green claims
	Proactive Prevention of Greenwashing	Automatic detection of unrealistic claims Preventing exaggeration before advertising publication Automatic alert to manager when claim does not match reality Strong digital evidence for reporting to regulatory bodies Turning greenwashing from an opportunity into a threat for the brand
	Real Sustainability Performance Optimization	Simulating process improvements with Digital Twin Actual reduction in energy and water consumption in factories Better waste and supply chain management Dynamic reporting for managerial decision-making
	Transformation of Green Marketing	Creating a new market for genuinely green products Shifting competition from claims to real proof Collaboration among brands on a shared platform Changing marketing role from advertising to proof New standard for green marketing
Action/Interaction Strategies	Simple and Practical Technical Integration	Secure connection of Digital Twin to blockchain Building a simple dashboard for all stakeholders Use of artificial intelligence for automatic problem detection Starting with a small pilot project on one product Gradual expansion to the entire company
	Internal Education and Cultural Change	Simple training for employees and managers Internal campaign to accept transparency culture Creating a small green technology team inside the company Customer education through app or website Changing managerial goals toward transparency
	Transparent Communication with Customers	Publishing real information on brand website and app Placing QR codes on products Real storytelling on social media Quick response to customer questions Turning transparency into a brand strength
	Continuous Evaluation and Improvement	Regular checking of system performance Gathering opinions from customers and stakeholders Updating system based on feedback Annual progress reporting to managers and institutions Simple internal audit every year
	Collaboration and Ecosystem Expansion	Creating a joint group of transparent brands Collaboration with knowledge-based companies Sharing experiences among companies Collaboration with science and technology parks and universities Expansion of the system to other industries
Consequences	Increased Consumer Trust and Loyalty	Increased repeat purchases from transparent brands Reduction in public skepticism toward green claims Customers themselves become brand advocates Improved brand image in people's minds
	Strengthened Brand Credibility and Value	Increased brand value in the market Greater investment attraction for transparent companies Reduced risk of crises and fines for the brand Better brand position in export markets
	Reduction in Greenwashing and Real Performance Improvement	Significant reduction in false claims among brands Actual improvement in energy and water consumption in factories Healthier competition among brands Reduction in legal costs and fines
	Market and Industry Transformation	Creation of a new market for genuinely green products Shift in competition from slogans to real action Creation of new jobs in green knowledge-based companies Strengthening digital green economy
	Improved Reporting and Corporate Governance	Simple and automatic reporting to the Department of Environment Reduction in environmental audit costs Greater trust from government institutions in company reports Better managerial decision-making with real data

The findings of this study are organized according to the six main categories of the Corbin and Strauss paradigm model; however, the relationships among these categories are not merely structural but dynamic and interactive, ultimately culminating in the development of the Integrated Digital Transparency Framework. Causal conditions

(stakeholder pressure, regulatory requirements, and technological maturity) create the initial motivation for moving toward digital transparency. These conditions become operative within the enabling environment of contextual conditions (digital infrastructure, institutional support, and organizational and consumer culture) while simultaneously being shaped by intervening conditions (cost, implementation complexity, security concerns, and organizational resistance). To overcome these barriers and capitalize on the causal and contextual conditions, organizations adopt specific action/interaction strategies, including simple and practical technical integration, education and cultural transformation, transparent communication with customers, continuous evaluation, and ecosystem expansion. The implementation of these strategies directly leads to consequences such as increased consumer trust and loyalty, strengthened brand credibility, reduction of greenwashing, improved actual sustainability performance, and market transformation. At the core of these dynamic relationships lies the central phenomenon—the Integrated Digital Transparency Framework—formed through the synergy of Digital Twin (real-time generation of objective environmental data) and Green Blockchain (immutable and verifiable recording). This central phenomenon is not merely the final output of the process but serves as the connecting hub that links all categories: it connects causal and contextual conditions to strategies, moderates the influence of intervening conditions, and ultimately enables the realization of the desired consequences. Thus, the final model of the study represents an interactive and integrated system in which each component plays a synergistic role in the development of credible and proactive digital transparency in green marketing The above table presents the grounded theory coding structure based on the Corbin and Strauss approach. The axial categories and open codes were derived from semi-structured interviews with 16 experts and specialists in green marketing, sustainable digital technologies, and supply chain transparency. The codes are tailored to reflect the real-world conditions of companies and brands in Iran, with a strong emphasis on the core innovation of the study: the integration of Digital Twin and Green Blockchain technologies for proactive prevention of greenwashing and establishment of genuine transparency. Open codes have been formulated to be clear, actionable, and aligned with existing challenges and opportunities in the local market and industry. This structure serves as the foundation for the study's paradigmatic model, systematically explaining the relationships among causal conditions, contextual conditions, intervening conditions, action/interaction strategies, and consequences.

