

Blockchain for Environmental Accountability: An Experimental Approach to Sustainable Tourism Reporting

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Abstract

This study evaluates the application of blockchain technology to enhance environmental accountability in sustainable tourism reporting in Bali, as a response to the risk of greenwashing practices. Given that traditional reporting systems often lack standardization and are vulnerable to manipulation, this study aims to empirically test the impact of blockchain integration on accuracy, efficiency, and stakeholder trust. Using a quasi-experimental method with a sample of 60 tourism businesses divided into treatment and control groups, data was analyzed through system metrics, surveys, and interviews. The results showed that blockchain significantly improved reporting accuracy by 18.6% and accelerated verification time by 67% (9.4 days faster). Furthermore, the use of smart contracts was shown to increase stakeholder trust and reduce audit costs with a return on investment ratio of 2.8:1. Theoretically, this study validates how automation and data immutability strengthen environmental accountability structures in complex tourism governance. In conclusion, blockchain technology is effective in increasing transparency and reporting efficiency, although its adoption by SMEs remains hampered by cost and technical barriers. The practical implications of this research emphasize the importance of developing user-friendly interfaces as well as financial support to ensure inclusive digital transformation for the sustainability of the tourism industry.

KEYWORDS

blockchain; sustainable tourism; environmental accountability; greenwashing; quasi-experimental study.

Introduction

The global tourism industry is a major economic driver, contributing approximately 10% of the world's GDP and supporting millions of jobs (Klamsaengsai et al., 2025; Panigrahy & Verma, 2025). However, its rapid expansion has come at a significant environmental cost, including carbon emissions, resource depletion, and ecosystem degradation.

Analytically, Bali serves as a critical research laboratory due to its unique position as a global tourism epicenter currently undergoing a transformation toward green economy regulations through Bali Provincial Regulation No. 8 of 2019 concerning Standards for the Implementation of Balinese Cultural Tourism. The region faces a high risk of greenwashing due to the fragmentation of reporting standards between traditional governance practices such as Subak and the demands of international certification, creating significant information asymmetries for tourists. By examining Bali, this research not only explores the technical challenges of blockchain adoption but also tests the technology's effectiveness in integrating local wisdom with global digital accountability, making it a representative case study for tourism destinations in developing countries transitioning to regulation-based digital transparency systems. As sustainability becomes a critical concern, there is an urgent need for transparent and verifiable environmental accountability mechanisms in tourism. Traditional reporting systems often

suffer from opacity, manipulation, and a lack of standardization, leading to widespread greenwashing—where businesses falsely claim sustainable practices to attract eco-conscious consumers (Capucho et al., 2025; Galli et al., 2025; Rejeb et al., 2025). In this context, blockchain technology emerges as a disruptive solution, offering immutable, decentralized, and auditable record-keeping that could revolutionize sustainability reporting. The integration of blockchain characteristics such as data immutability, decentralization, and auditable transparency significantly strengthens the empirical evidence base for validating corporate environmental claims, thereby narrowing the perceived gap between organizational activities and societal values. Through the lens of stakeholder theory, this technology serves as a digital governance mechanism that mitigates information asymmetry, enabling the real-time and reliable distribution of sustainability data to all stakeholders. By aligning these technical features within a broader governance framework, blockchain becomes more than just a record-keeping tool, but a strategic instrument for building systemic accountability that strengthens public trust and meets regulatory expectations within the sustainable tourism ecosystem.

Despite its potential, existing research presents contradictory findings on blockchain's efficacy in environmental accountability, while real-world adoption in tourism remains limited. This study seeks to experimentally evaluate blockchain's role in enhancing transparency and trust in sustainable tourism reporting, addressing both its promises and challenges (Galli et al., 2025; Li et al., 2025).

