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Empowering Sustainable Tourism Planning Through Penta-Helix Collaboration: Lessons from Renewable Energy Development in Indonesia

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ABSTRACT

This study examines how institutional capacity (IC) and penta-helix collaboration (PH) drive renewable energy adoption (REA) and enhance sustainable tourism (ST) performance in Indonesia's Green Canyon destination. Using an explanatory sequential mixed-methods design, the research combined surveys of 68 penta-helix stakeholders with in-depth interviews, analyzing data through PLS-SEM and thematic analysis. The findings reveal that IC significantly fosters PH and REA but demonstrates no direct effect on ST. Instead, PH serves as the crucial mediating mechanism that channels institutional strengths into both REA and ST outcomes. The adoption of solar power and electric boats emerges as a key factor in reducing emissions while strengthening the destination's eco-friendly reputation. This research provides original empirical evidence from the Indonesian tourism context, extending collaborative governance theory through the validated penta-helix mediation model. The study provides practical guidance for policymakers and tourism managers to enhance multi-stakeholder coordination and accelerate low-carbon tourism transitions in support of Indonesia's Net-Zero Emissions (NZE) 2060 targets.

1. INTRODUCTION

Sustainable tourism (ST) has become a strategic global agenda to reduce environmental impact and simultaneously improve the socio-economic welfare of communities [1]. Indonesia itself is targeting Net-Zero Emissions (NZE) by 2060, requiring a radical transformation of the tourism sector towards low-carbon practices through the use of new and renewable energy. The urgency of this transition is underscored by research showing tourism's significant vulnerability to climate change impacts, necessitating immediate decarbonization efforts [2]. The tourism sector is estimated to contribute around 8% of national carbon emissions [3]. Thus, the integration of renewable energy sources has become an important instrument in supporting the green economy agenda and the achievement of SDG 7 (Clean Energy). This alignment with sustainable development goals reflects the growing recognition that tourism must contribute to inclusive growth while addressing environmental challenges [4]. Figure 1 is an overview of the integration of renewable energy sources (SDG 7: Clean Energy) in ST.

Green Canyon in Pangandaran Regency, West Java, provides a compelling case study to examine the specific dilemma at the heart of this study. While this destination has pioneered renewable energy integration through collaboration with PLN, which includes implementing electric boat conversions, installing 5.5 kWp rooftop solar power plants, providing electric vehicle charging stations, and introducing electric stoves in SMEs [5], its progress confronts fundamental barriers that encapsulate the core challenge of Indonesia's green tourism transition. The central dilemma lies in the coexistence of technological advancement with persistent implementation barriers: institutional capacity (IC) constraints, business resistance to electric technology, and limited understanding of green energy benefits. These specific obstacles, if not systematically addressed, risk undermining the achievement of Indonesia's 2060 NZE target and represent the critical problem this research seeks to investigate [6].

These implementation challenges are not unique to Indonesia's tourism sector but reflect a broader global pattern in the transition to low-carbon technologies, which explains why this problem remains unresolved despite increasing policy attention. For instance, a parallel assessment of South Africa's automotive industry highlights strikingly similar barriers, including high upfront costs, limited infrastructure, and the need for strategic policy frameworks [7]. This persistent global pattern indicates that overcoming such hurdles requires more than political will or technological solutions alone; it demands systematic, multi-stakeholder approaches that can address the complex interplay of institutional, economic, and social factors simultaneously, a governance challenge that requires innovative collaborative frameworks [8].

Figure 1. Sustainable tourism (ST) [9]

The penta-helix approach, which involves government, business, academia, community, and media, is recognized as effective in promoting innovation and collaborative governance in various sectors, including smart city development [10], tourist village [11, 12], and post-pandemic tourism recovery [13]. The evolution of this framework from triple to quintuple helix models demonstrates its adaptability in addressing complex sustainability challenges through multi-stakeholder synergy [14, 15]. Despite the growing popularity of multi-stakeholder collaboration models such as the penta-helix, empirical evidence on their effectiveness in promoting renewable energy adoption (REA), particularly in the tourism sector, remains limited and fragmented. Previous studies have tended to examine this relationship in a fragmented manner; some focus on IC without examining the mechanisms of collaboration, while others examine collaboration without examining its ultimate impact on ST performance. This fragmentation is particularly evident in developing country contexts where institutional frameworks and collaborative governance are still evolving [16, 17]. This disconnect creates a gap in understanding how IC can be transformed through collaboration to promote green technology adoption and, ultimately, achieve sustainability. In other words, the 'black box' linking IC to ST outcomes remains unexplored.

To address this gap, this study proposes and tests an integrated conceptual model that positions penta-helix collaboration (PH) as a key mediating mechanism. We hypothesize that IC does not automatically generate ST, but must first be channeled through strong collaborative synergy among five key actors (government, business, academia, community, and media), which in turn facilitates the adoption of renewable energy. This mediation approach aligns with emerging research calling for more sophisticated governance models that can navigate the complex institutional landscapes of ST transitions [18]. Thus, the penta-helix approach is not merely an option, but rather a logical and necessary path to align IC with concrete actions. Therefore, this study aims to examine the direct and indirect effects of IC on ST performance through the mediating roles of PH and REA in the Green Canyon tourist destination, Indonesia.

The research findings are expected to contribute to the literature on green tourism governance while providing evidence-based policy recommendations to accelerate the clean energy transition and strengthen the sustainability of Indonesian tourist destinations on the global stage.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

This study is grounded in collaborative governance theory [19] and innovation diffusion theory [20], which together provide a robust framework for understanding multi-stakeholder dynamics in ST transitions. Collaborative governance theory elucidates how institutional arrangements facilitate cross-sector cooperation, while innovation diffusion theory explains the mechanisms through which new technologies like renewable energy are adopted within social systems. Recent extensions of collaborative governance emphasize the need for adaptive approaches that can address complex, multi-level sustainability challenges [8]. The penta-helix framework operationalizes these theories by specifying five key actors (government, business, academia, community, and media) whose synergy creates an ecosystem conducive to sustainable innovation [21].

