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System Dynamics Approach for Analyzing Coastal Legal Issues

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Abstract. Coastal legal issues are rarely caused by a single legal problem. They emerge from interactions among overlapping spatial plans, unclear permits, fragmented governance, weak enforcement, public distrust, development pressure, environmental degradation, and vulnerable coastal livelihoods. This article analyzes these issues through a System Dynamics approach by combining a PRISMA-based Systematic Literature Review, Causal Loop Diagram, Stock and Flow Diagram, and conceptual policy scenario simulation. The SLR–PRISMA process identifies and synthesizes studies on coastal law, governance, compliance, legitimacy, environmental pressure, livelihood vulnerability, and System Dynamics. The findings are translated into a CLD to map causal relationships, reinforcing loops, and balancing loops. The CLD is then developed into an SFD to describe key stocks, flows, and auxiliary variables shaping coastal legal conflicts. The analysis shows that these conflicts are not merely caused by zoning or permit violations, but also by legal uncertainty, limited governance capacity, declining legitimacy, environmental stress, and socio-economic vulnerability. The conceptual simulation suggests that partial policy responses may have limited effects when implemented separately. An integrated policy package is more promising because it addresses multiple leverage points simultaneously. This article concludes that System Dynamics provides an adaptive, feedback-oriented framework for coastal legal analysis

Keywords: *coastal law; CLD–SFD; SLR–PRISMA; system dynamics*

INTRODUCTION

Coastal areas are spaces where ecological, social, economic, and legal interests meet. They support fisheries, tourism, conservation, settlements, ports, reclamation projects, aquaculture, and coastal economic development. Because of this diversity, coastal areas are often governed by multiple actors, overlapping interests, and different regulatory regimes. Coastal legal issues therefore tend to appear as multi-actor and multi-level governance problems, especially when institutional mandates overlap, spatial plans are not synchronized, permits are unclear, enforcement is weak, and the interests of government, coastal communities, business actors, and local or customary groups do not always align (De Rooy *et al*., 2021; Frohlich *et al*., 2022; Bosboom & Stive, 2023; Sanromualdo-Collado *et al*., 2025).

In coastal governance, legal issues cannot be understood only as violations of formal rules. Coastal legal conflicts are also shaped by zoning and permitting certainty, spatial use compliance, recognition of community rights, policy legitimacy, enforcement capacity, and the impact of development on coastal environments and livelihoods. Studies on land rights in coastal conservation areas, for example, show the importance of regulatory synchronization and harmonization in ensuring legal certainty for communities living in or around coastal conservation zones (De Rooy *et al*., 2021). Similarly, research on coastal land use in Tulungagung shows that settlements, tourism activities, and aquaculture practices need to be assessed in relation to the legal framework governing coastal areas and small islands (Frohlich, 2021).

At the same time, coastal areas are dynamic socio-ecological systems. Development pressure, land-use change, ecosystem degradation, abrasion, coastal flooding, and shifts in local livelihoods can all affect the legitimacy and effectiveness of law. Frohlich *et al*. (2022) argue that adaptive coastal management law requires a balance between legal certainty and legal flexibility. Legal certainty is needed so that actors understand their rights, obligations, and limits, while legal flexibility is needed so that the law can respond to changing socio-ecological conditions. Sanromualdo-Collado *et al*. (2025) also show that coastal areas may function as one

connected ecological unit, while administratively they are often fragmented. This mismatch between ecological connectivity and administrative boundaries can create further governance and legal challenges.

These interactions show that coastal legal issues are not linear. A permitting policy may influence the behavior of coastal actors; that behavior may increase environmental pressure; environmental pressure may affect livelihoods; livelihood vulnerability may trigger dissatisfaction and conflict; and conflict may then weaken legitimacy, compliance, and governance capacity. Coastal legal issues therefore form feedback structures that are difficult to explain through conventional linear legal analysis. System Dynamics offers a useful framework for understanding such complexity through the concepts of stocks, flows, feedback loops, delays, and scenario analysis. The foundational works of Forrester (1961) and Sterman (2000) provide the basis for this approach, while later studies further emphasize the relevance of System Dynamics for understanding complex policy problems (Forrester, 2016; Barlas, 2025; Naugle *et al.*, 2024).

On this basis, this article applies a Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)-based Systematic Literature Review (SLR), Causal Loop Diagram (CLD), Stock and Flow Diagram (SFD, and policy scenario simulation. The SLR–PRISMA process is used to identify and synthesize relevant literature on coastal law, coastal governance, conflict, compliance, legitimacy, livelihoods, and System Dynamics. PRISMA is applied to make the process of identification, screening, eligibility assessment, and inclusion more transparent and structured (Page et al., *2021*; Hendijani, 2021; Pluchinotta *et al*.,2024). The CLD is used to map causal relationships and feedback loops, while the SFD translates these causal structures into stocks, flows, and auxiliary variables as the basis for dynamic model development (Forrester, 1961; Sterman, 2000; Naugle *et al*., 2024). The policy scenario simulation is then used conceptually to compare the possible direction of coastal legal conflict under several scenarios, including business as usual, regulatory harmonization, data integration, strengthened enforcement, dispute resolution, and an integrated policy package (Malbon and Parkhurst, 2023; Hosseinichimeh *et al*., 2024; Akhavan & Jalali, 2024).