Sustainable tourism relies on accurate and honest reporting of environmental impacts, yet current systems are plagued by inefficiencies. Many tourism operators voluntarily disclose sustainability metrics, but these reports are often unaudited, inconsistent, or misleading (Gričar et al., 2025). For instance, hotels may claim carbon neutrality without providing verifiable data, while tour operators might exaggerate their conservation efforts. This lack of accountability undermines consumer trust and hampers genuine progress toward sustainability. A 2023 survey by Booking.com revealed that 83% of global travelers prefer sustainable options, yet 52% distrust environmental claims made by tourism providers (Chauhan & Sahoo, 2024; Conefrey & Hanrahan, 2025). The primary report referenced is the "2023 Sustainable Travel Report" published by Booking.com in April 2023, its eighth annual comprehensive study of global traveler preferences. The survey's metadata covers a vast sample size of 33,228 respondents across 35 countries and territories worldwide (including key markets in Asia-Pacific, Europe, and the Americas). The study was conducted using an online survey of adults who had traveled at least once in the past 12 months and planned to travel in the coming year. This data confirms a consumer behavior paradox: 83% of global travelers expressed a strong desire to choose environmentally friendly options, yet there is a significant crisis of trust, with 52% of respondents expressing distrust in the validity of sustainability claims marketed by travel providers.

The skepticism stems from the absence of a reliable, tamper-proof system to validate sustainability assertions. Existing environmental reporting frameworks, such as the Global Reporting Initiative (GRI) and the Carbon Disclosure Project (CDP), rely on self-reported data and third-party audits, which are costly, time-consuming, and vulnerable to bias. Moreover, the fragmentation of sustainability standards across regions complicates cross-border comparisons (Gričar et al., 2025; Yap et al., 2024). Blockchain technology, with its inherent characteristics of decentralization, transparency, and cryptographic security, could address these challenges by enabling real-time, tamper-proof tracking of environmental

data (Hikal et al., 2025). However, despite its theoretical advantages, empirical evidence on blockchain's effectiveness in tourism sustainability remains inconclusive, with some studies highlighting its transformative potential while others point to significant implementation barriers.

Several studies advocate blockchain as a game-changer for environmental accountability. (Feng, 2025) demonstrated that blockchain enhances supply chain transparency by providing an immutable ledger for carbon footprint tracking, reducing opportunities for greenwashing. Similarly, (Gomez-Guillen & Tapias-Baque, 2024) found that smart contracts—self-executing agreements on blockchain—can automate sustainability compliance, eliminating the need for intermediaries and reducing fraud. In the tourism sector, pilot projects have shown that blockchain can verify eco-certifications, track energy consumption in hotels, and ensure fair carbon offsetting (Taufiqurrachman et al., 2024). These findings suggest that blockchain could standardize sustainability reporting and foster greater trust among stakeholders.

Conversely, other researchers caution against overestimating blockchain's capabilities. (Berbeka et al., 2024) argues that blockchain's immutability does not guarantee data accuracy; if input data is flawed (a "garbage in, garbage out" scenario), the blockchain merely records incorrect information permanently. Additionally, (Hong & Xiao, 2024) identify several barriers to blockchain adoption in environmental reporting, including high energy consumption (particularly in proof-of-work systems), technical complexity, and resistance from traditional auditors and policymakers. In tourism, small and medium-sized enterprises (SMEs)—which constitute the majority of the industry—often lack the resources and expertise to implement blockchain solutions, raising concerns about equitable access (Chen et al., 2025). These contradictions highlight a critical research gap: while blockchain theoretically offers robust solutions for sustainability reporting, its real-world applicability in tourism remains underexplored (Raja Segaran et al., 2025). Most studies focus on supply chains or energy sectors, leaving tourism—a highly fragmented and service-oriented industry—understudied. This study aims to bridge that gap by experimentally testing blockchain's feasibility and effectiveness in a tourism context (Kumar & Al-Sharif, 2024).

The growing demand for sustainable travel has fueled the rise of greenwashing practices, where businesses often exaggerate or falsify their environmental credentials. A 2021 report by the European Commission, which systematically scanned hundreds of tourism websites across the European Union using the Unfair Commercial Practices Directive (UCPD) criteria, found that 42% of online environmental claims were deceptive, false, or exaggerated. These findings from official regulatory sources provide a strong methodological basis for explaining the 52% of travelers' distrust of the validity of global sustainability certifications. Blockchain technology offers a solution to mitigate this problem by enabling real-time verification of claims, such as renewable energy use or waste reduction, through immutable data logs. Unlike financial accounting, sustainability reporting currently faces the challenge of data inconsistency due to the lack of universal standards (Saputra & Paranoan, 2024). Blockchain's ability to create standardized and auditable records can harmonize reporting practices, enabling stakeholders to objectively assess environmental performance. In addition to restoring consumer trust through public data accessibility, blockchain implementation also helps tourism businesses comply with increasingly stringent regulations, such as the European Union's Corporate Sustainability Reporting Directive (CSRD), efficiently while avoiding sanctions due to inaccurate reporting (Laksmi et al., 2024).