Building on this theoretical foundation, we develop six hypotheses to examine the relationships between IC, PH, REA, and ST performance.

2.1 Institutional capacity and penta-helix collaboration

Grounding in collaborative governance theory [19], we posit that IC, encompassing resources, rules, and coordination structures, serves as a fundamental enabler for multi-stakeholder collaboration. Effective IC provides the necessary governance infrastructure that reduces transaction costs and creates legitimate platforms for collective action [16, 17]. Empirical studies across various sectors confirm that institutional readiness facilitates cross-sector partnerships by reducing transaction costs, establishing legitimate platforms, and providing necessary resources [22, 23]. However, limited research has empirically tested this relationship within the complex penta-helix framework in developing country tourism contexts, particularly in the renewable energy transition domain where institutional complexity is heightened [14].

We propose that IC fosters PH through three mechanisms: (1) resource provision that lowers collaboration barriers; (2) rule-setting that reduces coordination uncertainties; and (3) legitimacy creation that enhances trust among diverse stakeholders. These mechanisms collectively enable the transformation of institutional potential into effective collaborative action.

H1: IC has a positive effect on PH.

2.2 Institutional capacity and renewable energy adoption

Grounded in the Resource-Based View (RBV), IC provides the essential resources, expertise, and regulatory frameworks necessary for adopting complex innovations, such as renewable energy. The successful adoption of renewable energy technologies in tourism destinations requires not only technical capacity but also supportive institutional frameworks that can navigate regulatory complexities [24, 25]. Empirical evidence confirms that institutions with strong capacity accelerate energy transitions through targeted policies, fiscal incentives, and technical support [26]. Studies in Southeast Asia have further demonstrated that local governments with clear regulations and adequate resources significantly accelerate the adoption of clean technology [27]. However, existing research remains predominantly cross-sectional, lacking examination of the specific mechanisms through which IC translates into concrete adoption behaviors within tourism ecosystems, particularly in archipelagic developing nations like Indonesia [28].

We argue that IC enables REA through three distinct pathways: (1) policy direction that creates strategic alignment and reduces regulatory uncertainty; (2) budgetary allocation that lowers financial barriers through subsidies and incentives; and (3) regulatory enforcement that ensures compliance and standards implementation. These institutional interventions collectively create an environment that enables the integration of renewable energy.

H2: IC has a positive effect on REA.

2.3 Institutional capacity and sustainable tourism

Drawing from institutional theory, we posit that IC provides the governance frameworks and implementation mechanisms essential for achieving ST outcomes. Strong IC enables effective policy formulation, resource allocation, and monitoring systems that directly support sustainability objectives [29]. However, the relationship between institutional strength and ST outcomes is often mediated by contextual factors and implementation capabilities [17]. Previous research by Spenceley and Meyer [30] demonstrates that capable institutions create inclusive policies that strike a balance between environmental conservation and community welfare. However, empirical evidence regarding the direct IC-ST relationship remains inconclusive, with several studies suggesting this influence may be predominantly indirect through mediating variables, particularly in contexts where tourism governance involves multiple jurisdictional levels [31, 32].

We propose that IC influences ST through dual pathways: (1) directly through policy enforcement, strategic planning, and regulatory oversight; and (2) indirectly by creating enabling conditions for stakeholder collaboration and innovation adoption. The direct pathway operates through institutional leadership in setting sustainability standards and ensuring compliance, while the indirect pathway functions through capacity's role in facilitating the collaborative and technological drivers of sustainability.

H3: IC has a positive effect on ST.

2.4 Penta-helix collaboration and renewable energy adoption

Drawing from innovation ecosystem theory, PH creates a synergistic environment where diverse stakeholders collectively drive technological innovation and adoption. The quintuple helix framework emphasizes that knowledge production and innovation increasingly occur at the intersection of multiple societal subsystems [14, 15]. The integration of government, business, academia, community, and media facilitates knowledge exchange, resource pooling, and risk sharing, which are essential for the implementation of renewable energy. Empirical studies demonstrate that multi-actor partnerships significantly accelerate clean energy adoption through the complementary capabilities and shared learning of their members [21, 23]. Recent research in Vietnam further confirms that penta-helix synergy enhances low-carbon energy investment in the hospitality sector [33]. However, limited research has quantitatively examined how this collaborative dynamic specifically influences REA in developing country tourism contexts, particularly through rigorous mixed-methods approaches [34].

We propose PH drives REA through three mechanisms: (1) knowledge integration from academia that enhances technical capacity; (2) resource mobilization from business and government that reduces financial constraints; and (3) social legitimization from community and media that increases acceptance. These collaborative advantages collectively overcome adoption barriers and accelerate the implementation of renewable energy in tourism destinations.

H4: PH has a positive effect on REA

2.5 Penta-helix collaboration and sustainable tourism

Grounded in stakeholder theory and collaborative governance, penta-helix collaboration integrates diverse perspectives and resources to achieve balanced, ST outcomes. Effective multi-stakeholder collaboration has been shown to enhance destination resilience and sustainability performance through integrated planning and complementary resource mobilization [35]. The synergy among government, business, academia, community, and media enables comprehensive destination management that simultaneously addresses economic, social, and environmental dimensions. Empirical studies have demonstrated that multi-stakeholder collaboration significantly enhances destination competitiveness through improved service quality, environmental conservation, and local community welfare [31]. Recent evidence from Batu City, Indonesia, further confirms that the penta-helix framework effectively synergizes stakeholders to enhance both tourist appeal and environmental management [12]. This aligns with global trends where collaborative governance models are increasingly recognized as essential for addressing complex sustainability challenges [8].

