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Green governance and institutional resilience: strengthening environmental policies for a low-carbon economy in mangrove ecosystems

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Introduction: This study addresses a significant empirical gap by examining how institutional resilience mediates the relationship between green governance and environmental policy effectiveness in managing mangrove ecosystems in Indonesia.

Methods: A mixed-methods design was employed, integrating Structural Equation Modeling (SEM) and MICMAC analysis to investigate causal relationships and strategic interdependencies.

Results: SEM results indicate that green governance exerts a significant influence on institutional resilience ($\beta = 0.67$), environmental policy effectiveness ($\beta = 0.61$), and the low-carbon economy ($\beta = 0.52$), with institutional resilience and policy effectiveness serving as key mediating variables (Sobel $z = 5.98$ and 5.47 , respectively). MICMAC analysis identifies public participation, regulatory enforcement, and environmental economic instruments as primary driving variables with high influence and low dependency. Institutional resilience emerges as a critical linkage factor, reflecting its dual function in both shaping and being shaped by governance dynamics.

Discussion: The study offers theoretical, methodological, and practical contributions. Theoretically, it elucidates the mediating role of institutional resilience in connecting green governance to policy effectiveness and the transition toward a low-carbon economy. Methodologically, it integrates SEM and MICMAC analysis, combining statistical rigor with strategic foresight. Contextually, it provides empirical insights from mangrove ecosystems in Indonesia, representing the Global South, where governance challenges remain pressing and underexplored. Practically, the findings highlight actionable priorities—such as public participation, regulatory enforcement, and economic instruments—offering evidence-based policy direction to strengthen institutional resilience and advance green governance toward a low-carbon transition.

KEYWORDS

green governance, institutional resilience, environmental policy effectiveness, local climate governance, sustainability governance

1 Introduction

In recent decades, environmental and sustainability issues have gained global attention due to the escalating impacts of climate change and ecological degradation. Among the various strategies explored to balance economic development and environmental preservation, green governance has emerged as a prominent approach. This concept emphasizes the importance of policies and regulations that promote sustainability through effective, collaborative, and ecologically just environmental management. As highlighted in previous research, innovation in governance is crucial for accelerating the transition toward a low-carbon economy. Such a transition requires policies that are adaptive to environmental change and efficient in managing natural resources sustainably (He G. et al., 2024; Jiang, 2023; Owen et al., 2018; Zhang, 2022).

A key challenge in implementing green governance lies in strengthening institutional resilience to ensure the effective execution of environmental policies. Institutional resilience refers to the ability of institutions to adapt and respond to environmental changes while maintaining the long-term sustainability of policies. However, in many contexts, institutional weaknesses—such as inefficient bureaucracy, poor coordination among stakeholders, and weak regulatory enforcement—remain major obstacles to achieving effective environmental policy outcomes (Howes et al., 2017; Mao et al., 2020).

One of the most critical ecosystems in the context of environmental policy and climate change mitigation is the mangrove ecosystem. Indonesia accounts for approximately 23% of the world's total mangrove area, making it the country with the largest mangrove coverage globally (Muhammad Farhaby et al., 2020). Despite this vast natural resource, Indonesia faces serious threats to the sustainability of its mangrove ecosystems, with nearly 40% estimated to have been degraded since 1980 (Monika and Yadav, 2022). The primary drivers of this degradation include land conversion for agriculture and settlements, illegal logging, pollution, and the impacts of climate change (Islam et al., 2024; Kumar et al., 2024).

The coastal region of Riau, one of the focal areas of this study, exemplifies the growing pressures on mangrove ecosystems in Indonesia. Extensive land conversion for agriculture and industrial zones has led to significant mangrove loss (Arkham et al., 2023; Asyri and Baiq Ishariaty Wika, 2024). In Bengkalis Regency alone, approximately 15% of mangrove forests have disappeared over the past two decades, with the most critical degradation occurring between 2000 and 2010 due to the expansion of oil palm plantations and infrastructure development. Nationally, Indonesia has lost an estimated 1.1 million hectares of mangroves between 1980 and 2020, endangering essential ecological functions, particularly as natural buffers against tidal surges, coastal erosion, and other climate-induced hazards (Wardiman et al., 2024).

This degradation not only undermines the carbon sequestration capacity of mangrove ecosystems but also heightens ecological vulnerability and reduces biodiversity essential for sustaining coastal livelihoods. For instance, small-scale fishers who rely heavily on marine species supported by healthy mangrove habitats are increasingly experiencing declining fish stocks.

This decline directly affects their income, food security, and socio-economic resilience, highlighting the urgent need for robust environmental governance and institutional capacity to safeguard mangrove ecosystems and the communities that depend on them.

In the context of a low-carbon economy, the effectiveness of environmental policies largely depends on how well green governance mechanisms enhance institutional resilience to support the transition toward clean energy and climate change mitigation. Countries with strong environmental governance typically demonstrate more adaptive policy frameworks and greater efficiency in sustainably managing natural resources (Alvi and Mudassar, 2025; Arai, 2021; Marini Govigli et al., 2022). As one of the world's largest carbon emitters, Indonesia plays a critical role in the global shift toward a low-carbon economy. The government has introduced several environmental initiatives, including the National Medium-Term Development Plan (RPJMN) and a formal commitment to achieving Net Zero Emissions by 2060. However, the success of these initiatives hinges on the continuity and quality of green governance and the strength of institutional resilience, both of which determine how effectively public institutions and other stakeholders respond to environmental and economic challenges (Chacartegui, 2018; Ibrahim et al., 2020; Shah et al., 2022).

Given Indonesia's extensive mangrove forests—spanning approximately 3.31 million hectares, the largest globally (Lee and Krasny, 2017), and the alarming rate of degradation (estimated at nearly 40% since 1980—and the alarming rate of degradation, estimated at nearly 40% since 1980, the country presents a critical context for investigating the interplay between green governance and institutional resilience. The province of Riau exemplifies the complex challenge of aligning economic development with ecological preservation. In such settings, understanding the interaction between governance structures and institutional adaptability is essential for designing policies that simultaneously protect ecosystems and promote climate objectives.

In this regard, exploring the relationship among green governance, institutional resilience, and environmental policy effectiveness becomes crucial to assess the extent to which policy instruments can drive a low-carbon economy. The mangrove ecosystem, in particular, plays a strategic role in carbon sequestration, coastal protection, and climate change mitigation. Beyond its ecological functions, mangroves hold significant potential to support sustainable development. However, realizing this potential largely depends on the effective implementation of adaptive environmental policies. In many developing countries, including Indonesia, mangrove governance is often constrained by weak institutional resilience and insufficient intersectoral coordination (Henry-Whyte, 2024; Subambang et al., 2024; Yap and Al-Mutairi, 2025).

Despite various policy efforts to strengthen green governance, substantial challenges remain, particularly in the Indonesian context. Existing studies tend to be largely theoretical and lack robust empirical investigations into the relationship between green governance and institutional resilience, especially within ecosystems that are highly relevant to climate change mitigation, such as mangroves. Furthermore, much of the literature focuses on specific sectors or developed countries, with

limited attention to the environmental policy challenges faced by developing nations.

While many studies have examined green governance from a normative or conceptual standpoint, limited empirical attention has been paid to how institutional resilience functions as a mediating variable within governance frameworks—particularly in fragile coastal ecosystems of the Global South. Moreover, the integration of strategic foresight tools such as MICMAC in environmental planning remains underutilized. This study seeks to address these gaps by focusing on the following research questions:

1. How does green governance contribute to the effectiveness of environmental policies in mangrove ecosystems?
2. What is the mediating role of institutional resilience in the relationship between stakeholder participation and policy performance?
3. Which strategic variables drive the success of environmental governance in supporting a low-carbon transition in mangrove regions?