This research was conducted in Bali's tourism sector, a globally renowned destination celebrated for its natural beauty,

rich cultural heritage, and thriving tourism industry. Bali was selected as the research site for several strategic reasons. First, as one of Indonesia's largest tourism hubs, Bali faces significant sustainability challenges, including pressure on natural resources, increasing waste generation, and growing demands for transparency in sustainable tourism practices. Second, Bali's tourism industry comprises diverse stakeholders, ranging from small and medium-sized enterprises (SMEs) to large corporations, providing a representative sample to evaluate blockchain's effectiveness across different business scales and operational contexts.

Furthermore, Bali has emerged as a pioneer in implementing sustainable tourism policies, such as the Bali Clean and Green Initiative and its commitment to achieving Net Zero Emissions by 2045, which aligns with this study's objectives. The adoption of blockchain technology is expected to enhance environmental accountability and mitigate widespread greenwashing practices in the tourism sector. The diversity of tourism businesses—including hotels, restaurants, tour operators, and cultural attractions—enables this study to assess blockchain implementation across various operational scenarios. By engaging tourism stakeholders in Bali, this research not only holds local relevance but also serves as a case study for other destinations facing similar challenges in achieving transparency and sustainability.

Core Features of Blockchain Relevant to Sustainability Reporting

Blockchain technology offers several fundamental characteristics that make it uniquely suited for enhancing sustainability reporting in the tourism sector. The first key feature is transparency, as blockchain operates on a distributed ledger system where all participants have access to the same verified data in real time (Putra et al., 2024). This transparency helps eliminate information asymmetry between tourism operators, regulators, and consumers, creating a shared source of truth for environmental claims. The second critical aspect is immutability, meaning once data is recorded on the blockchain, it cannot be altered retroactively without network consensus (Saputra et al., 2023b). This feature provides an auditable trail of sustainability metrics like energy consumption or waste reduction, preventing fraudulent manipulation of environmental data (Saputra et al., 2023a).

Another vital characteristic is decentralization, which removes the need for a central authority to validate transactions. In sustainability reporting, this reduces reliance on potentially biased third-party auditors and enables peer-to-peer verification of environmental performance data (Bhattacharyya et al., 2024; Konapure & Nawale, 2025). Blockchain's smart contract functionality further enhances accountability by automatically executing predefined sustainability agreements when specific conditions are met, such as releasing carbon offset payments only after verified emission reductions. The technology's cryptographic security ensures that all transactions and data entries are securely encrypted, protecting sensitive environmental data from unauthorized access or tampering (Boumaiza, 2025; Hikal et al., 2025).

Additionally, blockchain enables granular traceability throughout supply chains, allowing tourism businesses to track and verify the environmental impact of their operations at each stage (Ariffin et al., 2025; Yap et al., 2024). This is particularly valuable for monitoring sustainable sourcing of materials or measuring the carbon footprint of tourism activities. The interoperability of blockchain systems also facilitates standardized sustainability reporting across different organizations and jurisdictions, addressing current challenges of inconsistent measurement methodologies

(Chauhan & Sahoo, 2024; Gričar et al., 2025). These features collectively address major pain points in traditional sustainability reporting, including lack of trust, verification challenges, and inconsistent data quality, while providing a framework for more credible and efficient environmental accountability in the tourism industry.

Environmental Accountability in Sustainable Tourism

Environmental accountability in sustainable tourism refers to the responsibility of tourism stakeholders to measure, disclose, and take ownership of their ecological impacts through transparent and verifiable reporting systems (Almeida & Wasim, 2023; Broccardo et al., 2023). This concept has gained urgency as the tourism sector faces increasing scrutiny for its environmental footprint, including carbon emissions, water consumption, and ecosystem degradation. Effective accountability mechanisms require robust frameworks that go beyond superficial claims of sustainability to provide measurable, auditable evidence of environmental performance (Wagenseil et al., 2024). The current landscape reveals significant challenges, including inconsistent reporting standards, difficulties in verifying claims across complex supply chains, and limited tools for real-time impact monitoring. Traditional reporting methods often rely on periodic self-assessments that lack independent verification, creating opportunities for greenwashing where organizations exaggerate their environmental credentials (Scott, 2021). Moreover, the fragmented nature of global tourism operations makes it particularly difficult to establish comprehensive accountability across destinations, accommodations, and service providers (Sharpley, 2023).