We propose that PH enhances ST through three key mechanisms: (1) integrated planning that aligns diverse stakeholder interests with sustainability goals; (2) complementary resource mobilization that optimizes financial, human, and technical capabilities; and (3) enhanced social legitimacy that builds community support and tourist trust. These collaborative advantages enable destinations to maintain economic viability while preserving environmental integrity and ensuring social equity.

H5: PH has a positive effect on ST.

2.6 Renewable energy adoption and sustainable tourism

Grounded in signaling theory and green consumer behavior, the adoption of renewable energy serves as a credible environmental commitment that enhances destination attractiveness and competitive positioning. Tourists increasingly prefer destinations that demonstrate genuine environmental commitment through tangible actions like REA [36, 37]. The integration of clean energy technologies directly reduces ecological impact while signaling strong sustainability values to increasingly eco-conscious tourists. Empirical evidence demonstrates that destinations adopting renewable energy experience improved visitor satisfaction, enhanced market reputation, and increased economic returns through differentiated positioning [27, 36]. Recent studies have further confirmed that the implementation of renewable energy in tourism SMEs contributes to both environmental conservation and business performance [38]. This is particularly relevant in island destinations where energy costs are high and environmental footprints are visible [39, 40].

We propose that REA enhances ST through three primary mechanisms: (1) environmental impact reduction through decreased carbon emissions and resource consumption; (2) economic advantage via long-term cost savings and premium pricing potential; and (3) reputational enhancement that attracts environmentally conscious tourists and strengthens brand differentiation. These benefits collectively improve destination performance across environmental, economic, and social sustainability dimensions.

H6: REA has a positive impact on ST.

Based on the six hypotheses developed, this study proposes a conceptual model as shown in Figure 2. This model integrates four key constructs: IC, PH, REA, and ST Performance, and tests the hypothesized causal relationships among them. Specifically, this model not only examines the direct influence of IC on ST (H3), but also investigates the indirect pathways through PH (H1 and H5) and REA (H2 and H6). In addition, this model examines the role of PH in mediating the relationship between IC and REA (H4), while exploring how multi-stakeholder collaboration and green technology adoption collectively transform IC into ST performance. Based on this hypothesis, the following research model was used:

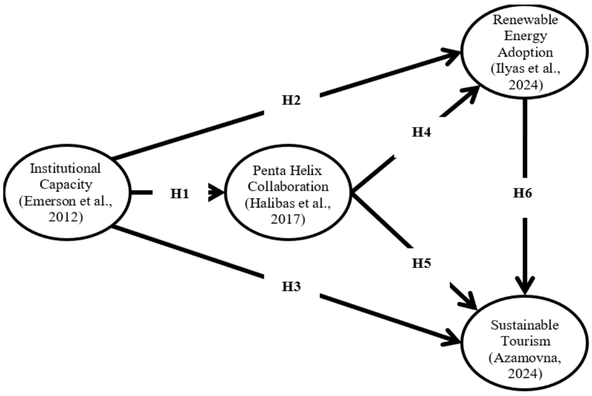

Figure 2. Research model

Thus, this research model provides a comprehensive framework for examining the mechanisms linking IC to tourism sustainability through penta-helix collaboration and REA in the context of Indonesian tourism destinations.

3. METHODOLOGY

3.1 Research design

This study employed an explanatory sequential mixed-methods design combining quantitative surveys and qualitative interviews [41, 42]. The research population included stakeholders from the penta-helix (government, business, academia, community, and media) involved in Green Canyon's renewable energy program, as well as tourists. A purposive census sampling approach captured all 64 identified penta-helix actors, supplemented by purposive sampling of four tourists (total N = 68). Purposive sampling is particularly appropriate for studying complex governance phenomena where researcher judgment is essential for selecting information-rich cases [43]. This approach ensured comprehensive stakeholder representation while maintaining methodological rigor for PLS-SEM analysis. Quantitative data from surveys tested hypothesized relationships, while qualitative interviews with 12-18 key informants provided contextual depth and explanatory insights into the statistical findings.

3.2 Data collection procedures

Data collection was conducted in two complementary phases from June to August 2025. Quantitative data were gathered using structured questionnaires with 4-point Likert scales adapted from established instruments to ensure content validity. The survey followed Dillman's [44] Tailored Design Method, using both online and face-to-face distribution to maximize response rates across stakeholder groups.

For qualitative data, semi-structured in-depth interviews were conducted with 16 key informants representing the five elements of the penta-helix framework (government, business, academia, community, and media), as well as tourists. Each interview lasted 45–60 minutes and was guided by an interview protocol developed based on preliminary quantitative findings, following the principles of explanatory sequential design [45]. This methodological triangulation enhances validity by capturing both the breadth of statistical patterns and the depth of lived experiences [46]. All interviews were audio-recorded with consent and transcribed verbatim.

Participants were selected through purposive sampling, focusing on individuals actively involved in ST governance and renewable energy initiatives in Green Canyon. Data collection followed the principle of theoretical saturation: after the 14th interview, recurring themes were observed, and two additional interviews confirmed thematic stability. No new themes emerged at the 16th interview.

The distribution of informants (Table 1) reflects stakeholder involvement in destination governance. Government representatives formed the largest group due to their regulatory and coordination roles. While tourists are not formally part of the penta-helix framework, their inclusion allowed the study to capture demand-side evaluations of sustainability performance.