1.1 Literature review and theoretical framework

The concept of green governance has emerged as a critical mechanism for addressing global environmental challenges, particularly in facilitating the transition toward a low-carbon economy. Green governance emphasizes participatory, transparent, and accountable environmental decision-making processes (Dai et al., 2025; Debbarma and Choi, 2022; Radtke, 2025). Scholars have increasingly underscored the necessity of robust governance structures to support climate policy implementation and sustainable natural resource management (He Q. et al., 2024). In parallel, the notion of institutional resilience—defined as the capacity of institutions to absorb disturbances, adapt to change, and maintain essential functions—has gained attention for its role in ensuring long-term environmental policy effectiveness (Chen et al., 2024).

The transition to a low-carbon economy requires both effective environmental governance and strong institutional resilience. Green governance involves policies and practices that promote sustainable development, while institutional resilience refers to an institution's ability to adapt and respond to environmental change. A study by Bambi et al. (2024) highlights that good governance and high institutional quality significantly reduce the ecological footprint in Sub-Saharan African countries. Their findings show that a 1% improvement in institutional quality can reduce the per capita ecological footprint by 0.0171, emphasizing the crucial role of governance in improving environmental outcomes. Using the Country Policy and Institutional Assessment (CPIA) index to assess institutional quality, the study demonstrates that effective governance can mitigate environmental degradation.

Similarly, research by Yuning et al. (2024) emphasizes that institutional pressures play a key role in driving low-carbon innovation policies. However, the adaptation of these policies is often constrained by diverse governance structures and differing environmental interpretations among organizations. Other studies

highlight the importance of Environmental Management Systems (EMS) as mediators translating institutional pressures into tangible innovations (Nguyen, 2022). Kassouri and Altıntaş (2020) explored how good governance influences environmental quality, revealing that strong regulatory systems and active participation of green political parties are essential for improving environmental outcomes (Adekunle, 2021).

In the context of low-carbon tourism in rural China, Guo and Li (2025) identified that the implementation of effective policies requires an adaptive, multi-level governance approach. Their study shows that policy success depends on the interaction among national policies, provincial adoption, and local implementation, taking into account economic, environmental, and institutional factors. Additionally, institutional pressures such as government regulations and societal expectations encourage businesses to adopt green innovations. Achieving a low-carbon economy requires not only technical policy innovation but also a philosophical foundation for public service that values responsibility, justice, and long-term stewardship (Tao, 2020). However, effectiveness is influenced by corporate environmental identity and mimetic pressures, indicating that internal organizational factors also play a significant role (Ding and Wang, 2025; Gao et al., 2025; Huang et al., 2022; Purnomo et al., 2024).

Other studies show that among the twelve largest emitting countries, green energy consumption and governance quality significantly reduce CO₂ emissions. However, green innovation does not have a significant effect, underscoring the importance of investment in green energy and improved governance to address environmental challenges (Khan, 2025). Research by Gao et al. (2025) in China demonstrates that low-carbon city pilot policies (LCCPP) significantly enhance corporate green innovation, particularly during the growth and maturity stages. These policies increase financial subsidies and R&D investment, thereby driving technological innovation and supporting the transition to a low-carbon economy. Tengfei and Ullah (2024) found that in OECD countries, market-based policies and pricing mechanisms play a key role in improving green total factor energy efficiency (GTTEE). However, economic growth shows a negative relationship with GTTEE, indicating a trade-off between economic expansion and energy efficiency, and highlighting the need for a global consensus on implementing green growth strategies. In mangrove ecosystems—where socio-ecological complexity intersects with governance challenges—institutional resilience becomes particularly relevant. Mangroves provide critical ecological services, including carbon sequestration, coastal protection, and biodiversity support, yet remain vulnerable to degradation driven by weak governance and fragmented institutional arrangements (Akram et al., 2023; Dabalà et al., 2023; Ferreira et al., 2022).

Recent scholarship continues to explore green governance in the context of climate adaptation and institutional development. For instance, Fuchs et al. (2025) emphasized the role of hybrid institutions in facilitating adaptive management in coastal regions. Similarly, Marks and Pulliat (2022) examined the evolving functions of institutional resilience in decentralized governance systems across Southeast Asia. These studies underscore the relevance of integrating resilience thinking into environmental governance, particularly in areas experiencing increasing ecological

stress. In addition, Allen et al. (2023) found that polycentric arrangements and cross-level collaboration enhance institutional responsiveness to climate-related risks. This study builds upon and extends this literature by empirically testing institutional resilience as a mediating factor within a low-carbon governance model, applied in a mangrove ecosystem.

2 Theoretical frameworks and key concepts

This study builds upon multiple intersecting theoretical frameworks (Figure 1), including environmental governance theory, institutional theory, adaptive governance, and socio-ecological resilience. **Environmental governance theory** provides a foundation for analyzing how state and non-state actors interact across different levels to manage environmental resources. It underscores the importance of transparency, accountability, stakeholder participation, and policy coherence (Geng and Lo, 2024; Idrees, 2024; Miao and Nduneseokwu, 2024; Sundram, 2025).

Institutional theory, particularly its ecological and sociological perspectives, focuses on how institutions respond to external pressures—coercive, normative, and mimetic—while striving for legitimacy and effectiveness (David et al., 2019; Galleli and Amaral, 2025; Kauppi, 2022; Peters, 2019). In this context, institutional resilience is seen not only as the ability to withstand shocks but also as a dynamic process of learning and adaptation that enhances policy implementation.

Institutional resilience is thus viewed as a dynamic socio-institutional process, shaped by local capacity, community cohesion, and institutional trust, rather than a static attribute of governance systems. Following the perspective offered by Carmen et al. (2023) in *Transforming Social Capital to Strengthen Local Government Resilience*, resilience should be framed as the ability of institutions to adapt, learn, and transform in response to socio-environmental pressures. This dynamic view is particularly important in mangrove governance, where uncertainty and ecological degradation challenge conventional regulatory mechanisms.

Adaptive governance, a complementary framework, emphasizes learning-based, flexible, and collaborative institutional arrangements that can respond effectively to environmental uncertainties and complex socio-ecological dynamics (Clever and Whaley, 2018; Sharma-Wallace et al., 2018; Steelman, 2022). This is particularly crucial in managing mangrove ecosystems, where interactions among biophysical, institutional, and community-level variables are non-linear and context-specific.

Local government resilience depends not only on the structural strength of institutions but also on social dynamics, including social capital, community trust, local adaptive capacity, and decentralized decision-making mechanisms. The transformation of social capital through community engagement, strong social networks, and stakeholder trust has been shown to enhance the ability of local governments to respond effectively to disasters and ecological risks, as highlighted in a recent study by (Karso et al., 2025).

The concept of **socio-ecological resilience** further enriches the analysis by integrating the adaptive capacity of ecosystems

and institutions. It highlights the interdependence of human and natural systems and the necessity for integrative, cross-scale governance mechanisms that can sustain ecological functions and support long-term sustainability (Baudoin et al., 2024; Golfopoulos and Koumparou, 2024). Collectively, these frameworks offer a nuanced lens to explore how green governance mechanisms influence institutional resilience and, ultimately, the effectiveness of environmental policies in achieving a low-carbon economy.

2.1 Identifying the research gap

While a growing body of literature addresses the roles of governance in climate policy (e.g., Adekunle, 2021; Altıntaş and Kassouri, 2020; Bambi et al., 2024), limited empirical research explicitly examines the mediating role of institutional resilience in the relationship between green governance and environmental policy effectiveness—particularly in mangrove ecosystems, which are both ecologically vital and institutionally complex. Existing studies also tend to focus on national-level policy, without sufficiently addressing how local institutional dynamics affect ecosystem governance and carbon mitigation strategies (Khanam et al., 2025; Ulibarri, 2019; Vallury et al., 2022). This study addresses that gap by empirically analyzing how green governance influences institutional resilience and, in turn, supports the low-carbon transition in the management of mangrove ecosystems in Indonesia.