Stakeholders ranging from hotel chains to local tour operators face growing pressure from environmentally conscious consumers, regulators, and investors to demonstrate genuine sustainability commitments. This demand has spurred innovation in monitoring technologies and reporting methodologies that can provide more accurate, timely, and comparable environmental data (Gomez-Guillen & Tapias-Baque, 2024; Li et al., 2025). The emergence of digital solutions, particularly blockchain-based systems, offers new possibilities for creating immutable records of sustainability metrics that are resistant to manipulation. Such technological advancements are transforming accountability from a retrospective compliance exercise into a proactive management tool that can guide operational decisions and policy development (Berbeka et al., 2024; Boumaiza, 2025). When properly implemented, environmental accountability systems not only ensure regulatory compliance but also create competitive advantages by building trust with eco-conscious travelers and meeting the requirements of sustainable investment criteria (Ariffin et al., 2025; Hikal et al., 2025). The transition toward meaningful environmental accountability represents a critical step in aligning the tourism industry with global sustainability goals while maintaining economic viability in an increasingly eco-aware marketplace.

Methods

This study used a quasi-experimental design to test the effectiveness of blockchain technology in improving environmental accountability in sustainable tourism reporting. The study involved two groups of subjects: a treatment group consisting of tourism businesses that implemented a blockchain-based reporting system, and a control group that continued to use traditional reporting methods. Participants were selected using a stratified random sampling technique to ensure a balanced representation of various tourism sectors, including hotels, tour operators, and tourist attractions, and businesses ranging in size from SMEs to large corporations in

Table 1. Operational Definition of Variables

Variable	Operational Definition	Measurement Criteria / Formula	Supporting Source
Reporting Accuracy	The degree to which digital records reflect actual transactions without discrepancy.	Measured by the Audit Discrepancy Rate: $\frac{\text{Disputed Transactions}}{\text{Total Transactions}} \times 100\%$.	Adapted from (Chen & Bellavitis, 2020)
Verification Time	The total duration required to validate a transaction or audit entry.	Timestamp Rules: Calculated from the moment a transaction is initiated until it reaches final consensus/block confirmation.	(Zhang et al., 2023)
Stakeholder Trust	The perceived reliability and integrity of the system by internal and external users.	Measured using a 5-point Likert Scale focusing on transparency, immutability, and data security.	Adapted from (Luo & Tang, 2023)
Operational Efficiency	The optimization of resources and costs in managing business processes.	Measured by the Reduction in Manual Reconciliation Costs and the 2.8:1 ROI metric.	(Hald & Kinra, 2019)

Table 2. Measurement and Economic Impact of Smart Contracts

Category	Component / Metric	Value / Specification
Economic Performance	Audit Cost Reduction	\$420
	Return on Investment (ROI)	2.8:1
Sampling & Scale	Initial Sample Size (n\$)	30 respondents
	Sampling Method	Stratified Random Sampling
Internal Consistency	Item-Total Correlation	> 0.30
Construct Validity	Analytical Method	Confirmatory Factor Analysis (CFA)
	Convergent Validity (AVE)	> 0.50
	Discriminant Validity	Confirmed (Fornell-Larcker/Cross-loadings)

Bali. The treatment and control groups were determined through a structured voluntary adoption procedure. Organizations in the treatment group were those that actively integrated blockchain technology into their operations during the study period, while the control group was selected through a matching technique based on industry profile and business scale to minimize selection bias. The independent variable in this study was blockchain technology implementation, while the dependent variables measured included reporting accuracy, verification time, stakeholder trust, and operational efficiency (Pamuk et al., 2014). Instrument validity was ensured through Confirmatory Factor Analysis (CFA) to ensure that the economic impact of smart contract use was accurately measured.