Table 1. Distribution of informants

Stakeholder Group	Number of Informants
Government	5
Business	2
Academia	2
Community	3
Media	2
Tourists	2
Total	16

3.3 Measurement instruments

All constructs were measured using validated scales adapted from previous studies to ensure content validity. IC was assessed using six items [19], measuring resource availability, coordination structures, and regulatory frameworks. The PH employed five items [21] to evaluate synergy, communication, and mutual benefits among stakeholders. REA utilized six items adapted from Ilyas et al. [47] to assess the intensity of technology implementation and utilization. ST Performance was measured using six items from Azamovna [48], which evaluated the economic, environmental, and social dimensions.

All instruments used 4-point Likert scales (1 = Strongly Disagree to 4 = Strongly Agree) to minimize central tendency bias and encourage directional responses [49]. The use of 4-point scales prevents neutral responses and forces directional opinions, thereby increasing measurement precision [50]. The survey instrument was first developed in English, then translated into Indonesian using back-translation procedures to ensure conceptual equivalence [51]. A pilot test with 15 respondents confirmed the clarity, relevance, and appropriateness of the completion time (15-20 minutes), leading to minor wording adjustments for the local context.

3.4 Data analysis

Quantitative data were analyzed using PLS-SEM with SmartPLS 3.2.9 software. This approach was chosen because it is suitable for predictive research models with a relatively small sample size (68 respondents) and complex variables. The analysis was conducted in two stages: (1) model measurement (outer model); and (2) structural model testing (inner model) to examine the relationships between variables using path coefficient values, t-statistics, and p-values through the bootstrapping procedure [52].

To examine the mediating effects proposed in the structural model, a bootstrapping procedure was employed using SmartPLS. Following established PLS-SEM guidelines, significance testing was conducted using 5,000 bootstrap resamples with bias-corrected and accelerated (BCa) confidence intervals. Indirect effects were considered statistically significant when the p-value was below 0.05 and when the corresponding 95% confidence interval did not include zero. This approach allows for robust estimation of mediation effects without assuming normal distribution of the sampling distribution.

Qualitative data were analyzed using thematic analysis [53] framework through NVivo 12. The process involved familiarization with data, generating initial codes, searching for themes, reviewing themes, defining themes, and producing the report. Thematic analysis provides a flexible yet systematic approach for identifying, analyzing, and reporting patterns within qualitative data [46]. Data triangulation was employed by comparing quantitative and qualitative findings to enhance validity, while member checking ensured accuracy of interpretations through participant feedback.

Integration of mixed methods followed the explanatory sequential design, where quantitative results informed qualitative probing, and qualitative findings provided explanatory depth to statistical relationships, creating a comprehensive understanding of the phenomenon. This integration approach leverages the complementary strengths of quantitative and qualitative methods to provide a more complete understanding of complex research problems [34].

4. RESULT

4.1 Respondent characteristic

In this study, the respondents were penta-helix elements involved in the renewable energy program in Pangandaran Regency Tourism. The data from the analysis unit is explained in order to provide a comprehensive description of the research results. Table 2 is the descriptive data of the respondents.

Table 2. Respondent characteristic

No.	Characteristic	Description	Distribution	
			Frequency	Percentage (%)
1.	Gender	Male	36	52.94
		Female	32	47.06
		Amount	**68**	**100.00**
2.	Age	< 25 years	5	7.35
		26-35 years	37	54.41
		36-45 years	15	22.05
		46-55 years	9	13.24
		> 56 years	2	2.95
		Amount	**68**	**100.00**
3.	Education	Middle School	1	1.48
		High School	24	35.29
		Associate's Degree	12	17.64
		Bachelor's Degree (S1)	24	35.29
		Magister (S2)	7	10.30
		Amount	**68**	**100.00**
4.	Penta-Helix	Local Government	2	2.95
		Department of Tourism	6	8.90
		Department of Communication and Information Technology	6	8.90
		Village Administration	4	5.88
		Entrepreneurs	9	13.23
		Academia	6	8.90
		Pokdarwis / Tourism Association / Business Group	10	14.70
		Community / NGO / Community Organization	2	2.95
		Pers/ Media Online/ Influencer	4	5.88
		BUMN (PLN/Bank/ business)	5	7.35
		Local Community	10	14.70
		Tourists	4	5.88
		Amount	**68**	**100.00**

Source: Research results (2025)

Based on the table, the gender composition is relatively balanced between men (52.94%) and women (47.06%), reflecting inclusive cross-gender participation. In terms of age, the majority of respondents are in the 26–35 age range (54.41%), indicating the dominance of the productive age group, which generally has a high adaptive capacity to innovation [20]. In terms of education, most respondents had a middle to upper-class background, with 35.29% having a high school education or equivalent and 35.29% having a bachelor's degree. This relatively high level of education has the potential to support renewable energy literacy and understanding of ST policies [54].

The distribution of the penta-helix elements confirms the collaborative approach. The largest groups come from Pokdarwis/Tourism Associations/Business Groups (14.70%) and the surrounding community (14.70%), followed by MSMEs/entrepreneurs (13.23%). The representation of academics/researchers (8.9%), relevant government agencies, state-owned enterprises, media, and tourists adds a cross-sector perspective. The involvement of these diverse actors is in line with the concept of collaborative governance, where the successful implementation of renewable energy requires multi-stakeholder participation [22]. Meanwhile, balanced representation of the penta-helix elements reflects the principle of collaborative governance, which requires the involvement of government, business, academia, community, and media to achieve sustainable development goals [31]. The diversity of respondents supports the validity of findings related to factors for successful renewable energy implementation at Green Canyon.