Much of the existing research relies heavily on qualitative or descriptive approaches. There remains a paucity of studies employing advanced quantitative models such as Structural Equation Modeling (SEM) integrated with MICMAC Analysis to test causal relationships among governance quality, institutional capacity, and policy outcomes (Fathi, 2024; Kanchanawongpaisan, 2024; Lutfi et al., 2024). To address this methodological gap, the present study adopts a mixed-methods approach. It applies SEM to quantitatively examine the mediating role of institutional resilience, complemented by MICMAC prospective analysis, conducted through surveys and Focus Group Discussions (FGDs) with academic experts and stakeholders in environmental governance. This integrative approach enhances the robustness of the findings by combining empirical modeling with participatory foresight, thereby offering both diagnostic and strategic insights into the low-carbon transition in mangrove ecosystem management.

2.2 Contextual literature and international perspectives

Studies from different regions provide useful points of comparison for positioning the Indonesian case. In Vietnam and Cambodia, mangrove governance is largely centralized under strong state authority (Fidelman et al., 2017; Nguyen, 2022). This centralization ensures more consistent policy enforcement but often limits space for meaningful community participation.

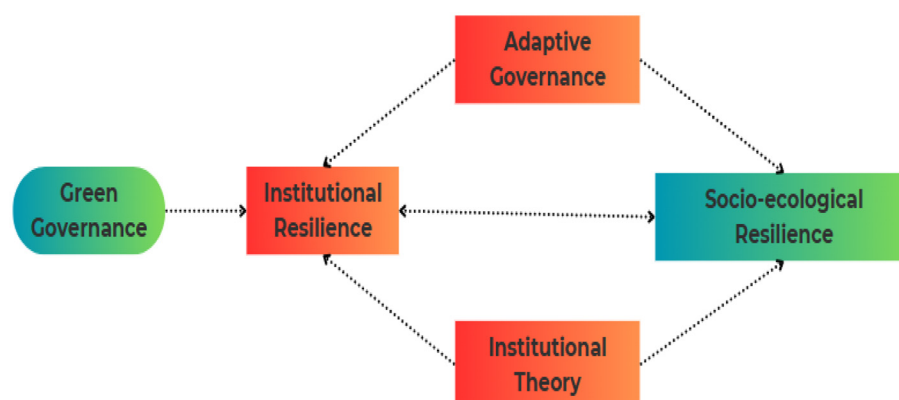


FIGURE 1
Theoretical frameworks and key concepts.

Similarly, in Myanmar, state-led frameworks dominate decision-making, leaving little room for local-level initiatives (Lin et al., 2019).

By contrast, in Bangladesh and Brazil, co-management arrangements that combine government regulation with community-based participation have been developed. These hybrid governance models enhance local ownership and adaptive capacity but often face challenges of scaling up and securing long-term political support (Arif, 2022; Favoretto et al., 2024). In Cameroon and Uruguay, institutional adaptation has relied on strong legal frameworks and donor-supported projects, but implementation gaps remain due to weak enforcement capacity (Ajonina, 2022; Owusu et al., 2024).

In East Asia and Southeast Asia more broadly, polycentric governance systems where multiple actors at different levels share overlapping responsibilities have been shown to increase institutional adaptability, though they also create coordination challenges (Lee and Krasny, 2017; Morita and Matsumoto, 2018). In Latin America, comparative studies highlight how governance innovations such as payments for ecosystem services have strengthened institutional resilience, but they require stable political and economic conditions to succeed (Pichancourt et al., 2025; Sattler, 2022).

Against this background, Indonesia represents a distinctive case. Its decentralized governance framework assigns significant authority to local governments under the autonomy system, creating opportunities for participatory approaches to mangrove management. However, decentralization has also led to fragmented responsibilities and overlapping mandates among institutions such as the Ministry of Environment and Forestry, the Ministry of Marine Affairs and Fisheries, and local governments. Unlike more centralized systems (e.g., Vietnam, Myanmar) or hybrid co-management models (e.g., Brazil, Bangladesh), Indonesia's governance challenges lie in ensuring coordination across multiple levels of authority. This makes institutional resilience particularly critical, as it enables governance systems to adapt, coordinate, and sustain effective environmental management amid decentralization and administrative complexity.

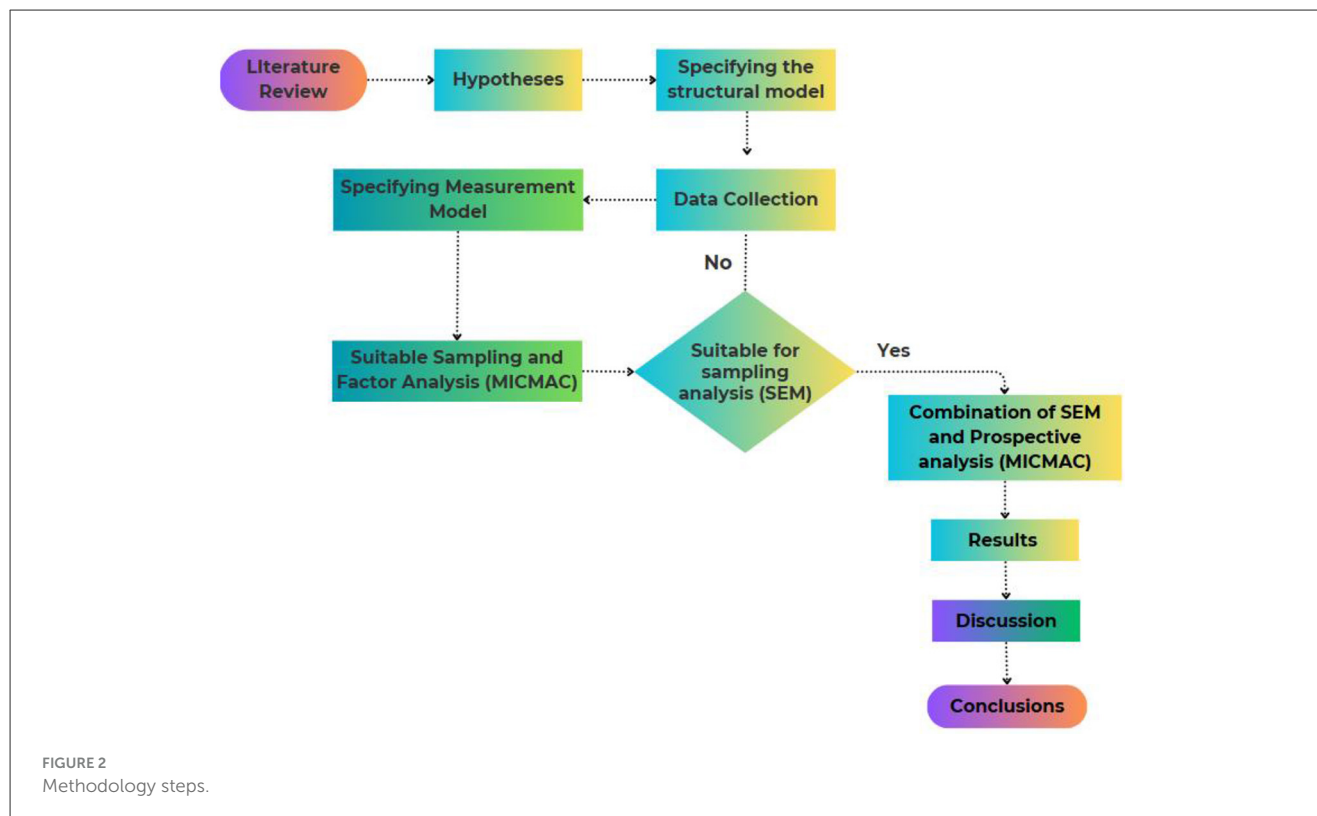
Building on this context, the literature highlights that strong green governance and institutional resilience are essential for the effectiveness of environmental policies and for facilitating the transition to a low-carbon economy. Effective policy implementation requires alignment within governance structures, investments in green energy, and adaptive environmental management systems. In Indonesia's case, addressing the challenges of fragmented authority and overlapping mandates through resilient institutions can enhance policy coherence, improve coordination across levels of government, and promote stakeholder engagement. Robust governance mechanisms, combined with investments in renewable energy and green financial support, play key roles in reducing carbon emissions and achieving sustainable development. Integrating green governance principles into environmental policies, while considering socio-economic contexts and involving various stakeholders, can thus strengthen institutional capacity, ensure policy effectiveness, and support Indonesia's transition toward a low-carbon, sustainable future.