Research Problems

Based on the background above, this article addresses the following main question: how can a System Dynamics approach, supported by SLR–PRISMA synthesis, CLD–SFD modeling, and policy scenario simulation, be used to analyze the structure, dynamics, and leverage points of coastal legal issues? This main question is developed into five operational questions:

1) How does the SLR–PRISMA process identify key themes, variables, and policy interventions related to coastal legal issues?
2) How can the causal structure of coastal legal issues be represented through a CLD?
3) How can the CLD be translated into an SFD as an initial dynamic model design?
4) How do different policy scenarios influence the possible direction of coastal legal conflict in a conceptual simulation?
5) Which policy scenario appears most reasonable for reducing coastal legal conflict in a systemic way?

These questions reflect the position of this article not merely as a literature review, but as an effort to develop a conceptual model and policy scenario framework. The focus is therefore not only on identifying legal problems, but also on understanding the systemic structure that produces and reinforces coastal legal conflict

State of the Art and Novelty

The state of the art in coastal governance studies shows three major streams of literature that support this article. The first stream concerns coastal governance and adaptive coastal management law. This literature emphasizes that effective coastal management requires both legal certainty and legal flexibility, coordination among institution, and the capacity to respond to socio-ecological change. Frohlich (2021) highlight the need to balance certainty and flexibility and to address legal path dependencies that can cause maladaptive outcomes. Empirical evidence from Indonesia tax governance illustrates a similar dynamic: when regulatory frameworks are complex or fragmented, knowledge of the law alone does not guarantee compliance, and overlapping or unclear regulations can reduce that ability of actors to follow rules effectively (Kunyati *et al*., 2024). This suggests that, in coastal governance, overlapping permits, fragmented authority, and unclear spatial arrangements may similarly undermine adaptive management if legal and institutional frameworks are not carefully aligned.

The second stream concerns law, compliance, and enforcement. This literature shows that law operates not only through formal rules, but also through institutional capacity, actor behavior, legal awareness, economic pressure, and social context. Adam *et al*. (2025), in their study of destructive fishing in Maluku, show that coastal law enforcement cannot rely only on penal instruments. It also requires stronger enforcement capacity, maritime surveillance technology, community empowerment, local norms such as sasi laut, and alternative livelihoods. This suggests that compliance and violations in coastal areas should be understood as part of a broader socio-legal system.

The third stream concerns System Dynamics. This literature provides a framework for analyzing non-linear relationships in public policy and legal systems. Classic works such as Forrester (1961) and Sterman (2000) offer the foundation for understanding stocks, flows, feedback, and delays. Studies linking law and System Dynamics, such as Dari-Mattiacci et al. (2011), and Madachy (2017), Hendijani (2021) also suggest that legal systems, legal reform, lawmaking processes, and dispute resolution can be analyzed as dynamic systems.

The novelty of this article lies in the integration of four components. First, it uses SLR–PRISMA to extract relevant themes, variables, and policy interventions from the literature. Second, it translates the SLR findings into a CLD to identify causal relationships, reinforcing loops, and balancing loops. Third, it develops the CLD into an SFD as an initial operational design of a dynamic model. Fourth, it presents a conceptual policy scenario simulation through 2D and 3D visualizations to compare the direction of coastal legal conflict under different policy options. Thus, the contribution of this article is not limited to reviewing the literature, but extends to building a policy modeling framework that can be developed further into a calibrated quantitative simulation.

Research Objectives

The general objective of this article is to analyze coastal legal issues through a System Dynamics approach based on SLR–PRISMA synthesis, CLD–SFD modeling, and conceptual policy scenario simulation. More specifically, this article aims to:

1. develop an evidence map through SLR–PRISMA on coastal law, coastal governance, conflict, compliance, legitimacy, environmental pressure, livelihoods, and System Dynamics;
2. identify the systemic variables that shape coastal legal issues, including zoning and permitting certainty, public legitimacy, compliance, violations, governance capacity, development pressure, environmental quality, and livelihood vulnerability;

3. develop a Causal Loop Diagram to represent causal relationships, reinforcing loops, and balancing loops in coastal legal conflict;
4. translate the Causal Loop Diagram into a Stock and Flow Diagram as an initial dynamic model design based on stocks, flows, and auxiliary variables;
5. formulate and compare policy scenarios through conceptual simulation to examine the possible direction of coastal legal conflict under different intervention options;
6. propose policy recommendations and a further research agenda within a three-year roadmap.

These objectives clarify the role of the present article as the first-year output of a broader three-year research roadmap. At this stage, the study produces the SLR–PRISMA synthesis, evidence map, conceptual CLD, initial SFD, policy scenarios, and conceptual simulation. The next stages of the roadmap will focus on parameterization, calibration, structural and behavioral validation, empirical simulation, sensitivity analysis, policy packaging, monitoring and evaluation design, and possible replication in comparable coastal areas. Through this staged roadmap, the study is expected to move from a conceptual model toward a more empirically grounded and practically useful framework for strengthening coastal legal governance in Indonesia.

METHODS

Research Design

This study uses a PRISMA-based Systematic Literature Review combined with a System Dynamics approach through the development of a Causal Loop Diagram, Stock and Flow Diagram, and conceptual policy scenario simulation. PRISMA 2020 is used as a reporting guideline for the systematic review process. It helps make the identification, screening, eligibility assessment, and inclusion of studies more transparent and structured (Page *et al*., 2021; Kunisch *et al*., 2023; Castellanos-Gomez, 2023; Juniarti et al., 2025). In this study, PRISMA is not treated as the analytical method itself, but as a reporting framework that supports the systematic selection and documentation of relevant literature.