The operational definition table (Table 1) provides a precise methodological framework for measuring the impact of blockchain implementation by transforming abstract concepts into quantifiable indicators. By establishing specific formulas such as the Audit Discrepancy Rate for reporting accuracy and timestamp rules for verification time, the study ensures that operational efficiencies are not merely claimed qualitatively but demonstrated through tangible cost savings and measurable ROI.

This study employed a stratified random sampling technique to recruit 60 tourism businesses in Bali, spanning the hotel sector, tour operators, and tourist attractions, ranging in scale from SMEs to large corporations. Given the quasi-experimental nature of the design, group assignment was not completely random, but rather based on their technology readiness and willingness to integrate blockchain

systems. Thirty businesses were assigned to the treatment group (blockchain users), while another 30 businesses were assigned to the control group (traditional method). To mitigate selection bias and confounding factors resulting from this non-random assignment, the researchers employed a stratified matching technique. Each business in the treatment group was matched with a business in the control group that had a similar profile in terms of industry sub-sector, number of employees, and operational volume. Furthermore, rigorous instrument testing was conducted to ensure data reliability. The validity of the Likert scale questionnaire was assessed using the Pearson Correlation Coefficient to confirm the accuracy of construct measurement, while internal consistency was ensured through Cronbach's Alpha with an alpha value of 0.7. Prior to the main data collection, a pilot test was conducted on 10 respondents outside the sample to evaluate the clarity of the instrument, thereby minimizing information bias during the research process. The test results showed that all instruments, consisting of 5 to 8 items per construct, were valid with item-total correlations > 0.30 and reliable with Cronbach's Alpha between 0.78 and 0.92 in the initial 30 respondents. Validity was further confirmed through Confirmatory Factor Analysis (CFA), which produced an Average Variance Extracted (AVE) value > 0.50 and met the discriminant validity criteria for all study variables (Table 2).

Data collection was conducted in three systematic phases: baseline assessment, intervention implementation, and post-intervention evaluation. During the baseline phase, both groups submitted sustainability reports using then-current methods to establish baseline performance metrics. The treatment group then received intensive training and access to a dedicated blockchain platform designed for environmental data recording, which integrates smart contracts for automated verification and real-time monitoring capabilities. During the six-month intervention period, researchers tracked key metrics including data discrepancies, audit costs, and reporting frequency (Crespo-Cebada et al., 2021). For quantitative data analysis, the study employed the Difference-in-Differences (DiD) method to compare changes between the treatment and control groups before and after the intervention, controlling for confounding variables. Statistical tests such as independent-samples t-tests and ANOVA were used to assess baseline equivalence, while ordinal regression and chi-square analysis were applied to test hypotheses related to improved reporting accuracy, stakeholder trust, and cost efficiency. Intervention effect sizes were measured using Cohen's d, with all analyses equipped with 95% confidence intervals and significance tests ($p < 0.05$). The results of this test validate the main hypothesis that the implementation of blockchain technology significantly improves environmental transparency and accountability in sustainable tourism reporting compared to traditional methods.

To ensure each construct has specific measurable outcomes, the main hypothesis is broken down into the following four operational hypotheses:

1. H1 (Accuracy & Transparency): The implementation of blockchain technology significantly reduces the audit discrepancy rate in sustainability reports compared to traditional reporting methods.
2. H2 (Time Efficiency): The use of a distributed ledger significantly accelerates the verification time of green transactions from the point of initiation to the final confirmation (consensus timestamp).
3. H3 (Accountability & Trust): The adoption of blockchain significantly improves the stakeholder trust score by providing a permanent and immutable audit trail.
4. H4 (Economic Impact): The implementation of smart contracts significantly reduces operational audit costs and increases the efficiency of return on investment (ROI) for tourism providers.

Sustainability Transparency: Inferred from data accessibility and the completeness of the audit trail. This is measured by stakeholders' ability to trace green claims back to their original source in real time without third-party intervention. **Environmental Accountability:** Inferred from the validation of empirical evidence. This is measured by low reporting error rates and the system's ability to prevent greenwashing through automated verification powered by blockchain protocols. By separating these hypotheses, the research moves from broad qualitative claims to rigorous statistical testing. For example, H1 and H4 directly test technical and economic effectiveness, while H2 and H3 test system performance and user perceptions. This approach allows for the use of more rigorous Partial Least Squares (PLS) or Confirmatory Factor Analysis (CFA) techniques to validate whether each indicator truly represents the intended constructs of transparency and accountability.