3 Materials and methods

3.1 Research design

This study adopts a mixed-method research design by integrating Structural Equation Modeling (SEM) and Prospective Analysis (MICMAC). The objective is to examine the causal relationships between green governance, institutional resilience, and their influence on the low-carbon transition, while simultaneously identifying strategic variables that shape the future policy landscape. The research methodology follows a systematic and iterative process, as illustrated in Figure 2.

The use of Structural Equation Modeling (SEM) enables a robust analysis of latent variables and mediation effects among governance constructs, whereas MICMAC provides strategic mapping of inter-variable influence and dependency relationships. These methods are complementary: SEM statistically tests the strength and direction of causal paths, while MICMAC offers



insight into the systemic structure of variables that drive or depend on green governance outcomes. Their integration thus allows a more comprehensive understanding of both empirical relationships and strategic institutional positioning.

The research methodology framework integrates SEM and MICMAC Prospective Analysis through a sequential process. It begins with a literature review, hypothesis formulation, and model specification. Following data collection, a decision point assesses the adequacy of the data for SEM analysis. If the data meet the statistical requirements, SEM is conducted and subsequently integrated with MICMAC to identify key influencing variables and possible future scenarios. If not, the MICMAC method is applied independently after the measurement model specification. This iterative approach enhances the robustness of the analysis by combining statistical modeling with expert-based foresight analysis.

An extensive literature review was conducted to identify theoretical frameworks and empirical findings related to green governance, institutional resilience, the low-carbon economy, and environmental performance. Based on this review, hypotheses were formulated to examine the relationships among key constructs, including governance quality, policy implementation, stakeholder engagement, and environmental outcomes. Based on the theoretical framework, this study formulates the following hypotheses:

H1: Green Governance positively influences the Low-Carbon Economy.

H2: Green Governance positively influences Institutional Resilience.

H3: Green Governance positively influences Environmental Policies.

H4: Institutional Resilience positively influences the Low-Carbon Economy.

H5: Environmental Policies positively influence the Low-Carbon Economy.

3.2 Study area and sampling

The study was conducted in Bengkalis Regency, located in Riau Province, Indonesia—a coastal area known for its ecological significance and strategic role in mangrove conservation. Bengkalis represents one of the regions with the lowest mangrove growth rates among coastal regencies in Riau Province, making it a critical case for examining governance and institutional resilience in low-carbon development strategies. The area is characterized by high ecological vulnerability resulting from anthropogenic pressures, climate change impacts, and fragmented environmental management frameworks.

The study population consisted of 135 identified experts in mangrove ecosystems, representing three main groups: academics, government officials, and NGO practitioners. A census approach was employed, inviting all identified individuals to participate in the SEM survey. A total of 101 valid responses were obtained, yielding a response rate of 74.8%, which is considered adequate for SEM analysis (Kabit et al., 2020). Since the entire population was targeted, no random sampling procedure was applied; the

earlier reference to “randomization” was inaccurate and has been corrected.

For the MICMAC analysis, a smaller expert panel of 10 individuals was convened, selected purposively based on their expertise in mangrove governance and professional experience. This panel was distinct from the SEM respondents to ensure methodological complementarity: the SEM survey captured broad quantitative perspectives, while the MICMAC approach focused on strategic foresight from senior experts. To enhance transparency and replicability, the full SEM questionnaire is provided in [Appendix A](#), and the MICMAC cross-impact matrix instrument in [Appendix B](#).

3.3 Data sources

Primary data were collected through structured surveys and expert interviews. Respondents included policymakers, environmental officers, NGO practitioners, and academic researchers with contextual expertise in green governance and mangrove ecosystem sustainability. Secondary data were obtained from government reports, environmental performance indicators, and academic publications to support data triangulation.

3.4 Ethical considerations

This research adheres to the ethical guidelines of Riau University. Prior to participation, informed consent was obtained from all respondents. Participants were assured of the confidentiality and anonymity of their responses, and participation was entirely voluntary. No personally identifiable information was collected or disclosed.

4 Results

4.1 Preliminary analysis and respondent characteristics

Before conducting the Structural Equation Modeling (SEM) analysis, a descriptive analysis was carried out to understand respondent characteristics and data distribution. This included descriptive statistics such as mean, standard deviation, frequency distribution, and data visualization, ensuring that the dataset met the basic assumptions required for subsequent statistical analyses.

A stratified random sampling technique was employed to ensure proportional representation of each subgroup within the population, reducing sampling bias and enhancing the validity of the study's findings. Using Slovin's formula with a 5% margin of error, the sample size was determined to be 101 respondents, deemed sufficient to accurately represent the target population. This sampling approach strengthened data reliability, allowing the dataset to be used confidently for validity and hypothesis testing within the SEM framework.

The respondents' distribution reflected diverse professional backgrounds and levels of environmental policy experience. Of

the total respondents, 40% were affiliated with government institutions and environmental regulatory bodies, serving as key actors in formulating and implementing green governance policies. Another 25% were academics and researchers, contributing to scientific assessments and evidence-based evaluations. The remaining 35% represented the private sector and industry, functioning as principal implementers of environmental policies in practical contexts.

Regarding experience in environmental policy-making, 30% of respondents had less than 5 years of experience, typically consisting of early-career professionals or those newly engaged in environmental governance. Approximately 45% reported 5 to 10 years of experience, indicating moderate engagement in environmental issues, while 25% possessed over 10 years of experience, reflecting deep expertise in policy development and implementation. This distribution underscores the inclusion of diverse stakeholders with varying experience levels, providing comprehensive insights into green governance, institutional resilience, and environmental policy effectiveness in advancing the low-carbon transition.

Before testing the structural relationships among variables, a Confirmatory Factor Analysis (CFA) was conducted to assess the validity and reliability of the measurement model ([Table 1](#)). This step ensured that each indicator accurately represented its respective construct and that the overall model demonstrated strong internal consistency and reliability.

The convergent validity test indicated that all indicators had factor loadings above 0.6, signifying that each strongly represented its respective construct. Furthermore, all Average Variance Extracted (AVE) values exceeded 0.5, confirming that each latent variable explained the majority of variance in its indicators. Thus, the measurement model demonstrated good convergent validity.

Discriminant validity was tested using the Fornell-Larcker criterion ([Table 2](#)). The results showed that the correlations between constructs were lower than the square roots of their respective AVE values, confirming that each construct was empirically distinct with minimal overlap. To further assess internal consistency and reliability, Cronbach's Alpha and Composite Reliability (CR) were examined. All constructs yielded Cronbach's Alpha and CR values above 0.7, indicating strong reliability and internal consistency. Based on these findings, the measurement model meets all necessary validity and reliability criteria, making it appropriate for subsequent structural analysis.

4.2 Structural model (inner model) – hypothesis testing

After confirming that the measurement model met the validity and reliability requirements, the next stage involved examining the structural relationships among variables using Structural Equation Modeling (SEM) with the support of SmartPLS software. This analysis aimed to evaluate how well the proposed model explains the relationships between green governance, institutional resilience, and environmental policy effectiveness in supporting the transition toward a low-carbon economy.

TABLE 1 Confirmatory Factor Analysis (CFA).

Variable	Factor Loading Range	AVE	CR	Cronbach's Alpha
Green Governance (GG)	0.72-0.81	0.58	0.85	0.80
Institutional Resilience (IR)	0.74-0.85	0.62	0.88	0.83
Environmental Policy Effectiveness (EP)	0.77-0.80	0.60	0.86	0.82
Low-Carbon Economy (LCE)	0.79-0.84	0.65	0.89	0.85

Table 3 presents the model evaluation based on several fit indices that assess the degree to which the proposed model aligns with the empirical data. The results are interpreted as follows:

- a) Chi-Square (χ^2/df): The value of 2.15 is below the recommended threshold of 3.00, indicating a good fit between the model and the observed data.
- b) Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI): Both indices exceed 0.90, suggesting that the model exhibits an excellent fit.
- c) Root Mean Square Error of Approximation (RMSEA): The RMSEA value of 0.054 is below 0.08, signifying a low approximation error and satisfactory model fit.
- d) Standardized Root Mean Square Residual (SRMR): The SRMR value of 0.041, being below 0.08, indicates that residuals are minimal and that the model fits the data well.

