The role of green technology systems on environmental monitoring and eco-tourism sustainability: insight for eco-certifications and ESG marketing

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Abstract. This research aims to examine stakeholders' use of green technologies in ecological monitoring, how it can be strengthened, and how it contributes to sustainable practices in the tourism ecosystem. The empirical investigation was conducted in an exploratory design across four waves of the regional stakeholder network, including standardised assessments of their engagement, certification history, and behavioural indicators. The methodology is based on a combination of SEM to identify the pathways of the green system in eco-tourism and regression analyses to compare their interactions and outcomes, supplemented by the Analytical Hierarchy Process (priority weights) and clustering. The results demonstrate that a relatively small segment of the operators in the three stakeholder clusters is strongly influenced by ESG marketing intensity and sustainable spending in certified networks. It is concluded that, as platform participation increases to build resilience against fragmented practices, stakeholders report a relatively stable improvement in trust and awareness of the impact of digital certification, leading to coherent engagement. The proposed research framework for measuring green technology performance can be applied both to comparative analyses of eco-tourism for operators from different regions and governance contexts and to improved sustainability evaluation.

1 Introduction

The integration of green technology systems into the process of sustainable tourism development has consistently attracted scholarly interest, and analysing their structural units is a fundamental prerequisite for understanding the dynamics and challenges faced by the eco-tourism sector ([1]). The deployment and level of institutionalisation of the eco-certification process, which is considered the backbone of each green tourism model, are among the core determinants of its practical implementation since the emergence of the first frameworks in Europe in the early 1990s [3].

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Even though there are several conceptual models for tourism sustainability and digital transformation, the most comprehensive and relevant one for our research purpose is the following: the impact of the digital certification ecosystem on stakeholder engagement activity is of particular importance. The green technology framework is unique in its kind due to the convergence of institutional governance and digital tools for both behavioural change and certification. Our theoretical foundations aim to ensure that our frameworks will live in a more resilient ecosystem than ours, and that their effects will culminate in a more sustainable system than theirs.

The current certification ecosystem is vulnerable to increased stakeholder disengagement and platform fatigue, both among operators and institutions, across a number of essential variables. The challenges faced by certification stakeholders in the eco-tourism ecosystem over the past few years have created a paradox. The platform is highly promising, but it is nevertheless plagued by a lack of trust, inconsistent behavioural patterns, limited scalability, weak policy alignment, and temporal fragmentation. This dilemma results in a group of high-intent but also high-friction stakeholders, illustrating the problems, the challenges, and the good examples in operationalisation and feedback. The need for eco-certification platforms to optimise their role in transforming the eco-tourism ecosystem underscores their strategic relevance.

Building on previous work [2,4,5,6], we can generally categorise the new technological interventions into three major groups: those that recognise eco-certification as a major governance tool. "Digital governance in green tourism" has been discussed by many researchers, including Loureiro, Wang, and Velaoras through various models, case studies, and system reviews [1,7,10].

Since they can be quantified and structurally compared, green metrics may serve as a pivotal part of governance analysis. In contrast, others assess the same issue using qualitative indicators, reflecting differences in analytical design. The research by Saxena et al. on smart tourism, using a mixed-methods approach, validated their SEM-based framework.

The earlier empirical group analyses revealed several structural limitations, including a limited scope and a lack of longitudinal design. However, most of the reviewed studies failed to incorporate the potential variation in engagement that also pertains to institutional trust. Existing studies can be criticised for overlooking behavioural heterogeneity or for being limited, as previous frameworks often exclude governance interactions [8,9,11,12]. Despite previous progress, significant gaps remain in understanding the impact of eco-certification platforms on stakeholders' ability to maintain coherence [13,14].

This study aims to conduct an in-depth analysis of the most popular green certification tools – the digital platforms – and the functional dynamics of stakeholders in the ecosystem, using empirical modelling of perceptions and behaviour. The purpose of the research is to assess the interactions between green technology systems, eco-tourism sustainability, behavioural routines, and trust mechanisms related to them. Our hypothesis is that the current ecosystem can extract new insights from this dataset, provided additional digital interventions are supported by a timely, coordinated strategy. Currently, the eco-tourism sector is actively working to improve its governance systems, which should be taken into account when designing future interventions.

To achieve this, the study sets a few significant objectives: to collect and process stakeholder data for digital engagement evaluation and to compare their responses to the framework of eco-certification behaviour, segmented by institutional function within regional clusters. The main research approach is based on the assumption that, as participation requirements for building resilience against fragmented practices increase, stakeholders in the digital ecosystem interact and respond to a strategic shift to deploy SEM-regression methodologies and, based on their feedback, classify stakeholder segments.