5. Discussion and Conclusion

Figure 2. Conceptual research model

This study aimed to design a digital transparency framework in green brand marketing based on Digital Twin and Green Blockchain technologies, employing the Corbin and Strauss grounded theory approach. The findings were organized into six axial categories: causal conditions, contextual conditions, intervening conditions, strategies, consequences, and the central phenomenon. Collectively, these categories form an integrated model for the proactive prevention of greenwashing.

5.1. Causal Conditions

Causal conditions refer to the factors that create the primary motivation for designing and implementing the digital transparency framework. The most significant factors include stakeholder pressure for genuine transparency, legal and policy requirements, the maturity of Digital Twin and Green Blockchain technologies, and increasing market demand for green credibility. The rising awareness of younger generations and their sensitivity to greenwashing, coupled with investor pressure for real-time and accurate environmental data, play a crucial role in shaping this demand. Recent studies indicate that consumer distrust toward environmental claims has significantly increased, reinforcing the need for verifiable mechanisms (Eze, 2025). Moreover, the advancement of blockchain and Digital Twin technologies, as infrastructures for generating and validating environmental data, has enabled the realization of genuine transparency (Ferone & Verrilli, 2025; Abdallah-Ou-Moussa et al., 2026). Additionally, governmental policies and environmental regulations are pushing organizations toward more accurate and transparent reporting (Wei, 2025). These conditions can be interpreted through the lenses of Legitimacy Theory and Signaling Theory, where the pursuit of genuine legitimacy and the need for credible signals act as key drivers for adopting this framework. A notable finding of this study is the simultaneous prominence of market pressure and technological readiness as driving forces—whereas prior research has often examined these factors in isolation.

5.2. Contextual Conditions

Contextual conditions refer to the environments that facilitate or constrain the implementation of the framework. These include digital infrastructure, institutional and governmental support, and organizational and consumer culture. The expansion of internet access, the growth of knowledge-based firms, and university–industry collaboration is among the most important enablers. Studies suggest that advanced digital infrastructure and innovation ecosystems are essential prerequisites for implementing transparency-oriented technologies (Nicolau & Petcu, 2026). Furthermore, an informed consumer culture and the rise of "conscious consumption" significantly contribute to the success of such frameworks (Budiarti et al., 2026). Compared to prior literature, the findings of this study place greater emphasis on organizational culture and the readiness of younger generations, indicating a paradigm shift from purely technology-driven approaches to more human-centered perspectives in green marketing.

5.3. Intervening Conditions

Intervening conditions refer to the barriers and challenges affecting the implementation of the framework. The most critical factors include high costs, implementation complexity, security and privacy concerns, and organizational resistance. Recent research highlights those high initial costs and a lack of expertise are among the main barriers to adopting advanced sustainability technologies (Owusu-Berko, 2025). Additionally, concerns regarding data security and the exposure of sensitive information pose significant challenges in blockchain applications (Charfi et al., 2025). A key contribution of this study is the reconceptualization of these barriers as strategic opportunities. For instance, organizational training and skill development can simultaneously address both the shortage of expertise and cultural resistance.

5.4. Strategies

The identified strategies include simple technical integration, education and cultural transformation, transparent communication with customers, continuous evaluation, and ecosystem collaboration. Key actions involve the use of user-friendly dashboards, QR codes, and data-driven storytelling. Studies demonstrate that providing accessible and comprehensible information to consumers plays a vital role in building trust and reducing greenwashing (Priyadarshi, 2025). Furthermore, the integration of artificial intelligence, Digital Twin, and blockchain technologies can enable the automatic detection of misleading claims (Nicolau & Petcu, 2026). In this study, strategies move beyond general recommendations and are translated into practical and actionable measures, representing one of the key innovations of the research.

5.5. Consequences

The consequences of implementing this framework include increased consumer trust and loyalty, enhanced brand value, reduction of greenwashing, improved actual environmental performance, and market transformation. Recent studies confirm that digital transparency directly enhances consumer trust and influences purchasing behavior (Alsaggaf, 2025). Additionally, the use of blockchain in ESG reporting improves credibility and reduces legal risks (Wei, 2025). A significant finding of this study is the direct relationship between digital transparency and sustainable competitive advantage, indicating that transparency is not only an ethical requirement but also a strategic marketing tool.