Based on these results, the SEM model demonstrates a strong overall fit, confirming its suitability for testing the hypothesized relationships among the study variables.

4.3 Hypothesis testing – path analysis

The results of hypothesis testing using SEM are presented in Table 4.

Table 4 presents the results of the Structural Equation Modeling (SEM), illustrating the relationships between the variables examined in this study. The strength and direction of these relationships are measured through path coefficients (β), as follows:

- 1. H1 ($\beta = 0.52$, Significant, $p < 0.001$): Green governance exerts a positive and significant effect on the low-carbon economy, indicating that its effective implementation contributes to advancing low-carbon development.
- 2. H2 ($\beta = 0.67$, Significant, $p < 0.001$): Green governance significantly enhances institutional resilience, suggesting that sound governance practices strengthen institutional capacity in environmental management.
- 3. H3 ($\beta = 0.61$, Significant, $p < 0.01$): Green governance positively affects environmental policy effectiveness, implying

TABLE 2 Discriminant validity – cross loadings (Outer Model).

Indicators	(GG)	(IR)	(EPE)	(LCE)
Transparency of environmental decision-making processes (GG1)	0.812			
Public participation in environmental governance (GG2)	0.857			
Enforcement of environmental regulations (GG3)	0.834			
Integration of environmental considerations (GG4)	0.803			
Accessibility of environmental information (GG5)	0.787			
Inter-agency coordination and collaboration (GG6)	0.825			
Institutional flexibility in policy adaptation (IR1)		0.841		
Availability of human, financial, and technical resources (IR2)		0.816		
Continuity and stability of organizational functions (IR3)		0.823		
Capacity for innovation in environmental strategies (IR4)		0.798		
Strength of networks and cross-sectoral collaboration (IR5)		0.835		
Responsiveness to environmental risks (IR6)		0.822		
Clarity of environmental policy goals and targets (EPE1)			0.832	
Consistency and coherence of policy implementation (EPE2)			0.817	
Level of compliance by industries and communities (EPE3)			0.841	
Monitoring and evaluation of environmental outcomes (EPE4)			0.824	
Political support and resource allocation (EPE5)			0.812	
Measurable improvements in ecosystem health and quality (EPE6)			0.835	
Share of renewable energy in the energy mix (LCE1)				0.811
Investment in low-carbon technologies and infrastructure (LCE2)				0.834
Energy efficiency in industrial and transport sectors (LCE3)				0.827
Carbon emissions per unit of GDP (LCE4)				0.803

(Continued)

TABLE 2 (Continued)

Indicators	(GG)	(IR)	(EPE)	(LCE)
Adoption of circular economy models (LCE5)				0.820
Fiscal incentives or carbon pricing mechanisms (LCE6)				0.836

GG, Green Governance; IR, Institutional Resilience; EPE, Environmental Policy Effectiveness; LCE, Low-Carbon Economy.

TABLE 3 Model fit indices.

Goodness-of-fit indicator	Cut-off Value	Model Fit Result	Interpretation
Chi-Square/df	<5.0	2.15	Good fit
RMSEA	<0.08	0.054	Good fit
CFI	>0.90	0.937	Good fit
TLI	>0.90	0.923	Good fit
SRMR	<0.08	0.041	Good fit

- that participatory and transparent governance fosters successful policy implementation.
4. H4 ($\beta = 0.45$, Significant, $p < 0.05$): Institutional resilience significantly improves low-carbon economic performance, confirming the critical role of adaptive and robust institutions in supporting sustainable transitions.
5. H5 ($\beta = 0.38$, Significant, $p < 0.05$): Environmental policy effectiveness has a positive impact on the low-carbon economy, demonstrating that effective policy frameworks contribute to sustainable growth outcomes.

Figure 3 illustrates the SEM outcomes, providing a comprehensive depiction of how Green Governance (GG) influences the development of a Low-Carbon Economy (LCE) within mangrove ecosystems through both direct and indirect pathways. Green Governance functions as a pivotal exogenous variable, exerting direct positive effects on Institutional Resilience ($\beta = 0.67$, $t = 7.89$, $p < 0.001$), Environmental Policy Effectiveness ($\beta = 0.61$, $t = 7.12$, $p < 0.001$), and the Low-Carbon Economy ($\beta = 0.52$, $t = 6.45$, $p < 0.001$). These findings underscore the fundamental role of governance mechanisms in driving systemic transformation toward sustainability.

Furthermore, Institutional Resilience and Environmental Policy Effectiveness emerge as critical mediating (endogenous) variables. Institutional resilience indirectly influences the Low-Carbon Economy ($\beta = 0.45$), supported by a significant Sobel test result ($z = 5.98$, $p < 0.005$). Similarly, Environmental Policy Effectiveness mediates the relationship between governance and economic outcomes ($\beta = 0.38$; Sobel $z = 5.47$, $p < 0.005$). These results highlight that resilient institutions and effective policies act as essential channels through which governance contributes to sustainable environmental and economic outcomes.

The Low-Carbon Economy serves as the ultimate endogenous construct, receiving both direct and indirect effects from the other variables. This demonstrates the interconnected nature of governance, institutional dynamics, and policy effectiveness in

achieving sustainable, low-carbon transitions within vulnerable coastal ecosystems. The strength and significance of these relationships confirm the robustness of the proposed theoretical framework and emphasize that enhancing governance quality and institutional resilience are key strategies for advancing low-carbon development in mangrove regions.

4.4 MICMAC analysis: identification and classification of key factors

The MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement) analysis was employed to map the influence and dependency relationships among 24 sub-variables across the four main constructs: Green Governance (GG), Institutional Resilience (IR), Environmental Policy Effectiveness (EPE), and Low-Carbon Economy (LCE). The analysis results are visualized in a four-quadrant matrix that categorizes variables according to their degree of influence and dependency within the overall system.

Figure 4 illustrates the results of the MICMAC analysis, which identifies the driving and influencing factors in Green Governance. The analysis divides the variables into four quadrants, as described below.

4.4.1 Quadrant 1—driving variables (INPUT)

This quadrant includes variables with high influence but low dependency, signifying their role as stable drivers of the system. Notably, public participation (GG2; Influence = 1.54) and the use of environmental economic instruments (EPE5) occupy this quadrant. Other sub-variables, such as GG4, GG5, and GG6, are also located here. These findings underscore the strategic importance of participatory mechanisms and economic instruments in initiating systemic change. Due to their stability and minimal dependence on other variables, these drivers serve as effective levers for policy interventions aimed at enhancing institutional resilience and improving environmental policy outcomes.