4.2 Measurement model assessment

We used SmartPLS software to analyze the data. Researchers referred to Chin in Ghozali for construct reliability tests measured by Cronbach's alpha and composite reliability. Variables are considered reliable if they have a Cronbach's alpha value above 0.60 and composite reliability above 0.70. Meanwhile, an adequate average variance extracted (AVE) value for measuring validity is 0.50 [55].

Overall, Table 3 shows that each variable indicator has an outer loading value of more than 7, except for the REA2 indicator. However, Chin in Ghozali argues that values between 0.5 and 0.6 are considered sufficient to meet the requirements [55]. Based on the recapitulation of the outer model analysis results, the data processing output shows that all outer model criteria have been met. Therefore, it can be concluded that the research data has good validity and reliability, and the research process can proceed to the next stage.

4.3 Hypothesis testing

Hypothesis testing was assisted using the Smart-PLS application. To see the results of the hypothesis test in the application, the t-statistic or p-value was examined. If the calculated t-statistic was greater than 1.96 (t-table) or the test p-value was less than 0.05, there was a significant effect between variables. In this study, the confidence level is 95% for the estimated path coefficient parameters. Table 4 shows the results of the hypothesis testing.

The structural model results, depicted in Figure 3, reveal the path coefficients and significance levels for the hypothesized relationships. PLS-SEM analysis revealed significant relationships for five of the six hypothesized paths. The visual representation in Figure 3 clearly illustrates how IC serves as a foundational driver that primarily influences ST through mediating mechanisms rather than through direct effects.

As shown in Figure 3, IC demonstrated strong positive effects on PH ($\beta = 0.596$, $p < 0.001$) and REA ($\beta = 0.540$, $p < 0.001$), supporting H1 and H2. However, the direct path from IC to ST was non-significant ($\beta = -0.074$, $p = 0.650$), leading to rejection of H3. PH significantly influenced both REA ($\beta = 0.312$, $p = 0.030$) and ST performance ($\beta = 0.426$, $p = 0.013$), supporting H4 and H5. Finally, REA positively affected ST ($\beta = 0.461$, $p = 0.010$), supporting H6.

Table 3. Outer model analysis

Variabel	Items	Outer Loading	Cronbachs Alpha	rho_A	Composite Reliability	AVE
Institutional Capacity (IC)	IC1	0.814	0.918	0.923	0.936	0.710
	IC2	0.791				
	IC3	0.921				
	IC4	0.865				
	IC5	0.816				
	IC6	0.843				
Penta-Helix Collaboration (PH)	PH1	0.813	0.942	0.946	0.956	0.814
	PH2	0.913				
	PH3	0.916				
	PH4	0.920				
	PH5	0.943				
Renewable Energy Adoption (REA)	REA1	0.878	0.900	0.905	0.924	0.670
	REA2	0.682				
	REA3	0.817				
	REA4	0.828				
	REA5	0.878				
	REA6	0.814				
Sustainable Tourism (ST)	ST1	0.838	0.897	0.911	0.920	0.658
	ST2	0.788				
	ST3	0.864				
	ST4	0.824				
	ST5	0.826				
	ST6	0.717				

Source: Research results (2025)

Table 4. Hypothesis testing (direct effect)

Hipotesis	Path Coefficient	T Statistics (|O/STDEV|)	P-Values	Confidence Intervals (2.5%)	(97.5%)	Decision
H1	0.596	5.380	**0.000**	0.361	0.789	Significant
H2	0.540	3.617	**0.000**	0.158	0.767	Significant
H3	-0.074	0.455	**0.650**	-0.403	0.239	Not Significant
H4	0.312	2.171	**0.030**	0.075	0.633	Significant
H5	0.426	2.498	**0.013**	0.038	0.664	Significant
H6	0.461	2.570	**0.010**	0.124	0.807	Significant

H1 = IC → PH
H2 = IC → REA
H3 = IC → ST
H4 = PH → REA
H5 = PH → ST
H6 = REA → ST

Source: Data processed by researchers (2025)