System Dynamics is used because coastal legal issues are non-linear, feedback-driven, and often affected by delayed policy impacts (Madachy, 2017; Pluchinotta *et al*., 2024). The System Dynamics tradition provides a way to understand how system behavior emerges from causal structures, accumulations, feedback loops, and delays (Forrester, 1961; Sterman, 2000). In the context of coastal and marine governance, this approach is useful for examining how legal certainty, compliance, enforcement, development pressure, environmental degradation, and social dissatisfaction interact over time.

General Research Procedure

The study was conducted through five main steps. First, the research questions were formulated based on the relationship between coastal legal issues and systemic governance problems. Second, relevant literature was identified and screened using the PRISMA 2020 procedure. Third, variables and causal relationships were extracted from the selected literature. Fourth, the extracted findings were organized into thematic synthesis. Fifth, the synthesis was translated into a CLD and then further developed into an initial SFD and conceptual policy scenario simulation. The overall methodological flow is shown in Figure 1.

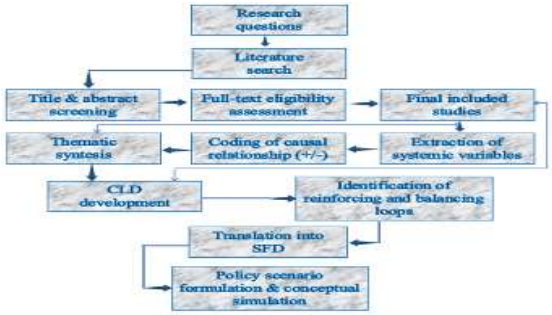


Figure 1. Methodological flow (Page *et al*., 2021; modified)

This methodological flow connects two purposes. The first is to build an evidence base from the literature on coastal law, governance, enforcement, compliance, legitimacy, and System Dynamics. The second is to translate that evidence into a systemic model that can explain causal relationships, feedback loops, and policy leverage points.

Research Questions

The systematic review and model-building process were guided by one main research question: How can SLR–PRISMA synthesis, CLD–SFD modeling, and conceptual policy scenario simulation be used to analyze the structure, dynamics, and policy leverage points of coastal legal issues?

This main question was translated into six operational research questions (Table 1).

Table 1. Operational research questions

Code	Research question (RQ)	Analytical purpose
RQ1	What themes, concepts, and policy issues emerge from the SLR–PRISMA synthesis of coastal law, coastal governance, legitimacy, environmental pressure, livelihoods, and System Dynamics literature?	To develop an evidence map and thematic foundation
RQ2	What systemic variables shape coastal legal issues?	To identify the core variables for the CLD and SFD
RQ3	How are these variables causally connected?	To determine causal relationships and polarity
RQ4	What reinforcing and balancing loops explain the dynamics of coastal legal conflict?	To identify feedback structures in the CLD
RQ5	How can the CLD be translated into an SFD as an initial dynamic model design?	To distinguish stocks, flows, and auxiliary variables
RQ6	How do different policy scenarios affect the possible direction of coastal legal conflict, and what recommendations can be drawn for the three-year research roadmap?	To compare policy scenarios and formulate recommendations

These questions reflect the role of this article as a conceptual and methodological study. The aim is not to produce a fully calibrated simulation model at this stage, but to develop a structured foundation that can later be expanded into a quantitative System Dynamics model.

Literature Search Strategy

The literature search was designed to capture studies located at the intersection of coastal law, coastal governance, Marine Spatial Planning, compliance, enforcement, environmental pressure, livelihood vulnerability, and System Dynamics. The search strategy combined academic databases and institutional sources.

The recommended databases include Scopus, Web of Science, ScienceDirect, SpringerLink, Taylor & Francis, Google Scholar, and national databases such as Garuda and SINTA. Institutional sources such as UNESCO-IOC and MSPglobal may also be used to support the discussion on Marine Spatial Planning and coastal governance (Table 2).

Table 2. Search keyword groups

Concept group	English keywords
Coastal law and conflict	coastal law, legal conflict, permit conflict, zoning conflict, compliance, enforcement
Coastal governance	coastal governance, marine governance, integrated coastal zone management
Marine Spatial Planning	marine spatial planning, ocean planning, marine zoning, coastal zoning
System Dynamics	system dynamics, causal loop diagram, stock and flow diagram, policy simulation
Social dimension	legitimacy, participation, customary law, local community, livelihood

Marine Spatial Planning was included as a key concept because it provides a governance framework for organizing the use of marine and coastal space in a more coordinated, ecosystem-based, and adaptive manner (Ehler and Douvere, 2009). In this article, MSP is not treated as a purely technical planning instrument, but as part of a broader legal and governance structure that influences zoning certainty, permitting consistency, public legitimacy, and potential conflict.

Inclusion and Exclusion Criteria

The inclusion and exclusion criteria were developed to ensure that the selected studies were relevant not only to coastal law (Table 3), but also to the development of a System Dynamics model. Studies were included when they provided useful information on legal issues, governance structures, actors, variables, causal relationships, or policy interventions related to coastal areas.