5.6. Central Phenomenon

The central phenomenon of this study is the design of an integrated digital transparency framework based on the synergy of Digital Twin and Green Blockchain technologies, leading to credible signaling, genuine legitimacy, proactive prevention of greenwashing, and the transformation of green marketing. By combining real-time data generation (via Digital Twin) with immutable data recording (via blockchain), this framework eliminates the gap between claims and reality. Unlike previous studies that primarily focus on detecting or mitigating greenwashing, this research offers a proactive and systemic approach (Budiarti et al., 2026; Eze, 2025). Overall, this framework represents a shift from claim-based green marketing to evidence-based green marketing, marking a fundamental transformation in the field.

Table5. Comparing research results with previous studies

Author(s) & Year	Main Findings of Previous Research	Findings of the Present Study	Research Gap Identified	Contribution of the Present Study
Eze (2025)	Demonstrated that increasing consumer distrust toward environmental claims highlights the need for credible verification mechanisms in sustainability marketing.	Stakeholder pressure, particularly from environmentally aware consumers and investors, emerged as one of the primary causal drivers for adopting Digital Twin and Green Blockchain technologies to establish digital transparency.	Previous research emphasized the existence of distrust but did not explain how organizations can operationally overcome it through an integrated technological framework.	This study develops a grounded theory framework explaining how Digital Twin and Green Blockchain jointly transform consumer distrust into verified trust through continuous environmental data transparency.
Ferone & Verrilli (2025)	Explained that blockchain enhances the security and transparency of Digital Twin systems by protecting digital information from manipulation.	The findings reveal that the integration of Digital Twin and Green Blockchain enables simultaneous real-time environmental monitoring and immutable verification of sustainability data.	Previous studies focused primarily on technological security and system transparency without addressing their application in green marketing.	The present study extends the technological perspective to green marketing by demonstrating how this integration prevents greenwashing and strengthens brand legitimacy.
Abdallah-Ou-Moussa et al. (2026)	Showed that blockchain and Digital Twins improve transparency in low-carbon circular supply chains.	Digital transparency was identified as the central phenomenon connecting operational environmental data with credible marketing communication.	Previous research concentrated on supply chain sustainability rather than consumer-oriented transparency and green branding.	This research expands the application of these technologies into green marketing and explains their role in creating trustworthy environmental communication.
Nicolau & Petcu (2026)	Identified advanced digital infrastructure as a prerequisite for blockchain-enabled environmental traceability.	Digital infrastructure, governmental support, and organizational readiness were identified as contextual conditions facilitating implementation of the proposed framework.	Previous studies focused mainly on technological infrastructure while overlooking organizational and institutional contexts.	This study demonstrates that successful implementation depends on the interaction between technological, institutional, and cultural environments.
Budiarti et al. (2026)	Reported that increasing public awareness and digital communication strengthen green marketing effectiveness.	Consumer culture, organizational culture, and transparency-oriented managerial attitudes emerged as critical contextual conditions supporting digital transparency.	Earlier research emphasized digital communication rather than organizational readiness for transparency.	The study integrates organizational culture with technological readiness to explain successful implementation of digital transparency.
Owusu-Berko (2025)	Reported that high implementation costs and shortage of technical expertise limit the adoption of Digital Twin and blockchain technologies.	Cost, implementation complexity, organizational resistance, and lack of expertise were identified as major intervening conditions affecting implementation.	Previous research treated these barriers individually.	The present study integrates technical, organizational, and cultural barriers into a unified grounded theory model and explains strategies to overcome them.
Charfi et al. (2025)	Highlighted blockchain privacy and cybersecurity concerns	Security concerns, privacy protection, and competitive information	Previous studies mainly focused on	This study extends security concerns to managerial decision-

	in sustainability applications.	disclosure were identified as critical barriers influencing organizational adoption.	technical cybersecurity challenges.	making and organizational acceptance within green marketing systems.
Priyadarshi (2025)	Found that transparent online communication enhances customer trust in sustainable brands.	Transparent communication through QR codes, blockchain dashboards, websites, and data-driven storytelling emerged as one of the core implementation strategies.	Previous research mainly investigated communication practices without explaining supporting technological infrastructure.	This study links transparent communication directly with Digital Twin and Green Blockchain technologies to ensure information credibility.
Alsaggaf (2025)	Concluded that digital transparency improves consumer trust and reduces skepticism toward environmental claims.	Increased consumer trust, loyalty, and repeat purchasing were identified as the primary consequences of implementing the proposed framework.	Previous studies mainly evaluated consumer perception without examining organizational mechanisms generating transparency.	The present research explains how technological integration creates sustainable trust and long-term customer loyalty.
Wei (2025)	Demonstrated that blockchain-based ESG reporting improves credibility and reduces legal risks associated with greenwashing.	Improved corporate reporting, stronger governance, reduced greenwashing, and enhanced competitive positioning emerged as organizational consequences.	Previous research concentrated on ESG reporting and financial transparency.	The present study broadens the outcomes by incorporating marketing performance, brand value, consumer trust, and market transformation into a unified conceptual framework.