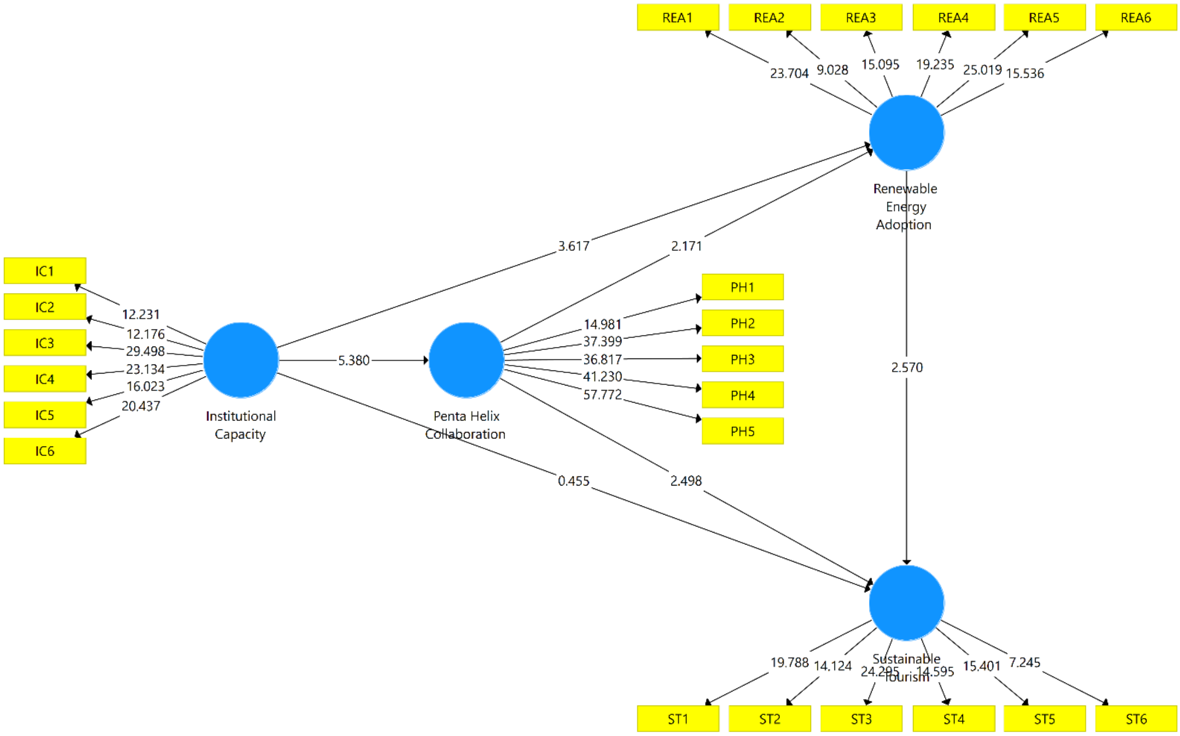

Figure 3. Path model in SmartPLS
Source: Smart-PLS Output (2025)

Table 5. Specific indirect effect

Indirect Path	Path Coefficient	T Statistics (|O/STDEV|)	P-Values	Decision
IC → PH → ST	0.254	2.711	**0.007**	Significant
IC → REA → ST	0.249	2.114	**0.035**	Significant
IC → PH → REA	0.186	1.677	**0.094**	Not Significant
PH → REA → ST	0.144	1.377	**0.169**	Not Significant
IC → PH → REA → ST	0.086	1.085	**0.278**	Not Significant

Source: Data processed by researchers (2025)

The indirect effects analysis (Table 5) demonstrates that IC affects ST through multiple indirect pathways. Specifically, the indirect effect through PH (IC → PH → ST) is positive and statistically significant ($\beta = 0.254$, $t = 2.711$, $p < 0.01$), highlighting the importance of collaborative governance in translating IC into ST outcomes. In addition, IC also influences ST indirectly through REA (IC → REA → ST) ($\beta = 0.249$, $t = 2.114$, $p < 0.05$), indicating that energy transition mechanisms complement collaborative arrangements.

By contrast, the indirect effect of IC on REA through PH (IC → PH → REA), the indirect pathway from PH through REA to ST (PH → REA → ST), and the serial mediation pathway (IC → PH → REA → ST) are not statistically significant. These results suggest that the mediating mechanisms operate in parallel rather than sequentially.

The total effects analysis (Table 6) reveals that IC has a strong and statistically significant overall effect on ST ($\beta = 0.514$, $t = 4.733$, $p < 0.001$), despite its non-significant direct effect. This finding indicates that the influence of IC on ST operates primarily through indirect mechanisms. In addition, IC demonstrates a significant total effect on REA ($\beta = 0.725$, $p < 0.001$), while PH also exhibits a strong total effect on ST ($\beta = 0.570$, $p < 0.001$). These results reinforce the central role of collaborative governance and energy transition pathways in the proposed model.

Table 6. Total effect

Indirect Path	Path Coefficient	T Statistics (|O/STDEV|)	P-Values	Decision
IC → ST	0.514	4.733	**0.000**	Significant
IC → REA	0.725	10.895	**0.000**	Significant
PH → ST	0.570	5.092	**0.000**	Significant

Source: Data processed by researchers (2025)

The structural model exhibited adequate explanatory power with R^2 values of 0.355 for PH, 0.482 for REA, and 0.507 for ST performance, indicating that the model explains substantial variance in the endogenous constructs. The blindfolding procedure confirmed predictive relevance with Q^2 values above zero for all endogenous variables.

Unexpected Finding: The non-significant direct relationship between IC and ST (H3) emerged as a noteworthy finding, clearly visible in Figure 3 as the weakest path, suggesting that institutional strengths alone are insufficient for achieving sustainability outcomes without effective collaboration and technology adoption mechanisms.

4.4 Qualitative findings: Explaining the statistical relationships

Thematic analysis of interview data with 16 key informants revealed three key mechanisms that elucidate the statistical relationships observed in the quantitative model, providing rich contextual understanding of how IC, collaboration, and REA interact to drive ST.

Theme 1: Organic Collaboration Amidst Institutional Constraints

Contrary to expectations, interview data revealed that PH emerged organically despite the absence of formal institutional platforms. A local business owner explained: "We started working together because we saw the practical benefits of renewable energy for our operations. The collaboration grew from shared interests rather than government-led initiatives." This insight provides crucial context for the strong quantitative relationship in H1 ($\beta = 0.596$), suggesting that IC may facilitate collaboration indirectly rather than directly. A community leader noted: "While there was no formal platform, the local government's willingness not to obstruct our efforts created space for collaboration to flourish."

Theme 2: Grant-Based Implementation with Collaborative Value-Addition

Interview data revealed that REA was primarily driven by grants from PLN, with PH adding crucial implementation value. A tourism operator explained: "PLN provided the electric boats and solar panels as part of their corporate social responsibility program. Our collaboration focused on making these technologies work in practice - training staff, maintaining equipment, and integrating them into the visitor experience." This insight clarifies the significant but modest H4 relationship ($\beta = 0.312$), indicating that collaboration enhances rather than drives the core adoption process. An academic participant added: "Our research team helped optimize the technical implementation and measure environmental impacts, while local businesses focused on operational integration and community groups facilitated social acceptance."