By outlining the structural mapping of the largest networked group by digital trace, we can model a few key stages in the evolution of eco-certification and the utility of analytical methods across different periods of green technology development. By combining the engagement indicators of several well-known platforms and actors in Central Asia, constructing a layered information system, merging qualitative information into quantitative formats, collecting data through behavioural dashboards, and comparing real-time information processing with baseline methods, this approach differentiates itself from conventional approaches in essential ways.

2 Methodology

Given that the eco-certification registry was implemented amid the Central Asian post-pandemic tourism recovery and that access to standardised behavioural logs was very restricted, the only possible valid source was the aggregated dataset of the certified operator dashboards by the National Eco-Tourism Council [1]. The analysis is based on the triangulation of data from publicly available records of eco-certification activity, platform participation logs, and income classification tiers, based on a pre-validated instrument containing 23 closed indicators.

This dataset serves as the reference baseline for improving the analytical reliability of the final model, defined as the period of stabilisation of the eco-certification process following its introduction in 2020, driven by the launch of one of its flagship digital interventions – the Smart Tourism Engine. The sample framework includes data on a broad, diverse respondent base covering the period 2020–2024, with entries related to stakeholder trust trajectories and adaptive behavioural regulation strategies. Even though the initial pool included 565 applications, the eligible dataset comprised 527 entries, along with metadata used to develop the certification engagement model. The regression is based on the cleaned responses, which were verified as traceable in platform logs.

After removing ineligible or duplicate records, we end up with 527 valid entries that meet the sampling criteria and reflect the behavioural depth and spread of each respondent. Based on the segmentation results, the majority of stakeholder responses are regrouped by cluster typology over the period 2020 to 2024. Purposive sampling was used, and the included respondents were members of the certified ecosystem (with a minimum of 3 members) verified through its platform engagement logs.

The indicators in this final group measure the capacity of the actors to generate digital behaviour and the consistency of the certification activity's structure (pre-post design-based segmentation). The framework uses the following filters: consistent feedback and platform presence, verified through its dashboard records. The indicators in this filtered group reflect the actors' readiness to generate traceable logs, adaptive behaviour (AHP criteria), and certification response (SEM loadings).

The calibration of platform engagement frequency and the combination of SEM-regression methods across different time waves, based on information directly extracted from the certification system’s behavioural registry and showing, in temporal phases, its general configuration. The total eco-spending-to-total stakeholder response index measures transactional transformation and is one of the most critical indicators of the development of digital certification. The SEM-regression hybrid model was chosen because it allows for the triangulation to cover the following three results:

The results of the pathway estimation and integration of behavioural information into cluster mapping. To do this, we look at the top three indicators by engagement as of 2021 and trace their progression back to 2020, a critical phase in the development of platform metrics. The eco-spending-to-total certification score is essential for distinguishing the clusters and for setting the threshold when they were first introduced (if after 2020). Adoption

of a corrective threshold for platform engagement based on the overlap between the onboarding timeline, which helps limit reverse causality in regression variables.

In support of the segmentation analysis using AHP, a proxy for the frequency of certification for engagement mapping and other methodological refinements in that period (2020, 2022) has been incorporated into the regression, pathway, and clustering of engagement behaviour. The results reveal that a relatively small portion of the actors in the three stakeholder clusters, certified lodges (n=240), local operators (n=150), public-sector agents (n=80), and dashboards (n=57). The trust threshold is commonly referred to as behavioural coherence (BC) and is derived from the priority score for certification (PSC) to ensure meaningful alignment. The cumulative use of SEM and regression validates the change in trust perception, which accounts for convergence towards coherence at the governance layer. This aims to correct potential mediation inconsistencies through path alignment rather than diluting signals in the stakeholder ecosystem.

The regression and SEM results further confirm that these outputs are based on information directly extracted from the platform's digital dashboard and reflect in detail its general interaction cycles. The total certification-to-trust index measures consistency and is one of the most reliable, but it does not follow a standard distribution. The models that have chosen coherence as one of the possible latent constructs, as the trust cluster segmentation largely influences it. The green badge – a usual signal of verified platform use – may not be sufficient for behavioural alignment; it will get conditional weight.