6. Pactical Implications

The findings of this study provide several practical implications for managers, policymakers, technology providers, and organizations seeking to improve transparency in green marketing. The proposed Digital Transparency Framework offers actionable guidance for translating the empirical findings into organizational practice. The recommendations presented below are directly derived from the grounded theory analysis and reflect the identified strategies, contextual conditions, and implementation challenges.

6.1. Adopt a Phased Implementation Strategy

Rather than introducing the Digital Transparency Framework across the entire organization, firms should begin with pilot implementation in a single product line, production process, or business unit. This phased approach enables managers to evaluate technical feasibility, identify operational challenges, and minimise implementation risks before large-scale deployment. It also provides opportunities for organizational learning, gradual employee adaptation, and continuous refinement of the Digital Twin and Green Blockchain infrastructure based on practical experience.

6.2. Establish Real-Time Transparency Platforms for Stakeholders

Organizations should transform environmental performance data into accessible and verifiable information for external stakeholders. Environmental indicators such as carbon emissions, energy consumption, water usage, and waste generation should be continuously collected through Digital Twin technology and securely verified using Green Blockchain. These data should then be presented through user-friendly dashboards and QR-code-enabled product labels, allowing customers, investors, and regulators to independently verify environmental claims. Such an approach strengthens credibility while substantially reducing the likelihood of greenwashing accusations.

6.3. Strengthen Organizational Capabilities and Transparency Culture

Since organizational resistance and insufficient technical expertise emerged as major implementation barriers, firms should invest in continuous training programmes for managers and employees. Training should integrate technical competencies related to Digital Twin and Green Blockchain technologies with organizational initiatives that promote transparency, accountability, and sustainability-oriented decision-making. Establishing cross-functional teams involving marketing, sustainability, information technology, and operations departments can further facilitate successful implementation and ensure consistency between actual environmental performance and corporate communication.

6.4. Promote Collaborative Digital Transparency Ecosystems

Successful implementation requires collaboration beyond organizational boundaries. Companies should establish strategic partnerships with universities, technology providers, knowledge-based enterprises, government agencies, and industry associations to develop common technical standards, exchange implementation experience, and accelerate innovation. Policymakers can further facilitate adoption by providing regulatory guidance, financial incentives, and industry-wide transparency standards that encourage the broader diffusion of Digital Twin and Green Blockchain technologies for sustainable marketing practices. these practical implications demonstrate that combating greenwashing requires more than transparent communication alone. Organizations need an integrated technological, managerial, and institutional approach that combines real-time environmental monitoring, immutable data verification, employee capability development, and stakeholder collaboration to establish credible and sustainable green marketing practices.

7. Research Limitations

1. Qualitative and interpretive nature of the study

The data analysis may be influenced by the researcher's subjectivity, although efforts such as member checking were employed to minimize this effect.

2. Exclusive reliance on interviews

The use of interviews as the sole data collection method may be limiting, and combining it with other methods could enhance the validity of the findings.

3. Time constraints of the study

Conducting the research within a specific timeframe limits the ability to capture dynamic changes in market trends and technologies, suggesting the need for longitudinal studies in future research.

8. Future Research Directions

Building upon the findings and limitations of the present study, several directions for future research are recommended. First, future studies could quantitatively validate the proposed Digital Transparency Framework using structural equation modelling (SEM) or other statistical techniques to examine the relationships among Digital Twin, Green Blockchain, digital transparency, consumer trust, and greenwashing prevention across different industries.

Second, comparative studies across countries with different regulatory environments and levels of digital maturity would provide valuable insights into how institutional and cultural factors influence the implementation of digital transparency initiatives.

Third, longitudinal research is recommended to investigate how organizations' adoption of Digital Twin and Green Blockchain technologies evolves over time and how these technologies influence long-term consumer trust, brand reputation, and sustainable competitive advantage.

Fourth, future studies could explore the integration of emerging technologies such as Artificial Intelligence, Internet of Things (IoT), and machine learning with Digital Twin and Green Blockchain to enhance automated environmental monitoring, predictive sustainability analytics, and real-time detection of misleading environmental claims.

Finally, future research may examine the applicability of the proposed framework across different industrial sectors, including manufacturing, agriculture, healthcare, tourism, and energy, to assess its generalizability and identify sector-specific implementation strategies.

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