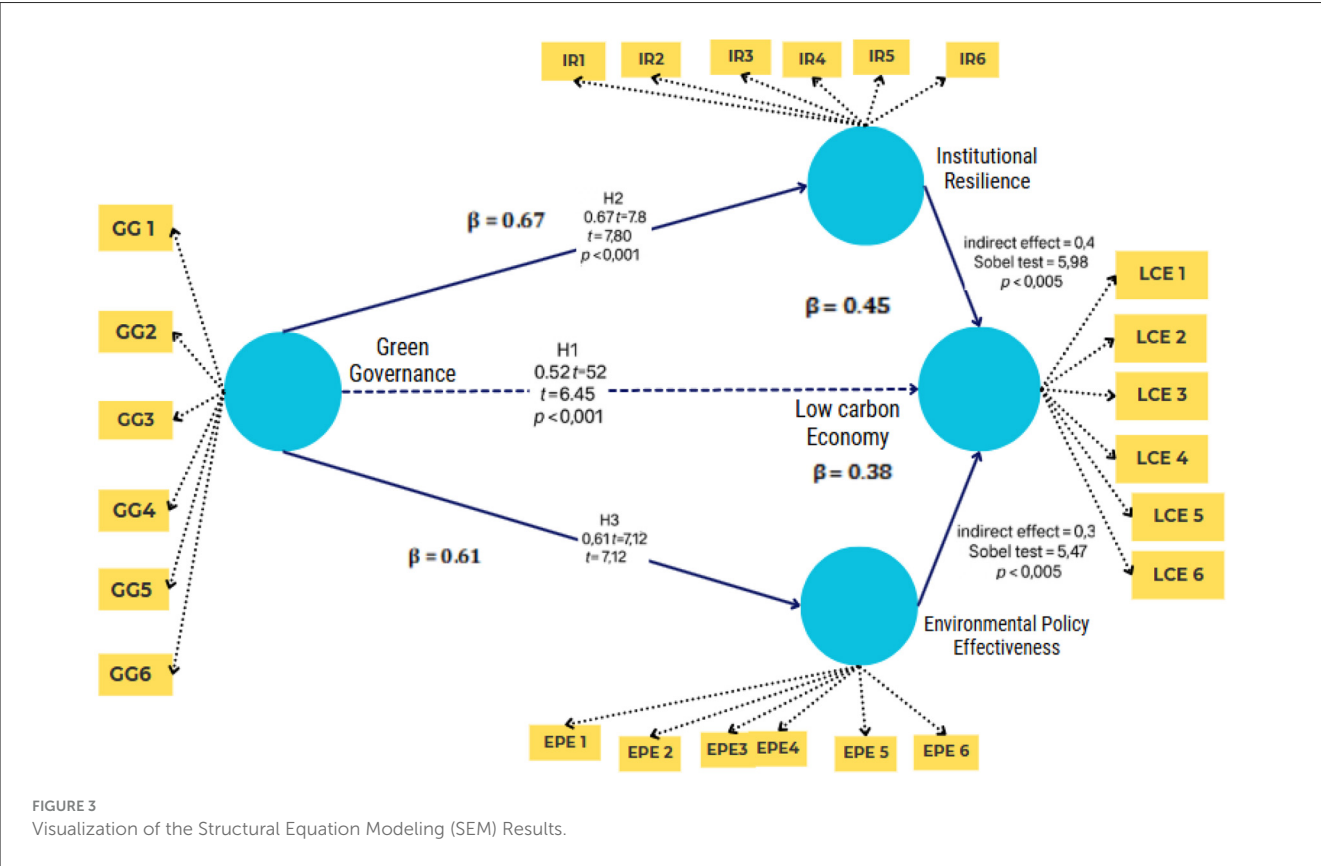
4.4.2 Quadrant 2—leverage variables (STAKE)

Variables in this quadrant exhibit both high influence and high dependency, positioning them as leverage points that are highly sensitive to systemic shifts. Key variables include long-term organizational stability (IR3; Influence = 1.81), institutional coordination (GG3), leadership commitment (IR4), and environmental supervision (EPE4). Cross-sectoral collaboration (GG6) is also situated in this category.

These leverage variables are essential for systemic transformation, as they connect multiple elements within the governance structure. Their interdependent nature aligns with the SEM findings, which identified Institutional Resilience and Environmental Policy Effectiveness as mediating variables influencing the transition toward a low-carbon economy. Because of their dual characteristics of influence and vulnerability, these variables should be prioritized in governance and

TABLE 4 Hypothesis testing using structural equation modeling.

Hypothesis	Path Coefficient (β)	t-value	p-value	Conclusion
H1 Green Governance → Low-Carbon Economy	0.52	6.45	<0.001	Supported
H2 Green Governance → Institutional Resilience	0.67	7.89	<0.001	Supported
H3 Green Governance → Environmental Policy Effectiveness	0.61	7.12	<0.001	Supported
H4 Institutional resilience → Low-Carbon Economy	Indirect Effect: 0.45	Sobel Test: 5.98	<0.005	Supported
H5 Environmental Policies→ Low-Carbon Economy	Indirect Effect: 0.38	Sobel Test: 5.47	<0.005	Supported



policy reform efforts to enhance overall system stability and adaptability.

4.4.3 Quadrant 3—dependent variables (OUTPUT)

Variables in this quadrant have low influence but high dependency, indicating their role as system outcomes. These include LCE1, LCE4, LCE5, LCE6, as well as certain components of EPE and IR, such as EPE1, EPE3, and IR5. Their placement suggests that while these factors are significantly affected by other system dynamics, they exert limited feedback influence.

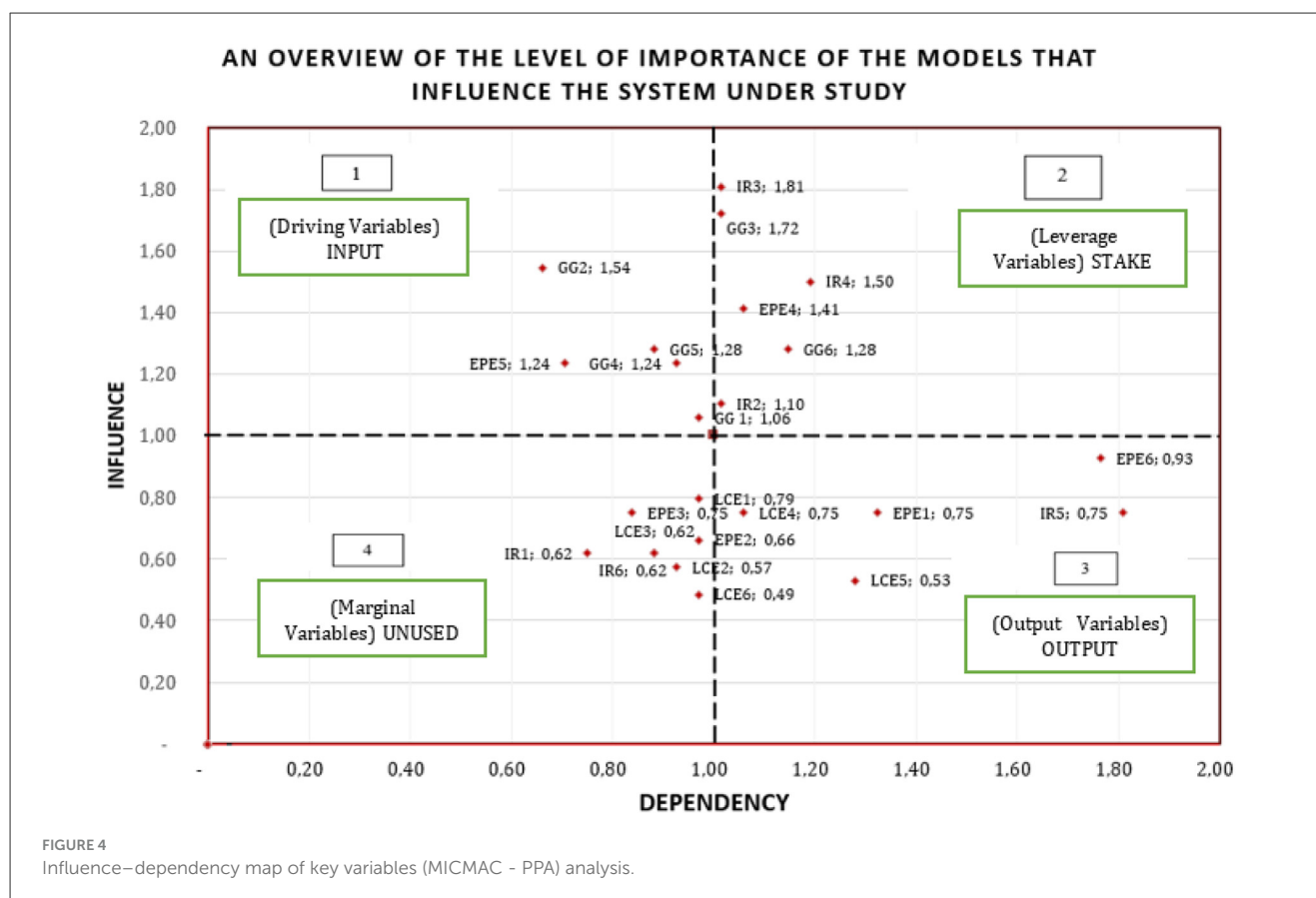
These variables should be treated as performance indicators for monitoring policy success rather than as direct intervention targets. Sustainable improvement in these outcomes depends on addressing the upstream drivers and leverage variables identified in Quadrants 1 and 2.