Table 3. Inclusion and exclusion criteria

Aspect	Inclusion criteria	Exclusion criteria
Substantive focus	Studies discussing coastal governance, MSP, spatial conflict, permitting, enforcement, compliance, legitimacy, or customary/local law	Studies discussing coastal areas only from a biological or ecological perspective without legal or governance relevance
Analytical approach	Studies containing policy, institutional, conflict, participation, or systems analysis	Opinion pieces without clear methodology or evidence base
Model relevance	Studies containing systemic variables, causal relationships, CLD, SFD, System Dynamics	Studies that do not provide extractable variables or causal relationships
Study area	Global, regional, or Indonesian studies relevant to coastal or marine governance	Studies unrelated to coastal, marine, or coastal-space governance
Language	English or Indonesian	Other languages that cannot be analyzed
Document type	Journal articles, proceedings, books, credible institutional reports, policy guidelines	Popular documents without academic or institutional support

PRISMA-Based Study Selection Procedure

The study selection process followed four main PRISMA stages: identification, screening, eligibility, and inclusion. In the identification stage, records were gathered from academic databases, institutional sources, and the author's compiled reference list. In the screening stage, titles and abstracts were reviewed to remove studies that were clearly irrelevant. In the eligibility stage, full texts or extended abstracts were assessed against the inclusion and exclusion criteria. Finally, the included studies were used for thematic synthesis and CLD–SFD construction.

PRISMA 2020 was used to ensure that the review process was transparent and traceable (Page *et al*., 2021). In this article, the PRISMA flow (Figure 2) is presented as a working structure because the study is part of the first-year output. The numbers may be refined in future work when database searching is expanded and documented more fully.

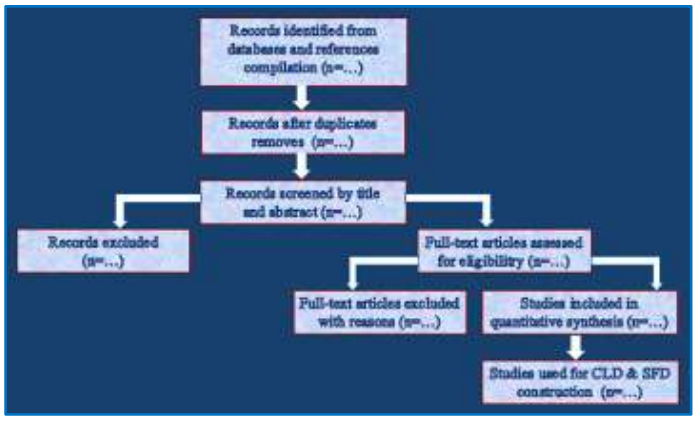


Figure 2. Proposed PRISMA flow diagram

Data Extraction and Syntesis

Data were extracted from the included studies using a synthesis matrix. The extraction was not limited to general findings; it focused on information that could be translated into systemic variables and causal relationships. Each study was reviewed to identify its context, main issue, actors, variables, causal logic, policy intervention, and relevance to the CLD–SFD model.

This extraction process helped ensure that each variable in the model could be traced back to the literature. For example, the variable consistency between MSP, spatial plans, and permits was derived from coastal governance and MSP literature. The variable public legitimacy was derived from studies on participation, trust, and social sustainability. The variable development pressure was derived from literature on coastal development, blue economy, special economic zones, and land-use change.

After extraction, the findings were organized through thematic synthesis (Figure 3). The purpose of this synthesis was to group the literature into themes that could support the construction of the CLD and SFD. Each theme was then translated into model variables, causal relationships, and possible feedback loops.

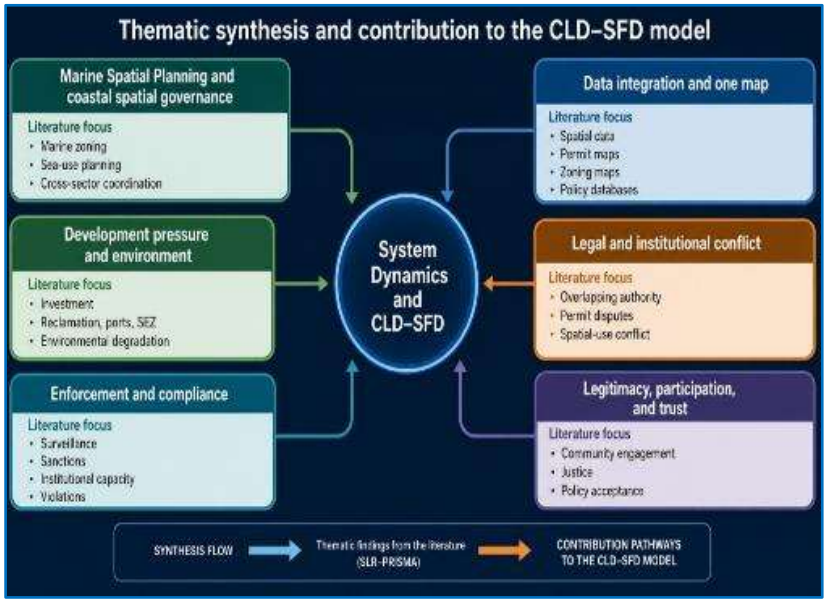


Figure 3. Thematic synthesis and contribution to the CLD–SFD model

Development of the Causal Loop Diagram

The CLD was developed by translating the thematic synthesis into variables and causal relationships. Each relationship was assigned a polarity (Stearman, 2000). A positive relationship **(+)** means that a change in one variable leads to a change in the same direction in another variable. For example, higher consistency between MSP, spatial plans, and permits increases zoning and permitting certainty. A negative relationship **(−)** means that a change in one variable leads to a change in the opposite direction in another variable. For example, higher zoning and permitting certainty reduces coastal legal conflict (Table 6).

The CLD is used to identify how coastal legal conflict emerges, persists, and potentially escalates. It also helps identify where policy interventions may be most effective.