Result and Discussion

This table presents the results of the baseline equivalence testing conducted before the intervention to ensure that the control and treatment groups were statistically comparable (Wilmschurst & Frost, 2000). Independent Samples t-tests or ANOVA were used to compare the means of key variables between the two groups.

Table 3 explains, before implementing the blockchain intervention, a baseline equivalence test was conducted to ensure that the control and treatment groups were comparable. The results showed no significant differences between the two groups in terms of reporting accuracy (Control: $72.3\% \pm 8.5$; Treatment: $73.1\% \pm 7.9$, $p = 0.682$), verification time (Control: 14.2 ± 3.1 days; Treatment: 13.8 ± 2.7 days, $p = 0.541$), or stakeholder trust (Control: 3.2 ± 0.9 ; Treatment: 3.3 ± 0.8 , $p = 0.610$). This confirmed that any post-intervention differences could be attributed to the blockchain system rather than pre-existing disparities between the groups. Next, This table displays the Difference-in-Differences (DiD) regression results, quantifying the impact of blockchain technology on key outcome variables by comparing changes in the treatment group relative to the control group (Chen et al., 2025).

Table 4 explains, the Difference-in-Differences (DiD) analysis revealed significant improvements in the treatment group after blockchain implementation. Reporting accuracy increased by 18.6% ($p < 0.001$), verification time decreased by 9.4 days (67% faster, $p < 0.001$), and stakeholder trust rose by 1.2 points on a 5-point scale ($p = 0.002$). Additionally, audit costs dropped by \$420 due to automation, yielding a strong return on investment (ROI = 2.8:1). These findings demonstrate that blockchain not only enhances transparency

and efficiency but also reduces operational costs in sustainability reporting (Li et al., 2025).

Table 5 states that, participant interviews highlighted key themes regarding blockchain adoption. While 25 out of 30 respondents reported increased trust due to real-time data transparency, 12 noted usability challenges, particularly for non-technical staff. Additionally, 8 participants—primarily from small and medium-sized enterprises (SMEs)—expressed concerns about high setup costs potentially excluding smaller businesses (Chen et al., 2025). These insights suggest that while blockchain enhances accountability, successful implementation requires user-friendly interfaces, training programs, and financial support to ensure equitable access across the tourism sector (Capucho et al., 2025; Li et al., 2025).

The table above details the cost structure and savings underlying the 2.8:1 ROI ratio, with all values expressed in USD per company (see Table 6). Implementation costs are broken down into the initial (one-time) investment for software integration and staff training, and recurring operational costs for maintaining the cloud infrastructure. Savings of \$420 resulted from the reduction in third-party audit fees (from a standard cost base of \$1,500 to \$1,080) due to the availability of a digital audit trail automatically verified by smart contracts. With the unit of analysis at the individual tourism provider level and a six-month report review period, the model demonstrates that the efficiencies resulting from reduced manual reconciliation time and verification costs can recoup the initial investment within the first year of operation. To operationalize these recommendations, policymakers and Destination Management Organizations (DMOs) should adopt a public-private partnership (PPP) approach that provides subsidies or tax incentives for tourism SMEs to lower entry barriers in the initial phase of blockchain implementation. Tourism authorities can facilitate regulatory sandboxes and provide shared cloud-based digital infrastructure that allows small businesses to access distributed ledgers without having to build systems from scratch, supported by certified digital literacy training modules to ensure human resource readiness. Furthermore, destination management organizations can integrate this blockchain-based sustainability data into official destination marketing platforms, thereby providing competitive advantage to credible SMEs and creating an inclusive, transparent, and economically equitable tourism ecosystem.

The qualitative insights gathered from participant interviews provide a nuanced understanding of the real-world challenges and benefits associated with blockchain adoption in sustainable tourism reporting. One of the most prominent themes was trust enhancement, with 25 out of 30 stakeholders emphasizing how real-time, immutable data access significantly boosted their confidence in sustainability claims (Klamsaengsai et al., 2025). For instance, a tour operator noted, *"Seeing live updates on energy usage and waste reduction made us feel these eco-claims were credible, not just marketing fluff."* This sentiment underscores blockchain's potential to combat greenwashing by replacing opaque, self-reported data with verifiable records. However, the technology's impact on trust was not uniform—smaller businesses, particularly those with limited digital literacy, struggled to interpret blockchain-generated reports, suggesting that transparency alone is insufficient without user-friendly interfaces and training.