4.4.4 Quadrant 4—marginal variables (UNUSED)

This quadrant consists of variables with low influence and low dependency, reflecting their marginal role within the current system configuration. Examples include IR1 (organizational adaptability), IR6, LCE2, LCE3, and EPE2. Although these variables may assume greater relevance under specific future scenarios, they currently exert limited systemic leverage. Hence, these variables can be deprioritized in short-term strategic planning, while still being monitored for potential shifts in influence as the policy and governance environment evolves.

5 Discussion

This study provides a comprehensive perspective by integrating quantitative modeling through Structural Equation Modeling (SEM) with prospective structural analysis using the MICMAC approach. This integration enables a deeper understanding



of the systemic interactions among variables related to green governance, institutional resilience, environmental policy effectiveness, and the low-carbon economy, as shown in Table 5. The discussion highlights how these elements contribute to systemic transformation and policy implications.

5.1 Green governance—low carbon economy: a strategic driver of systemic change

The SEM results underscore the pivotal role of Green Governance (GG) in shaping both Institutional Resilience (IR) ($\beta = 0.67$) and Environmental Policy Effectiveness (EPE) ($\beta = 0.61$), with an indirect pathway to the Low Carbon Economy (LCE). This indicates that governance mechanisms such as public participation (GG2) and institutional coordination (GG3) function as upstream enablers. The MICMAC analysis positions these indicators in Quadrant I (high influence, low dependency), confirming their role as driving variables.

These findings are consistent with previous research indicating that robust green governance practices—such as policy transparency, inclusive stakeholder engagement, and the use of environmental incentives—serve as critical enablers for advancing low-carbon economic strategies (Araujo-Vizuete and Robalino-López, 2025; He G. et al., 2024; Kwilinski et al., 2023; Raihan et al., 2025; Zhang and Chen, 2025). Strengthening policy frameworks that emphasize sustainability, energy efficiency, and

climate change mitigation can play a key role in helping industrial and business sectors reduce carbon emissions.

This result highlights that governance is not merely an administrative or regulatory function but a strategic lever for sustainable transformation. Effective green governance ensures stakeholder engagement, accountability, and coordinated policy execution. In contexts where ecological sustainability is at risk, activating participatory and integrative governance frameworks becomes essential. Although this study aligns with Sustainable Development Goals (SDGs) such as SDG 13 (climate action), SDG 14 (life below water), and SDG 16 (strong institutions), our findings suggest a more substantive link: effective mangrove governance supports broader development objectives by enhancing institutional equity, fostering participatory environmental management, and ensuring the equitable distribution of ecological benefits. These outcomes illustrate the embeddedness of ecosystem resilience within sustainable development efforts, especially at the subnational level.

5.2 Institutional resilience as a mediating mechanism in green governance

Institutional Resilience (IR) emerges in the SEM model as a mediating variable between GG and LCE, with a significant indirect effect (0.4; Sobel test = 5.98, $p < 0.005$). The MICMAC findings show that variables such as IR3 (stability) and IR4 (capacity for innovation in environmental strategies) are located in Quadrant

TABLE 5 Synthesis of SEM + MICMAC integration.

Aspect	SEM result	MICMAC result	Integrated synthesis	Policy implication
Green Governance (GG)	Direct effect on IR ($\beta = 0.67$), EPE ($\beta = 0.61$); indirect to LCE	GG2 (Public participation) and GG3 (Institutional coordination): High influence, low dependency (Quadrant II)	GG is a strategic enabler for system transformation	Strengthen participation platforms and inter-agency coordination mechanisms
Institutional Resilience (IR)	Mediator toward LCE (Indirect effect = 0.4, Sobel test = 5.98, $p < 0.005$)	IR3 (Stability) and IR4 (Capacity for innovation in environmental strategies): High influence and dependency (Quadrant I)	IR is a leverage subsystem requiring stable and committed institutions	Foster leadership capacity and ensure long-term institutional stability
Environmental Policy Effectiveness (EPE)	Mediator toward LCE (Indirect effect = 0.3, Sobel test = 5.47, $p < 0.005$)	EPE4 (Supervision) and EPE5 (Economic instruments): High influence, low dependency (Quadrant II)	EPE plays a critical role as a policy enabler for the transition toward a low-carbon economy	Enhance regulatory enforcement and expand the use of green economic instruments
Low Carbon Economy (LCE)	Final outcome driven by IR and EPE	Most sub-variables in Quadrant III: High dependency, low influence	LCE is a dependent variable that reflects upstream governance and institutional inputs	Strengthen enabling environments and structural policies to support LCE outcomes

II (high influence and high dependency), classifying them as leverage variables.

The relatively high path coefficient between green governance and institutional resilience ($\beta = 0.67$, $p < 0.001$) suggests a strong and significant relationship, underscoring the critical role of institutional frameworks in supporting environmental governance systems. This finding indicates that effective governance practices—such as transparency, stakeholder participation, inter-agency coordination, and long-term policy commitment—can substantially enhance institutional capacity to withstand and adapt to environmental pressures and evolving policy landscapes.

Institutional resilience, in this regard, functions as a mediating mechanism that enables systems to remain stable while being flexible in responding to uncertainties. Resilient institutions facilitate regulatory adaptability, promote learning-based policy reform, and strengthen cross-sectoral cooperation—all of which are essential to address complex sustainability challenges (Ostrom, 2009; Pichancourt et al., 2025). This aligns with prior research emphasizing that institutional robustness and adaptability are fundamental to achieving long-term environmental objectives (Akhtar et al., 2023; Guttman et al., 2018; Yuning et al., 2024).

Moreover, the MICMAC analysis reinforces this interpretation by positioning key institutional elements such as leadership commitment and stability in the quadrant of high influence and high dependency. This dual role underscores the systemic leverage potential of institutional resilience: it is shaped by governance practices yet exerts critical influence on downstream outcomes such as environmental policy effectiveness and the low-carbon economy. Therefore, fostering institutional resilience requires targeted investments in leadership development, regulatory innovation, and institutional learning frameworks.

Ultimately, the effectiveness of green governance initiatives is contingent upon the capacity of institutions to remain responsive and adaptive. In rapidly evolving environmental and socio-political contexts, policy implementation cannot be static; it must be supported by institutions capable of iterative learning, multi-actor engagement, and dynamic strategy adjustment (Johnson et al., 2021; Partidário et al., 2023). Strengthening institutional resilience is thus not merely a technical necessity but a strategic imperative in the transition toward sustainable and low-carbon development.

5.3 Green governance and environmental policy effectiveness as systemic leverage

The empirical findings reveal that green governance (GG) exerts a significant positive influence on environmental policy effectiveness (EPE) ($\beta = 0.61$, $p < 0.01$), supporting prior studies linking governance quality to environmental performance (Dincă et al., 2022; Najia et al., 2024; Wang et al., 2023). This suggests that governance frameworks embedding transparency, inclusiveness, stakeholder engagement, and accountability enhance both institutional legitimacy and policy implementation effectiveness.

Furthermore, the study identifies EPE as a partial mediator in the relationship between green governance and low-carbon economic transformation, with an indirect effect size of 0.3 (Sobel test = 5.47, $p < 0.005$). This mediation implies that governance mechanisms exert much of their transformative influence through the design, enforcement, and responsiveness of environmental policy instruments. The significance of EPE as an intermediary variable underscores that policy quality is a key channel through which governance is translated into tangible climate and sustainability outcomes.