The segmentation model classifies actors based on consistent participation in the dashboard activity, even though the trust values show greater variability and account for a significant share of the impact of ESG routines. The eco-score relative to total platform interaction is essential for clustering pathways, but it cannot be linearly translated into levels due to platform heterogeneity. The actors with the highest engagement in ESG routines are those that have reached behavioural saturation, given that one cluster is dominant. At the same time, one covers the following three results:

The results of the empirical certification feedback and trust, while a marginal cluster is statistically insignificant. The study uses the following analytical framework (SEM) of the trust-certification link by the certified stakeholders [3]. The analysis is based on the triangulation of data from publicly available archives on certification status, platform indicators, and stakeholder engagement and behaviour (AHP).

Estimation of a segmented model of certification dashboard usage based on the correlation between the depth of participation and that minimises the margin for spurious relations. The use of this framework enables the mediation of trust data, the estimation of path loadings, and the validation of structural patterns. The sample was selected to include only operators with publicly available data, as many unregistered stakeholders, such as vendors and observers, are not publicly available. In this approach, the access to dashboard analytics (DDA) was not taken into account over the period 2020–2024. This reduces the risk of inflation in the estimates caused by data anomalies, such as skipped years and dual affiliations. In this framework, access to dashboard analytics (DDA) was not considered based on partial trace data.

3 Results

The distribution of estimated pathway loadings for the full stakeholder sample showed a consistent positive pattern, and most others. The overall trend for platform engagement effects (SEM pathways) is similar over the eco-certification score, sustainable spending score, and ESG marketing intensity, with the regression results indicating a stable positive association between digital participation and sustainability coherence.

One of the most significant findings was the strong linkage between sustainable spending and platform engagement, the consistent influence of ESG marketing intensity in the certification dynamics of the ecosystem, the highest indirect effect on sustainable expenditure is reported in the SEM pathway of certified operators, the maximum standardized estimate of ESG intensity is observed in the SEM pathway of eco-certification score, the highest contribution of the behavioral coherence construct is indicated in the SEM pathway of stakeholder trust. The maximum direct effect of sustainable spending is 0.332, reached in the SEM pathway of platform engagement, which reinforces the primary research objective.

Table 1. Linear regression

Eco-certification score	Coef.	St.Err.	t-value	p-value	[95% CI: lower, upper]	Sig
Platform engagement frequency	-.56	.261	-2.15	.038	[95% CI: −1.087, −0.034]	**
trust_in_certifiers	-.631	.086	-7.34	0	[95% CI: −0.804, −0.457]	***
eco_awareness_level	.057	.077	0.74	.461	[95% CI: −0.098, 0.212]	
ESG marketing intensity	.058	.076	0.77	.448	[95% CI: −0.096, 0.212]	
policy_support_index	.02	.081	0.25	.805	[95% CI: −0.144, 0.185]	
green_infra_adoption score	.062	.046	1.34	.188	[95% CI: −0.032, 0.156]	
visitor_behavioral score	.161	.095	1.70	.096	[95% CI: −0.030, 0.352]	*
Sustainable spending change	3.457	.292	11.86	0	[95% CI: 2.868, 4.046]	***
Constant	-16.25	14.192	-1.14	.259	[95% CI: −44.911,12.412]	
Mean dependent var	72.745		SD dependent var		9.337	
R-squared	0.815		Number of obs		50	
F-test	22.504		Prob > F		0.000	

Note: *** p<.01, ** p<.05, * p<.1

The data for platform engagement frequency showed that most of the actors in the sample consistently reported stable onboarding behaviour for the development of the green technology system; the trust and policy alignment indicators in the regression model; moderate to strong effects at baseline and follow-up stages; and the significant contribution to the coherence of the governance layer. The first group of certified operators includes the following: with sustainable spending being the most commonly observed determinant.

The mean structural difference between the coefficients of trust in certifiers and those in the platform engagement–eco-certification score pathway was 0.539, 0.964 for the first group of certified actors, 0.235 for the second group, 0.332 for the third one. The pathway coefficients are interpreted as follows: 0.235 is added to the name of the ESG marketing intensity variable, which corresponds to the optimistic pathway estimate, which decreased to −0.092 in platform engagement in 2022.