Theme 3: Technology Adoption as Sustainability Signaling

Tourists and operators perceived REA as the most visible, tangible expression of sustainability commitment that directly influenced destination attractiveness and performance. A tourist shared: "Seeing the electric boats operating silently and solar panels powering facilities made me believe this destination was genuinely committed to environmental protection. This experience positively influenced my satisfaction and willingness to recommend." This insight clarifies the significant H6 relationship ($\beta = 0.461$) and explains why the direct IC-sustainability link (H3) was insignificant. An MSME owner confirmed: "Visitors specifically comment on our use of electric stoves. It's become part of our brand identity and competitive advantage."

Cross-cutting Insight: Organic Collaboration in Grant-Driven Initiatives

The qualitative data revealed a fundamental paradox: while the REA was externally funded through PLN's grant program, the PH emerged organically to ensure its successful implementation. A local government official reflected: "The grant provided the technology, but it was the collective ownership among stakeholders that made it work. Businesses adapted operations, communities provided local knowledge, academics offered technical support, and media created visibility - all without centralized coordination." This insight explains the non-significant H3 while highlighting an emergent collaboration model where IC is enabled through permission rather than direction.

A community leader captured this dynamic: "We didn't wait for instructions. When the solar panels arrived, we naturally divided responsibilities - some handled installation coordination, others managed community outreach, and local businesses integrated the technology into their operations." This bottom-up, self-organizing approach to collaboration, facilitated but not directed by institutional actors, ultimately drove both REA and ST outcomes, validating the mediation pathways in the quantitative model.

5. DISCUSSION

5.1 Theoretical interpretation

This study provides a nuanced understanding of how ST is achieved through the interplay of IC, multi-stakeholder collaboration, and REA. The key finding demonstrates that IC alone is insufficient for achieving ST outcomes; rather, it functions as an enabling condition whose effects materialize through indirect mechanisms. Specifically, the results reveal a parallel mediation structure, where both PH and REA independently transmit the influence of IC on ST performance.

The non-significant direct path between IC and ST (H3), combined with the significant indirect pathways, underscores that institutional potential must be operationalized through collaborative governance and technological transition processes. This finding aligns with research on polycentric governance systems, which emphasizes distributed authority and the need for coordination across multiple actors in complex sustainability transitions [17, 39, 56]. The mediated relationship reflects broader patterns observed in developing economies where formal institutions require complementary networks and innovation mechanisms to generate development outcomes [57].

Our findings both confirm and challenge existing literature on collaborative governance in ST. The positive relationship between IC and PH (H1) aligns with Emerson's collaborative governance framework, which emphasizes institutional foundations for effective partnerships [19, 22]. However, the non-significant direct effect of IC on ST (H3) contrasts with Grindle's assertion that institutional strength directly determines development outcomes [29]. This divergence suggests that in complex, multi-stakeholder environments like tourism destinations, traditional IC may be necessary but insufficient without effective collaborative mechanisms [8]. The findings resonate with institutional theory perspectives that distinguish between institutional frameworks and their operationalization through collaborative networks [58, 59].

The mediating role of PH extends previous work by Halibas et al. [21] and Yasir et al. [23] by demonstrating how collaboration functions as one of the critical channels through which IC influences sustainability outcomes [21, 23]. At the same time, the significant mediation through REA highlights the importance of technological pathways operating alongside collaborative mechanisms. These findings suggest that sustainability performance emerges not from a single dominant mediator, but from the combined and parallel influence of governance and energy transition processes.

5.2 Integration of quantitative and qualitative findings

Consistent with the explanatory sequential mixed-methods design, the qualitative findings provide deeper explanations for the statistical results. While earlier studies identified the importance of multi-stakeholder approaches, our mixed-methods design reveals the specific mechanisms (knowledge integration, resource complementarity, and social legitimization) through which collaboration contributes to sustainability outcomes. These mechanisms align with emerging research on innovation ecosystems that emphasize the synergistic potential of multi-actor engagement in sustainability transitions [14, 15]. Our findings also support recent work on sustainability transitions that highlights the importance of intermediary actors and bridging organizations in facilitating change [60, 61].

Importantly, the qualitative results indicate that collaboration can emerge organically even without formal institutional platforms. This suggests that IC may function as a permissive condition that enables both collaborative governance and technological innovation processes, rather than acting as a directive force in isolation. In this sense, ST performance reflects the combined influence of governance coordination and renewable energy transition mechanisms operating in parallel.

In particular, interview evidence helps explain the non-significant direct relationship between IC and ST performance (H3). Several informants emphasized that policies and institutional frameworks create enabling conditions but do not automatically generate sustainability outcomes unless translated into concrete collaborative actions and technological implementation. This insight substantiates the statistical finding that IC exerts its influence indirectly rather than directly.

The significant relationship between REA and ST performance (H6) reinforces the growing recognition that clean energy technologies serve dual purposes in tourism destinations. Beyond their functional role in reducing emissions, renewable energy installations act as powerful sustainability signals that influence visitor perceptions and destination competitiveness [24, 36]. This signaling function is particularly important in experience-based industries like tourism, where intangible attributes significantly influence consumer choice [62, 63]. This finding is particularly relevant in the Indonesian context, where tourism destinations face increasing pressure to demonstrate environmental commitment while maintaining economic viability [4, 64]. The Indonesian case exemplifies broader patterns in Southeast Asia, where rapid tourism development necessitates innovative approaches to sustainability governance [65].

To enhance analytical transparency, a joint display Table 7 is provided to present quantitative results alongside corresponding qualitative themes, illustrating how interview findings explain and contextualize each hypothesis test result.