Operationalization of CLD Variables

To make the CLD analytically useful, each variable was operationalized. This step is important because the study is intended to serve as a foundation for future quantitative modeling (Forrester, 2016; Barlas, 2025). Operational definitions (Table 7) also help clarify how each variable may later be measured in empirical research.

Policy Scenario Formulation

Policy scenarios were formulated based on the policy levers identified in the CLD and SFD. The scenarios are conceptual at this stage. They are not yet based on calibrated empirical parameters, but they help compare the expected direction of system behavior under different policy assumptions.

Table 6. Main variable groups in the CLD

Variable group	Variables	Function
Policy levers	A1 Consistency between MSP, spatial plans, and permits; A2 One data/one map; A4 Effectiveness; A5 Strength of control	Points of policy intervention
Development pressure	A3 Investment/development pressure; P1 Increased spatial use and activity intensity	Development-driven pressure
Governance mechanism	S2 Zoning and permitting certainty; S4 Governance and control capacity; S6 Public legitimacy	Institutional mechanism
Compliance and conflict	S3 Compliance with spatial use rules; V1 Zoning/permit violations; S1 Coastal legal conflict	Actor behavior and legal outcome
Socio-ecological channel	S5 Coastal environmental pressure/ quality decline; L1 Livelihood vulnerability and dissatisfaction	Social-ecological pathway to conflict

Table 7. Operationalization of CLD variables

Code	Variable	Operational definition	Potential indicators
A1	Consistency between MSP, spatial plans, and permits	Degree of alignment between marine spatial plans, land-based spatial plans, and coastal permits	Number of overlapping permits; permit-zoning consistency
A2	One data / one map	Integration of permit data, zoning data, boundaries, and activities	Availability of integrated database; map interoperability
A3	Investment/development pressure	Physical and economic development pressure in coastal areas	Number of projects, investment permits, reclamation, ports, SEZ
P1	Spatial-use intensity	Degree of coastal and marine space utilization	Activity density, number of users, volume of activities
S2	Zoning and permitting certainty	Clarity of spatial rules, permit status, and limits of use	Zoning clarity, permit consistency, predictability
S1	Coastal legal conflict	Legal disputes or tensions related to coastal spatial use	Number of disputes, lawsuits, complaints, protests, conflicts
S6	Public legitimacy/trust	Public acceptance of coastal governance processes and outcomes	Public trust, participation, perceived fairness
S3	Compliance with spatial use rules	Degree to which actors follow zoning and permit rules	Violation rate, permit compliance rate
V1	Zoning/permit violations	Activities inconsistent with zoning or permits	Illegal activities, permit deviations, spatial violations
S4	Governance and control capacity	Institutional ability to coordinate, monitor, and enforce rules	Number of inspectors, budget, inspection frequency
A5	Strength of control and sanctions	Consistency and enforceability of monitoring and sanctions	Number of sanctions, enforcement effectiveness
A4	Effectiveness of dispute resolution	Speed, accessibility, and fairness of conflict resolution mechanisms	Duration of disputes, mediation outcomes
S5	Coastal environmental pressure	Decline in ecological quality due to coastal activities	Pollution, habitat damage, sedimentation, abrasion
L1	Livelihood vulnerability and dissatisfaction	Socio-economic impacts experienced by coastal communities	Fisher income, loss of access, community complaints

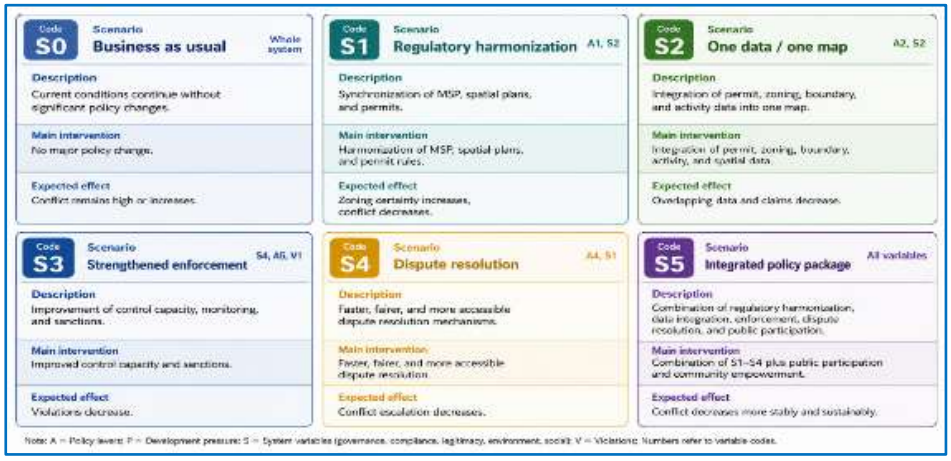


Figure 4. Policy scenario design

The scenario design reflects the systemic character of coastal legal conflict. A single intervention may help, but it may not be sufficient if other parts of the system remain weak (Barlas, 2025). For example, stronger sanctions may reduce violations, but their effect may be limited if zoning certainty is low and public legitimacy is weak. This is why the integrated policy package is expected to produce the strongest effect.

Conceptual 2D and 3D Simulation

This conceptual simulation develops a System Dynamics framework to visualize coastal legal conflict patterns over a ten-year period using a hypothetical 0–100 index, comparing six distinct policy scenarios across 2D and 3D visualizations. Rather than serving as an empirical forecast, the exploratory model highlights policy interactions, demonstrating that conflict declines most effectively when multiple leverage points are strengthened simultaneously.