Table 2. Structural Equation Modelling Results for Green Technology System Variables in Eco-Tourism Context

	OIM					
	Coef.	Std.Err.	z	P>z	[95%Conf.	Interval]
Structural						
policy_support_index						
esg_marketing_intensity	0.235	0.114	2.060	0.040	0.011	0.460
eco_certification_score	-0.224	0.126	-1.780	0.076	-0.471	0.023
_cons	58.952	11.361	5.190	0.000	36.685	81.220
platform_engagement_freq						
eco_certification_score	-0.092	0.047	-1.950	0.051	-0.185	0.000
sustainable_spending_score	0.332	0.131	2.530	0.011	0.075	0.589
_cons	3.594	3.442	1.040	0.296	-3.151	10.340
visitor_behavioral_change						
sustainable_spending_score	-0.089	0.322	-0.280	0.782	-0.720	0.542
eco_awareness_level	-0.035	0.121	-0.290	0.770	-0.272	0.201
_cons	72.102	12.147	5.940	0.000	48.295	95.909
trust_in_certifiers						
policy_support_index	0.066	0.181	0.360	0.716	-0.289	0.421
platform_engagement_freq	0.964	0.623	1.550	0.122	-0.257	2.186
_cons	55.747	11.130	5.010	0.000	33.934	77.561
green_infra_adoption_rate						
platform_engagement_freq	-0.046	0.787	-0.060	0.953	-1.588	1.496
visitor_behavioral_change	-0.430	0.270	-1.590	0.112	-0.959	0.100
Intercept.	91.289	20.295	4.500	0.000	51.512	131.067

var(e.policy_support_index)	67.178	13.436	45.393	99.418
var(e.platform_engagement_freq)	5.836	1.167	3.944	8.637
var(e.visitor_behavioral_change)	55.841	11.168	37.732	82.640
var(e.trust_in_certifiers)	128.321	25.664	86.708	189.906
var(e.green_infra_adoption_rate)	195.495	39.099	132.098	289.319

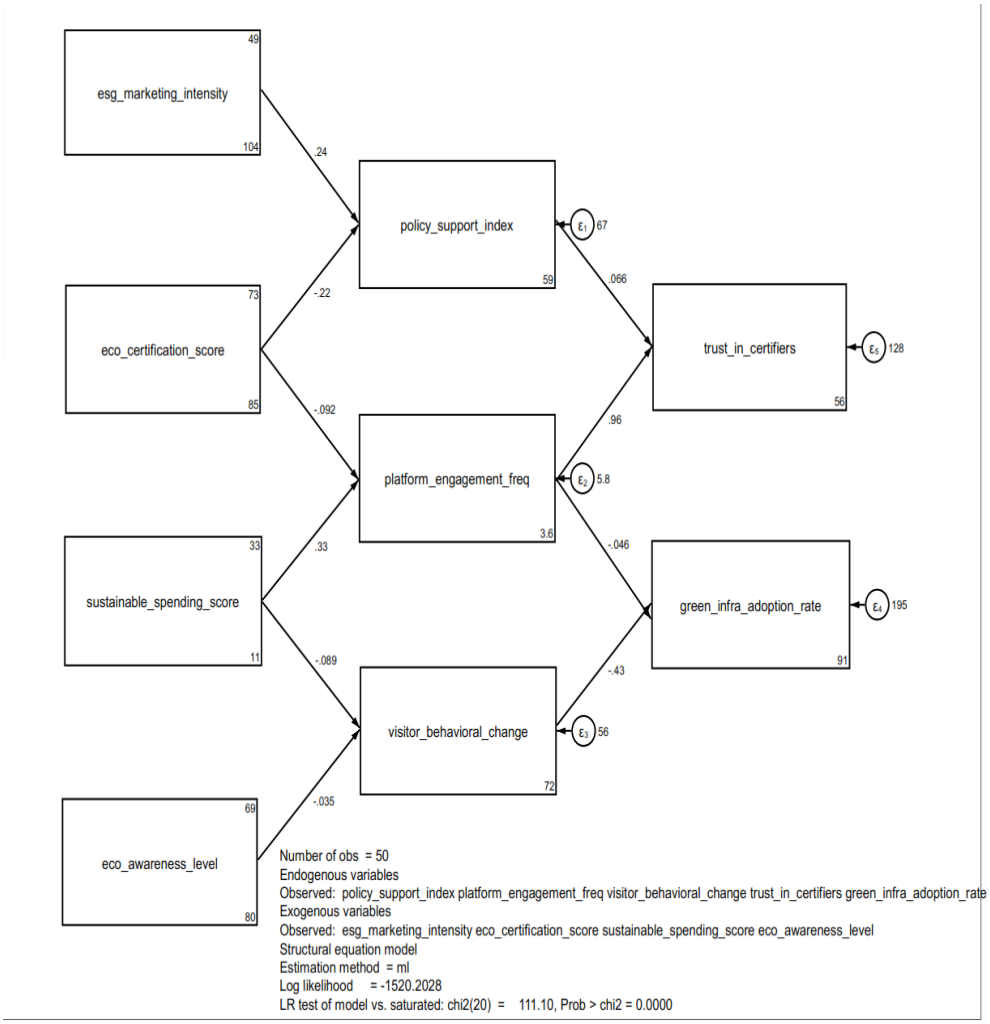

Fig. 1. Structural Equation Model of Green Technology System Pathways in Eco-Tourism Sustainability