Another critical theme was usability challenges, cited by 12 participants, primarily managers of small hotels and local tour companies. Many described the blockchain platform as *"overly technical"* and *"difficult to integrate with existing workflows."* One hotel manager remarked, *"Our staff spent weeks just learning how to input data correctly—this isn't feasible for seasonal businesses."* These barriers highlight a

Table 3. Baseline Equivalence Testing (Pre-Test) (Independent Samples t-test/ANOVA)

Variable	Control Group (Mean ± SD)	Treatment Group (Mean ± SD)	p-value	Conclusion
Reporting Accuracy (%)	72.3 ± 8.5	73.1 ± 7.9	0.682	Groups statistically equivalent
Verification Time (days)	14.2 ± 3.1	13.8 ± 2.7	0.541	No significant difference
Stakeholder Trust (1-5)	3.2 ± 0.9	3.3 ± 0.8	0.610	Baseline parity confirmed

Source: Primary Data

Table 4. Post-Intervention Comparison (Difference-in-Differences Analysis) (DiD Regression Results)

Outcome Variable	DiD Coefficient (β)	95% CI	p-value	Effect Size (Cohen's d)	Interpretation
Reporting Accuracy (%)	+18.6	[15.2, 22.0]	<0.001***	1.45 (Large)	Blockchain significantly improved accuracy
Verification Time (days)	-9.4	[-11.2, -7.6]	<0.001***	1.12 (Large)	67% faster verification
Stakeholder Trust (1-5)	+1.2	[0.8, 1.6]	0.001**	0.89 (Medium)	Trust increased significantly
Audit Costs (USD)	-420	[-510, -330]	0.001**	1.05 (Large)	Cost reduction due to automation

**p<0.001, *p<0.01

Source: Primary Data

Table 5. Qualitative Findings (Thematic Analysis)

Theme	Representative Quotes	Frequency	Implications
Usability Challenges	"The blockchain interface was complex for non-technical staff." (Hotel Manager)	12/30	Need for better training
Trust Enhancement	"Real-time data access made us feel confident about the eco-claims." (Tour Operator)	25/30	Transparency boosts credibility
Barriers for SMEs	"High setup costs could exclude small businesses." (Local Guide)	8/30	Equity concerns in adoption

Source: Primary Data

Table 6. Cost-Benefit Analysis of Blockchain Implementation

Category	Cost/Savings Component	Specification	Unit of Analysis	Period
Implementation Cost	Software Licensing & System Integration	\$1,200 (Initial Setup)	Per Company	One-time
Implementation Cost	Staff Training & Digital Literacy	\$300 (Workshops/Manuals)	Per Company	One-time
Implementation Cost	Hardware Maintenance (IoT/Cloud)	\$50 (Cloud Infrastructure)	Per Company	Monthly
Savings Component	Reduction in Audit Fees	\$420 savings from a base audit fee of \$1,500	Per Audit Cycle	Bi-annually
Savings Component	Manual Reconciliation Labor	\$250 (Labor hours saved)	Per Company	Bi-annually
Financial Outcome	Return on Investment (ROI)	2.8:1	Per Company	12 Months

gap between blockchain's theoretical promise and its practical implementation, particularly for organizations lacking IT support. Interestingly, larger enterprises with dedicated sustainability teams reported smoother transitions, indicating that resource availability plays a pivotal role in adoption success (Gomez-Guillen & Tapias-Baque, 2024; Taufiqurrachman et al., 2024).

The third major theme, barriers for SMEs, emerged from 8 respondents who raised concerns about equity and accessibility. A local guide pointed out, "High setup costs and ongoing maintenance fees could lock out small operators, even if the system works." This aligns with broader critiques of blockchain's scalability, where energy-intensive protocols (e.g., proof-of-work) and proprietary platforms create financial hurdles. Some participants proposed hybrid models—such as subsidized pilot programs or simplified, low-cost blockchain modules—to democratize access (Durmuş Şenyapar, 2024;

Feng, 2025). These findings suggest that without systemic support, blockchain could exacerbate inequalities in the tourism sector, favoring well-funded players over smaller, community-based businesses.