To ensure conceptual robustness, the model's validity was addressed through three rigorous approaches. First, literature-based validity anchored core variables—including zoning certainty, legitimacy, compliance, and livelihood vulnerability—within established coastal governance, socio-ecological, and System Dynamics studies (Frohlich, 2021; Letortu et al., 2023; Van Rooij, 2023). Second, system logic validity confirmed that the proposed causal relationships were conceptually plausible, ensuring that feedback directions—such as higher zoning certainty reducing conflict, or stronger governance capacity mitigating violations—aligned with systemic expectations (Adam *et al*., 2025). Third, initial structural validity verified that the model captured meaningful reinforcing and balancing loops, though full validation will still require expert reviews and empirical calibration in future research roadmaps (Ebeler *et al*., 2025; Kunyati *et al*., 2024).

Consequently, this study acknowledges key methodological limitations: the framework remains conceptual without empirical estimates, the SFD lacks local or longitudinal data calibration, the simulations rely on hypothetical indices, and the PRISMA literature flow may require future expansion.

RESULTS AND DISCUSSION

Results of the SLR–PRISMA Process

The SLR–PRISMA process produced a focused body of literature that supports the development of a System Dynamics model for coastal legal issues. The included studies are not

limited to legal scholarship in a narrow doctrinal sense. Instead, they cover four interconnected bodies of knowledge: coastal law and governance, System Dynamics and causal modeling, law as a dynamic system, and socio-ecological coastal change. This combination is important because coastal legal conflict does not emerge from legal rules alone. It is shaped by the interaction between legal certainty, institutional capacity, public legitimacy, compliance behavior, development pressure, environmental change, and livelihood vulnerability.

The initial reference pool contained works on System Dynamics, legal systems, coastal management law, coastal ecological change, community resilience, coastal land use, environmental law, dispute resolution, and public governance. During screening, studies that were too distant from the article's focus—such as those dealing primarily with blockchain governance, artificial intelligence in civil justice, or genetic and genomic legal modeling—were not used as core sources for the synthesis. They were considered peripheral because they did not directly support the construction of variables, causal relationships, or feedback loops for coastal legal governance.

The final included literature was organized into four main groups (Table 8). The first group consists of studies on coastal law, coastal governance, and adaptive coastal management, including several recent studies (Frohlich *et al*., 2022; De Rooy *et al*., 2021; among others) These studies provide the substantive foundation for understanding legal uncertainty, spatial-use conflict, rights recognition, enforcement limitations, participation, and livelihood vulnerability in coastal areas. Frohlich *et al*. (2022), for instance, emphasize that adaptive coastal management requires both legal certainty and legal flexibility, while De Rooy *et al*. (2021) highlight the importance of harmonizing regulations to protect community rights in coastal conservation areas.

Table 8. Final grouping of included literature

Literature group	Main references	Main contribution to the article
Coastal law and governance	Frohlich et al. (2022); De Rooy et al. (2021); De Lucia, (2020); Haniah and Putranto (2024); Tyas (2023); Bollier (2020); Adam et al. (2025); Sanromualdo-Collado et al. (2025); Coffman et al. (2025); Ebeler et al. (2025); Letortu et al. (2023); Kunyati et al. (2024)	Provides the substantive basis for legal certainty, spatial-use conflict, enforcement, dispute resolution, participation, and livelihood vulnerability
System Dynamics and CLD–SFD methods	Forrester (1961); Sterman (2000); Ngonga (2019); Forrester (2016); Barlas (2025); Hosseinichimeh et al. (2024); Malbon and Parkhurst (2023); Naugle et al. (2024)	Provides the methodological basis for feedback thinking, CLD, SFD, stock-flow logic, and policy simulation
Law as a dynamic system	Dari-Mattiacci et al. (2011); Madachy (2017); Turner (2018); Van Rooij (2023); Vladimirova (2022); Wardhani et al. (2022); Pavlov et al. (2025); Trofimov (2025); Liu et al. (2025)	Supports the interpretation of law as a dynamic system shaped by behavior, institutions, values, and dispute mechanisms
Environmental dynamics and community resilience	Avilés-Pagán et al. (2024); Yomo et al. (2023); Nevzati et al. (2024); Famous et al. (2025); Cramer et al. (2023); Kurnia et al. (2022); da Silva Ferreira et al. (2023)	Supports the socio-ecological pathway linking environmental pressure, land-use change, well-being, livelihood vulnerability

As can be seen in Table 8, group two is found in articles written by, for example, Hosseinichimeh *et al*. (2024), and Naugle *et al*. (2024). Furthermore, for group three, the literature reviewed includes Madachy (2017), Turner (2018), and Van Rooij (2023). Meanwhile, for group four, the literature reviewed includes literature from Yomo *et al.* (2023), and Nevzati *et al*. (2024). .Overall, the PRISMA-based selection shows that the most useful literature for this article is not confined to one discipline. The final body of literature is interdisciplinary, combining law, governance, systems modeling, environmental change, and

community livelihood studies. This reflects the nature of coastal legal issues themselves: they are legal problems, but they are also institutional, ecological, social, and behavioral problems.

A simplified PRISMA result can be presented as follows (Figure 5).