Table 7. Joint display of quantitative and qualitative findings

Structural Path	Quantitative Result	Key Qualitative Insight	Integrated Interpretation
IC → PH (H1)	Significant	Government coordination and regulatory clarity facilitate stakeholder engagement	Institutional capacity strengthens collaboration structures.
PH → REA (H2)	Significant	Knowledge sharing and resource complementarity support energy initiatives	Collaboration enables renewable energy implementation.
IC → ST (H3)	Not significant	Policies viewed as supportive but not directly outcome-generating	Institutional capacity influences sustainability indirectly.
REA → ST (H6)	Significant	Renewable energy improves efficiency and enhances destination image	Technological adoption contributes functionally and symbolically to sustainability performance.
IC → PH → ST	Significant indirect	Collaboration operationalizes institutional support	Governance mediation pathway confirmed.
IC → REA → ST	Significant indirect	Institutional support facilitates energy transition	Technological mediation pathway confirmed.

Source: Data processed by researchers (2025)

Implications, Limitations, and Future Research

This study's major strength lies in its explanatory sequential mixed-methods design, which enabled both statistical testing of relationships and deep qualitative exploration of underlying mechanisms. The combination of PLS-SEM analysis with thematic analysis provided complementary insights that neither approach could achieve alone [66]. This methodological triangulation aligns with best practices in sustainability research, where complex socio-ecological systems require multiple epistemological approaches [67, 68]. However, several limitations warrant acknowledgment. The single-case study design in Green Canyon, while providing rich contextual understanding, limits generalizability to other destinations with different stakeholder dynamics. The modest sample size (N = 68), though adequate for PLS-SEM analysis, suggests caution in interpreting the results. The cross-sectional nature of the data prevents definitive conclusions about causal relationships over time. Methodologically, the use of purposive sampling for both quantitative and qualitative components is appropriate for capturing key stakeholder perspectives, but it may introduce selection bias. Future research could benefit from the use of random sampling techniques and longitudinal designs to track the evolution of collaborative relationships.

This research solves several theoretical puzzles while revealing new questions. We have demonstrated why IC requires mediation, as ST inherently demands distributed capabilities that no single institution possesses [56]. This distributed capability approach aligns with RBV of competitive advantage that emphasize the strategic combination of complementary resources across organizational boundaries [69, 70]. The organic emergence of PH despite limited formal platforms suggests that shared practical interests can sometimes outweigh institutional design in driving collaboration [18]. The mechanism of renewable energy, both as a practical solution and a symbolic commitment, explains how technological adoption influences ST performance [37]. However, what remains unresolved is how these collaborative patterns might evolve as the renewable energy initiatives mature, and how power dynamics among penta-helix actors affect long-term sustainability [32]. Future research should explore how digital platforms might facilitate more equitable participation in PHs and how blockchain technologies could enhance transparency in renewable energy transactions [71].

For practitioners and policymakers, these findings suggest several strategic priorities: First, focus on creating enabling conditions for organic collaboration rather than over-designing institutional frameworks. As our qualitative findings showed, stakeholders naturally organized around practical problem-solving when given the space to do so. This approach aligns with principles of adaptive management that emphasize learning and experimentation in complex systems [72, 73]. Second, recognize that REA serves dual purposes: it reduces environmental impact and signals a commitment to sustainability to tourists [38]. This suggests the importance of visible, tangible green technologies in destination marketing. Third, develop targeted interventions for different penta-helix elements: providing technical support for businesses, policy stability for government actors, research partnerships for academics, engagement opportunities for communities, and authentic stories for media [35]. These differentiated strategies reflect the principle of stakeholder salience, which recognizes that different actors possess varying levels of power, legitimacy, and urgency [74, 75]. Finally, our findings support the need for patient capital and long-term perspectives in ST development, as the complex mediation pathways identified indicate that impacts emerge through indirect rather than direct routes.

6. CONCLUSION

This study provides robust evidence that ST performance is achieved through complex mediated pathways rather than direct institutional interventions. The findings demonstrate that while IC significantly enables PH and REA, its influence on ST is entirely mediated through these mechanisms. This resolves a key theoretical puzzle in collaborative governance literature by explaining why institutional strength alone cannot guarantee sustainability outcomes in complex tourism ecosystems.

Theoretically, this research offers three significant advancements. First, it validates the penta-helix model as a crucial mediating framework that operationalizes how IC transforms into ST outcomes. Second, it reveals the emergent nature of collaboration in developing contexts, demonstrating that organic, bottom-up coordination can effectively complement formal institutional arrangements. Third, it establishes REA as both a functional solution and a powerful symbolic commitment that directly shapes tourism sustainability perceptions and performance.

For practitioners and policymakers, these findings suggest strategic priorities: (1) focus on creating enabling environments for organic multi-stakeholder collaboration rather than over-designing institutional frameworks; (2) prioritize visible renewable energy projects that combine practical benefits with sustainability signaling; and (3) develop targeted support mechanisms for different penta-helix actors based on their unique capabilities and contributions.

Despite these contributions, this study acknowledges limitations in its single-case design and cross-sectional data, which constrain generalizability and temporal analysis. Future research should employ longitudinal approaches across multiple destinations to investigate how digital technologies and power dynamics influence the effectiveness of collaborative governance over time. Ultimately, achieving ST requires recognizing that institutions must cultivate ecosystems where diverse stakeholders collaboratively co-create solutions, with the penta-helix model offering a validated pathway toward Indonesia's NZE 2060 targets and enhanced destination competitiveness.

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NOMENCLATURE

Latin symbols

IC	Institutional Capacity construct
n	Sample size
N	Population size
p	Probability value in statistical testing
PH	Penta-Helix Collaboration construct
Q^2	Predictive relevance statistic in PLS-SEM
REA	Renewable Energy Adoption construct
R^2	Coefficient of determination
ST	Sustainable Tourism Performance construct
t	t-statistic value

Greek symbol

α	Cronbach's alpha reliability coefficient
β	Standardized regression coefficient
ρ	Composite reliability coefficient
χ^2	Chi-square statistic