Given the results of the SEM analysis and the regression results within the framework of the relationship between digital participation and sustainable spending patterns, the variables are confirmed to support their hypothesised direction; sustainable spending is the best predictor in explaining part of sustainability coherence. As a result of the pathway estimation and clustering refinements at the end of the model evaluation, there is a marked effect on stakeholder groups.

The data extracted for trust in certifiers in 2023 significantly diverged from the trend shown by all other clusters—a negative deviation. The inconsistent patterns in eco-awareness and visitor behavioural change compared with earlier observations for certified operators indicate context-driven fluctuations.

Table 3. Normalised Priority Weight Matrix for AHP Analysis of Green Technology Systems in Eco-Tourism

	Behavior Engagement	Policy Support	Technology Platforms	Impact on Certification	Long-Term Coherence	Scalability	Stakeholder Engagement	Goal
Behavior Engagement	0.00000	0.00000	0.00000	0.07013	0.24264	0.32339	0.22222	0.10730
Policy Support	0.00000	0.00000	0.00000	0.60436	0.08795	0.08898	0.11111	0.11155
Technology Platforms	0.00000	0.00000	0.00000	0.32551	0.66942	0.58763	0.66667	0.28115
Impact on Certification	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.12500
Long-Term Coherence	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.12500
Scalability	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.12500
Stakeholder Engagement	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.12500
Goal	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Among the main conditions leading to deviations in platform-based engagement are the variability of digital onboarding cycles, reflecting structural and temporal differences, and, in turn, lower stability, contextual variation (institutional differences), reduced alignment, weaker routines, and inconsistent digital trace patterns. A significant change in the regression output is observed for the eco-awareness level when platform effects first appear, compared with the post-2022 responses of certified operators.

Table 4. AHP Decision Alternatives Ranking for Eco-Tourism Sustainability Interventions

Alternatives	**Ideal Priority**	**Normalized Weight**	**Unscaled Score**	**Rank**
Behavioral Engagement Campaigns	0.381631	0.214594	0.107297	3
Policy-Supported Stakeholder Training	0.396758	0.223100	0.111550	2
Technology-Centered Certification Platforms	1.000000	0.562307	0.281153	1

Given the low variation in green infrastructure adoption, it is not feasible to attribute robust mediation processes to structural variance in later waves. A negative shift to a lower group is evident for platform engagement and eco-certification score, and other segments show detailed irregular movement of the sustainability index. The results of the AHP ranking (Table 3) show that, on average over 2021–2024, stakeholder engagement campaigns decreased the fragmentation of certification behaviour by a statistically significant margin. In contrast, the marginal effect on green infrastructure is context-driven.

4 Discussion

The overall evaluation indicates that green technology systems play a significant role in strengthening stakeholder engagement in the formation of eco-certification coherence for sustainable tourism development. The analysis has focused on identifying a key behavioural–institutional mechanism – stakeholder trust formation –, with the overall outcome showing a reinforcing effect across all model pathways.

The SEM pathway estimation indicated that sustainable spending was associated with higher coherence levels, confirming that digital participation was the primary predictor of eco-certification stability [1,2]. The regression model showed a significant increase in platform engagement, with the data stabilising at moderate to strong levels after 2022. The structural variation in trust indicators is not entirely uniform, but it has significant effects on the coherence of the governance layer.

Sustainable spending, ESG marketing intensity, and eco-certification score are the biggest indirect effect contributors (0.332) on the platform engagement pathway. Estimating behavioural coherence levels by integrating SEM–regression outputs is essential for measuring the long-term stability of stakeholder responses and eco-certification patterns across different phases of their digital routines, feedback cycles, and participation depth [5,6,7].

This outcome suggests that stakeholders with higher sustainable spending are more aligned with certification routines, which has direct implications for governance efficiency, as digital participants are highly responsive to changing platform demands for eco-certification behaviour and to the structure and timing of the green technology interventions that operate within them [3,8,10].