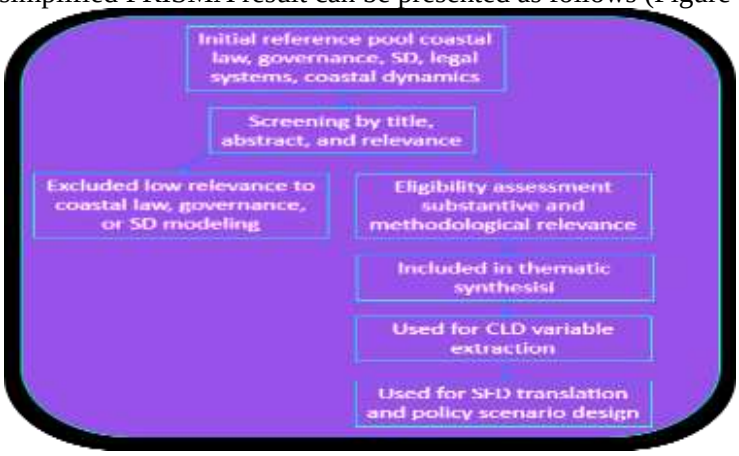


Figure 5. Simplified PRISMA flow for literature selection

A key finding from this process is that the selected literature points to one key point: coastal legal conflict is not a single event. It is a systemic phenomenon, with a number of keywords mapped by frequency of occurrence in Figure 6. Legal uncertainty, fragmented governance, weak enforcement, public distrust, development pressure, and environmental degradation interact over time. This is why the article proceeds from literature synthesis to CLD construction, SFD translation, and conceptual scenario simulation.

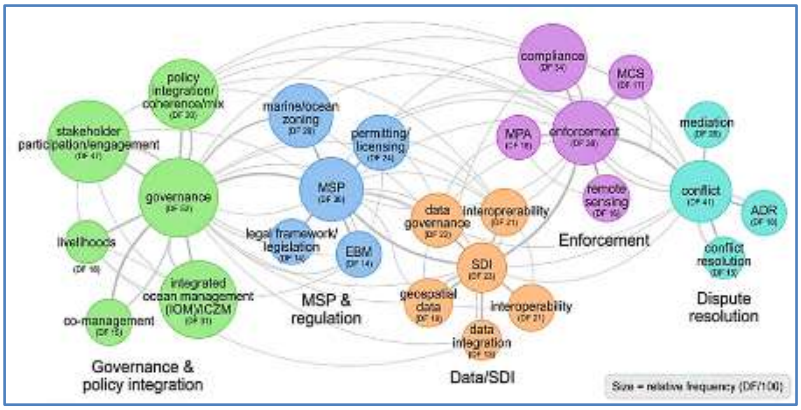


Figure 6. Keywords mapped by frequency of occurrence

Thematic Mapping of the Included Literature

The thematic synthesis produced six major themes. These themes serve as the bridge between the SLR–PRISMA findings and the System Dynamics model. Each theme contributes to the identification of variables, causal relationships, feedback loops, and policy leverage points (Table 9).

Legal certainty and adaptive coastal management emerge as a key theme. Adaptive coastal governance requires both legal certainty and legal flexibility, since coastal areas change dynamically while legal systems often rely on fixed categories, jurisdictional boundaries, and formal procedures (Frohlich, 2021). Legal certainty also depends on regulatory synchronization and harmonization, especially where community rights in coastal conservation areas are involved (De Rooy *et al*., 2021). A second theme concerns spatial-use compliance and enforcement. Coastal land use for settlements, tourism, and aquaculture must align with the

legal framework governing coastal areas and small islands (Haniah & Putranto, 2024). Enforcement challenges, such as destructive fishing, are also shaped by geography, weak surveillance, limited investigators, economic pressure, and low legal awareness (Adam *et al*., 2025).

Table 9. Thematic mapping of the included literature

Theme	Main literature	Key insight	Contribution to CLD–SFD
Legal certainty and adaptive coastal management	Frohlich et al. (2022); De Rooy et al. (2021); Avilés-Pagán et al. (2024)	Coastal law must balance certainty, flexibility, harmonization, and adaptive	Supports S2 zoning and permitting certainty; A1 regulatory consistency
Spatial-use compliance and enforcement	Haniah and Putranto (2024); Adam et al. (2025); Van Rooij (2023)	Compliance depends on legal clarity, enforcement capacity, socio-economic pressure, and legal awareness	Supports S3 compliance; V1 violations; S4 governance capacity; A5 sanctions
Legitimacy, participation, and governance	Kunyati et al. (2024); Ebeler et al. (2025); Kurnia et al. (2022)	Trust and compliance are strengthened by participation, local, and perceived fairness	Supports S6 public legitimacy; L1 livelihood vulnerability
Environmental pressure and socio-ecological change	Sanromualdo-Collado et al. (2025); Fanous et al. (2025)	Coastal change is dynamic, spatially connected, and often shaped by development	Supports A3 development pressure; P1 spatial-use intensity
Dispute resolution and legal conflict	Tyas (2023); Karcher (2015); Madachy (2017) Ngongan (2019)	Legal conflict involves interpretation, institutions, dispute mechanisms	Supports S1 coastal legal conflict; A4 dispute resolution
Scenario thinking and policy simulation	Guo et al. (2021); Malbon and Parkhurst (2023); Naugle et al. (2024)	Scenario analysis helps explore future system behavior under different policy assumptions	Supports conceptual 2D–3D simulation and policy scenario comparison

Legitimacy, participation, and community-based governance form a third major theme. Citizen monitoring can help coastal actors understand hazards, discuss risks, and support more responsive coastal management (Bakker *et al*., 2019; Letortu *et al*., 2023). In Indonesia, local potential and local wisdom are also important for developing sustainable coastal villages (Kunyati et al., 2024). Mangrove restoration further shows that coastal governance is closely linked to livelihoods, economic resilience, benefit distribution, institutional dynamics, and community participation (Venegas *et al*., 2023; Chang *et al*., 2025; Ebeler *et al*., 2025). These studies suggest that legitimacy is not produced by formal regulation alone, but through trust, participation, local relevance, and perceived fairness.