This study bridges inconsistencies in previous literature by providing empirical evidence that contradictions regarding blockchain's effectiveness are often rooted in differences in digital maturity and scale of implementation, rather than in the technology itself. Through an experimental approach, this study clarifies that blockchain significantly improves environmental accountability when integrated with smart contracts that automate data validation, addressing skepticism regarding high costs versus tangible benefits. While previous studies (e.g., Galli et al., 2025) highlight the initial cost burden as a barrier, our findings demonstrate that a reduction in audit costs of \$420 per cycle and a 2.8:1 ROI provide strong economic justification for medium-scale adoption. This study

demonstrates that traveler mistrust (as high as 52% according to Booking.com data) can be significantly mitigated through blockchain's technical transparency. This provides an answer to the contradictory findings regarding whether digital technology can truly change consumer perceptions of greenwashing claims. Our findings suggest that blockchain's effectiveness in improving environmental accountability is highly dependent on the accuracy of data input (such as the use of IoT sensors), thus explaining why some previous studies relying on manual input have reported suboptimal results.

Blockchain's significant effect in improving reporting accuracy is due to its smart contracts and immutable ledger mechanisms, which technically eliminate manual intervention in data validation. However, this effectiveness is highly dependent on the integrity of the initial input. This phenomenon faces the risk of a "garbage in-garbage out" cycle, where environmental accountability collapses if sensor data or manual data entry from third parties at the point of origin is inaccurate or manipulated before entering the blockchain. In the context of SMEs with limited digital infrastructure, blockchain's benefits may be limited to administrative efficiency rather than full transparency, unlike large companies that can integrate IoT for data automation. This finding clarifies a contradiction in previous research by demonstrating that blockchain supports true accountability only when supported by strict data entry governance; otherwise, the technology becomes merely an efficiency tool without substantial information integrity.

While providing strong empirical evidence in the Bali context, this study has notable methodological limitations, particularly regarding the validity of the assignment and the potential for selection bias in experimental participants who may already have higher digital literacy than the average industry participant. The measurement validity is also limited to short-term performance indicators, thus not fully capturing the long-term impact on stakeholder trust, which is dynamic. Furthermore, generalizing the findings beyond the Bali context requires caution, given that Bali has a specific regional regulatory structure and extensive tourism support that may not be found in other destinations. Future research should test this framework in regions with varying levels of digital maturity to verify whether the strengths of digital transparency remain consistent under the pressure of weaker governance or limited technological infrastructure.

Conclusion

This study provides comparative evidence on the potential of blockchain technology to enhance environmental accountability in the tourism sector in Bali. Based on

experimental results over a six-month intervention period, improvements in reporting accuracy and verification efficiency were found compared to conventional methods within the sample tested. The transparency features and smart contract functionality within blockchain were identified as helping mitigate the risk of greenwashing at the organizational level by providing accountable data records and reducing audit costs, specifically for the entities studied. These findings provide an important contribution to the tourism governance debate regarding the tension between corporate sustainability claims and public trust, particularly in Bali. By complementing traditional reporting models with a digital transparency system, this study indicates that strengthening systemic accountability can be achieved without unduly burdening operations, although these findings should be interpreted within the limitations of the quasi-experimental group assignment and limited observation duration.

While offering a pathway to developing a more credible green reporting standard, this study identified significant implementation barriers, particularly for SMEs. Technical complexity and initial investment hindered adoption for approximately 40% of small operators in the sample, highlighting the need for a phased approach with specialized training, platform simplification, and financial incentive support. Overall, this study provides a theoretical contribution by extending the discussion of legitimacy theory to the digital space, and a methodological contribution by presenting stronger comparative evidence than previous conceptual studies. Practically, this study offers an initial roadmap for inclusive adoption through smart contract integration, demonstrating a trend toward cost-efficiency. Future implementation success will depend heavily on cross-sector collaboration to address interoperability challenges, enabling blockchain technology to serve as a foundation for a more transparent and inclusive sustainability reporting system in the tourism industry.

Author Contributions

The authors equally contributed to the present research at all stages, from the problem formulation to the final findings and solution.

Acknowledgements

The authors would like to thank all parties who supported this research, which also helped the authors do much research. This research helped increase the authors' knowledge and skills. This research will be helpful for knowledge and a better future.

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