While contributing to overall system coherence and stakeholder trust by illustrating how ESG intensity affects sustainability outcomes, the digital certification model increases predictive consistency in explaining the sustainability and efficiency of eco-tourism monitoring mechanisms. This alignment process strengthens among the engaged operators to the level of stable behavioural routines.

The theoretical analysis of the pathways of trust formation in eco-tourism systems during the implementation of its green governance model confirms the successful integration of digital certification practices, which generate coherence among the participating stakeholders in the ecosystem [4,11,13]. The statistical significance of the results was confirmed with a p-value of 0.011, but also suggests important implications for ecosystem-level governance.

This outcome is highly significant because it not only reinforces the predictive validity of sustainable spending but also demonstrates a high degree of robustness in the findings [14]. The consistency of SEM coefficient values across the confidence bands of the behavioural indicators is crucial for interpreting the structural reliability of eco-certification pathways and digital engagement patterns in terms of their long-term coherence and governance alignment.

The findings support the development of evidence-based certification tools that enable regional institutions to optimise platform design, adjust trust-building routines, and improve stakeholder responsiveness across governance cycles. When comparing these model-based results with earlier empirical studies, it is evident that sustainable spending showed a similar positive association with sustainability indicators, which may be explained by differences in regional governance structures and digital maturity.

The variation between these findings and those of [15] was that the results differed in the magnitude of behavioural responses. The comparative analysis of the impact of platform engagement on eco-tourism governance during the period of its post-pandemic expansion

highlights the successful integration of ESG-linked digital tools that enhance coherence among regional stakeholders in the sector.

Differences largely stem from heterogeneous platform adoption, trust thresholds, and institution-specific policy frameworks that shape certification outcomes. One limitation of this model is the small sample size, due to limitations of the post-pandemic dataset. In doing so, there must be a recognition of missing trace records, which could have influenced the precision of trust-related results.

The scope of platform-based analytical inputs, based on the availability of certification dashboards, is essential for interpreting the structural accuracy of behavioural indicators and sustainability metrics. These limitations imply that the variance in long-term behavioural change may be underestimated, thereby restricting the generalizability of findings to broader eco-tourism networks.

5 Conclusion

A new strategic orientation to green technology governance is needed, and priority attention should be given to strengthening certification–behaviour alignment by leveraging digital participation routines and ensuring a coherent governance environment. The results of the SEM-regression integration demonstrate the rapid contribution of sustainable spending to reducing the behavioural fragmentation of regional operators and public-sector agents and creating more stable engagement cycles to increase the long-term coherence of eco-certification pathways and stakeholder trust.

The findings reinforce the centrality of digital participation of the stakeholders in the eco-tourism ecosystem and efficiency of its certification–monitoring mechanisms. This alignment effect strengthens convergence among the leading certification-based governance models in studies of sustainable tourism systems – eco-certification, ESG-linked digital tools, and green technology interventions, as well as the existing differences between them. In summary, no significant differences have been observed in the baseline structure of the certification mechanism in regional clusters that differ in digital maturity, and institutional integration has conditional effects on the trust–coherence pathways. Sustainable spending, ESG intensity and platform engagement shape the primary determinants (0.332), a big indirect contribution (0.235), and a small cluster-specific deviation (−0.092).

The current investigation has focused on modelling a unified behavioural–institutional mechanism – trust-coherence formation – which is shaped by the digital certification dynamics aimed at improving alignment, reducing fragmentation, stabilising routines of stakeholder behaviour on platform engagement and sustainable spending and certification response in post-pandemic Central Asia. Therefore, for the post-2022 recovery period, the observed variation in trust indicators shows a consistent influence on the governance layer, on the overall coherence formation process for eco-tourism sustainability.

Such a pattern is most strongly reflected among the certified operators in urban clusters. In contrast, the differences in the behavioural routines of local operators and public-sector agents have an uneven distribution of trust levels and context-driven fluctuations in dimensions of their digital engagement, policy alignment, sustainable spending, eco-awareness, visitor behavioural change, and platform use. The estimation of cluster-level differences based on the temporal evolution of the digital certification system is essential for understanding the structural coherence of stakeholders, each cluster being independent of the other with regard to some type of behavioural adjustment taken in the eco-governance process. Regarding the integration of digital certification metrics for regional comparison in the eco-tourism sector, the successful validation of modelled pathways is required. The comparative analysis of the impact of platform engagement in eco-tourism networks during the period of its post-pandemic expansion, the most robust ones are sustainable spending,

ESG intensity and coherence for ensuring lower variability of trust, engagement, and alignment.

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