Complementing the structural model, the MICMAC analysis further highlights the strategic positioning of two EPE-related variables—EPE4 (supervision) and EPE5 (economic instruments)—both categorized in Quadrant II, indicating high influence and low dependency. These findings suggest that supervision mechanisms (e.g., compliance audits, environmental monitoring) and market-based instruments (e.g., green subsidies, environmental taxes) are pivotal leverage points. Their relatively autonomous position indicates that targeted enhancements in these domains can produce ripple effects across the governance system without requiring heavy reliance on upstream variables.

The alignment between SEM and MICMAC thus provides analytical convergence, emphasizing that environmental policy effectiveness is not merely an outcome of governance but a strategically situated subsystem capable of driving systemic transitions when properly empowered. As the literature highlights, leveraging economic instruments and ensuring robust oversight mechanisms are essential for achieving long-term decarbonization targets and fostering adaptive environmental institutions (Ali,

2024; Liu, 2023; Madadzadeh et al., 2024; Shah et al., 2022; Wu and Tham, 2023).

Accordingly, strengthening EPE—particularly through improved supervision and economic instruments—can act as a catalytic mechanism for accelerating the transition toward a low-carbon economy. These efforts must be embedded within a broader governance strategy that promotes institutional coherence, enhances participatory processes, and fosters regulatory innovation.

5.4 Low carbon economy: a dependent system outcome

As a result, the Low Carbon Economy (LCE) is the final dependent variable in the SEM framework, significantly influenced by IR and EPE. The MICMAC results confirm this, placing most LCE indicators in Quadrant III (high dependency, low influence), marking them as output variables. This configuration reflects the nature of the LCE as a systemic outcome dependent on the upstream performance of governance structures, institutional quality, and policy effectiveness. It also indicates that interventions targeting LCE outcomes must be preceded by strong institutional and governance foundations. Policy pathways toward a low-carbon economy should therefore be designed using an ecosystemic logic that integrates governance, regulation, participation, and institutional reform.

This study reveals that institutional resilience serves as a significant mediating factor between green governance and the low-carbon economy ($\beta = 0.45$, $p < 0.05$). Institutional resilience plays a pivotal role in sustaining green policy implementation and enhancing the preparedness of both public and private sectors in responding to environmental challenges. In this regard, adaptive regulatory frameworks and robust institutional support are essential to facilitate the transition toward a low-carbon economy (Green and Gambhir, 2020; Hall et al., 2017).

Moreover, environmental policy effectiveness also emerges as a key determinant of low-carbon economic outcomes ($\beta = 0.38$, $p < 0.05$). Strong environmental regulations can incentivize investment in renewable energy, resource efficiency, and sustainable production practices. These findings align with previous studies emphasizing the central role of environmental policy in fostering sustainable business ecosystems and promoting green innovation (Ullah et al., 2025; Naruetharadhol et al., 2024). Similarly, Rahman and Islam (2024) and Setyadi et al. (2025) highlighted the mediating influence of institutional capacity in coastal policy outcomes. However, unlike their studies, this research incorporates strategic variable mapping through MICMAC to provide a more dynamic view of institutional interdependencies. Additionally, our results differ from Owusu et al. (2024), who found no significant mediation effect of resilience in lowland forest governance, suggesting that ecosystem type and governance structure play a critical role in shaping institutional function.

By combining SEM and MICMAC, this study offers a novel empirical contribution to the literature on green governance—particularly in fragile coastal ecosystems where institutional dynamics are highly complex. The integration of institutional resilience within the low-carbon policy framework provides new

insights into how adaptive governance models can be developed to address localized environmental challenges.

5.5 Theoretical, contextual, and practical contribution

This study contributes to the literature not only through its methodological innovation but also through its theoretical, contextual, and practical insights. From a theoretical standpoint, the research advances the discourse on environmental governance by empirically demonstrating the mediating role of institutional resilience in linking green governance to environmental policy effectiveness and the transition toward a low-carbon economy. Whereas, previous studies have typically examined these constructs in isolation, this study integrates them into a unified explanatory framework, thereby extending governance and institutional theories within socio-ecological systems.

From a methodological perspective, novelty arises from the combined application of Structural Equation Modeling (SEM) and MICMAC analysis. SEM offers robust statistical validation of causal linkages among governance, resilience, policy effectiveness, and low-carbon transition, while MICMAC provides a strategic mapping of variable interdependencies. The integration of these two methods bridges the gap between quantitative validation and strategic foresight, resulting in a more holistic framework for evidence-based policy formulation.

In terms of contextual contribution, the research focuses on mangrove ecosystems in Indonesia, which host the largest expanse of mangroves globally yet face severe degradation pressures. Unlike most previous studies conducted in developed contexts or at the national level, this study highlights a Global South perspective at the local governance scale. This lens underscores the governance challenges of reconciling ecological preservation with socio-economic needs in coastal regions, generating insights that are both locally grounded and globally resonant.

Finally, the study makes a practical contribution by identifying actionable priorities for policymakers. The integration of SEM and MICMAC results points to public participation, regulatory enforcement, and economic instruments as key leverage factors for institutional strengthening. This dual methodological and strategic orientation ensures that the findings are both academically rigorous and policy-relevant, providing concrete pathways for enhancing green governance and institutional resilience in the pursuit of a low-carbon economy.

5.6 Policy implications and study limitations

The findings hold several policy implications. First, enhancing institutional resilience is critical to improving environmental policy effectiveness in mangrove ecosystems. This can be achieved through capacity-building, decentralized decision-making, and participatory planning that empowers local communities. Second, governance drivers such as cross-sectoral coordination and regulatory enforcement should be prioritized in policy reform agendas. Nonetheless, this study has limitations. The empirical data were collected from a single agency, which may constrain the

generalizability of findings to broader national or regional contexts. Moreover, while SEM and MICMAC provide strong analytical capabilities, their outputs depend on the accuracy of input variables and expert assessments, which may introduce interpretive bias.

6 Conclusion

This study provides empirical evidence on how green governance, mediated by institutional resilience, can significantly enhance the effectiveness of environmental policies in fragile ecosystems such as mangrove regions. By integrating Structural Equation Modeling (SEM) and MICMAC analysis, the research offers a unique methodological approach to map both statistical relationships and strategic governance drivers. The results confirm that institutional resilience plays a pivotal mediating role in linking participatory governance with policy outcomes, while also highlighting the importance of regulatory enforcement and cross-sectoral coordination as core components of strategic governance. Institutional resilience emerges as a fundamental capacity that enables institutions to adapt and sustain effective environmental governance amid evolving challenges. Consequently, the transition to a low-carbon economy is dependent on robust upstream governance and institutional foundations.

Beyond its methodological contribution, this study advances the literature by offering theoretical novelty, demonstrating the mediating role of institutional resilience as a critical mechanism in green governance frameworks. It also provides contextual novelty by generating evidence from mangrove ecosystems in Indonesia, a climate-vulnerable region in the Global South that has received limited scholarly attention. Furthermore, it delivers practical novelty by identifying actionable priorities such as public participation, regulatory enforcement, and ecosystem-sensitive planning that can guide policymakers in designing effective low-carbon transitions. Future research should further explore the temporal dimensions of institutional resilience and expand comparative perspectives across different ecological zones to strengthen the external validity and policy relevance of green governance frameworks.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Lembaga Penelitian dan Pengabdian Masyarakat UNRI. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

MN: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. ZR: Methodology, Supervision, Formal analysis, Validation, Writing – review & editing. MH: Formal analysis, Software, Validation, Visualization, Writing – review & editing. Z: Resources, Validation, Writing – original draft. AS: Conceptualization, Formal analysis, Investigation, Validation, Writing – original draft. M: Data curation, Resources, Software, Writing – original draft. A: Formal analysis, Project administration, Validation, Visualization, Writing – original draft. I: Conceptualization, Investigation, Software, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fpos.2025.1631249/full#supplementary-material>

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