The fourth theme concerns environmental pressure and socio-ecological change. Anthropogenic activities can reduce natural coastal wetlands while increasing artificial and non-wetland areas (Guo *et al*., 2021). Coastal systems may also function as integrated ecological units despite being divided by administrative boundaries (Sanromualdo-Collado *et al*., 2025). Modeling such ecosystems is complex, particularly in data-scarce contexts (Fanous et al., 2025).

The fifth theme is dispute resolution and the political nature of legal conflict. Maritime disputes involve legal claims, resource interests, geopolitical dynamics, and negotiation (Tyas, 2023), while System Dynamics can help examine legal reform and lawmaking processes (Karcher, 2015; Madachy, 2017). Finally, scenario thinking supports policy simulation. Scenario-based models help explore future spatial and environmental dynamics (Guo *et al*., 2021; Yomo *et al*., 2023; Nevzati et al., 2024), while System Dynamics supports evidence-informed policymaking and distinguishes conceptual from quantitative modeling (Malbon & Parkhurst, 2023; Naugle *et al*., 2024).

This thematic map shows that the literature does not point to a single cause of coastal legal conflict. Instead, it reveals several interacting pathways. Some pathways are legal and institutional, such as zoning certainty, harmonization, enforcement, and dispute resolution. Others are social, such as legitimacy, participation, and livelihood vulnerability. Others are ecological and spatial, such as environmental pressure and land-use change. The role of System Dynamics is to bring these pathways into one coherent structure.

Systemic Variables Extracted from the SLR

The thematic synthesis shows that coastal legal conflict is shaped by a set of interrelated systemic variables. These variables are not isolated factors. They work together through legal, institutional, behavioral, economic, and ecological pathways. For this reason, the variables extracted from the literature were not treated merely as descriptive categories, but as elements of a dynamic system that can influence one another over time.

The most central variable in the model is coastal legal conflict. This variable represents disputes, tensions, complaints, protests, permit conflicts, jurisdictional disagreements, or legal uncertainty related to the use and governance of coastal space. The literature suggests that such conflict may arise from unclear zoning, overlapping permits, weak enforcement, socio-economic pressure, environmental degradation, and competing interests among actors. Tyas (2023), for example, shows that maritime conflict may involve legal interpretation, resource interests, sovereignty claims, and dispute resolution mechanisms. Although the Natuna case operates at an international scale, it illustrates that legal conflict in coastal and maritime spaces is rarely a purely technical legal matter. It is shaped by law, interest, power, and institutional response.

The second important variable is zoning and permitting certainty. This variable refers to the clarity, consistency, and predictability of spatial rules, permits, and coastal-use boundaries. Frohlich *et al*. (2022) show that adaptive coastal management requires legal certainty, because actors need a clear understanding of what is allowed, restricted, or prohibited. At the same time, De Rooy *et al*. (2021) emphasize the importance of regulatory synchronization and harmonization in coastal conservation areas, especially when community rights and land-use claims are involved. These findings justify the inclusion of zoning and permitting certainty as a key stock in the SFD and as a major balancing force in the CLD.

The third variable is consistency between Marine Spatial Planning, spatial plans, and permits. This variable functions as a policy lever. It captures the degree to which marine spatial planning, land-based spatial plans, coastal permits, conservation rules, and sectoral licenses are aligned (Ehler & Douvere (2009). When planning and permitting instruments are inconsistent, actors may receive conflicting signals, and legal disputes become more likely. Haniah & Putranto (2024) show that coastal land use for settlements, tourism, and aquaculture needs to be assessed against the applicable legal framework. Their findings highlight the practical importance of aligning spatial allocation with actual coastal use.

The fourth variable is data integration, represented in the model as one data / one map. This variable refers to the integration of spatial data, zoning maps, permit data, administrative boundaries, ecological information, and community-use areas. Data fragmentation may produce conflicting interpretations of who has rights, where activities may take place, and whether a permit is consistent with zoning. Letortu *et al*. (2023) show that citizen monitoring can help generate useful coastal information and support discussion among territorial actors. This supports the idea that data is not only technical infrastructure; it also influences trust, transparency, and governance legitimacy.

The fifth variable is public legitimacy and trust. Legitimacy refers to the extent to which coastal communities and other actors accept governance processes and outcomes as fair, transparent, and credible. The literature shows that legitimacy is closely related to participation, benefit distribution, local relevance, and recognition of community knowledge. Ebeler *et al*. (2025) show that mangrove restoration and conservation affect livelihoods, economic resilience, institutional dynamics, and community participation. Kunyati *et al*. (2024) also emphasize the role of local potential and wisdom in developing sustainable coastal

communities. These studies support the model's assumption that legitimacy strengthens compliance and reduces the likelihood of conflict escalation.

The sixth variable is compliance with spatial-use rules. Compliance refers to the extent to which actors follow zoning rules, permits, conservation restrictions, and coastal-use regulations. Compliance is not produced only by formal sanctions. It is also shaped by legal clarity, trust, enforcement capacity, socio-economic conditions, and legal awareness. Van Rooij (2023) emphasizes the need to understand law and behavior holistically, while Adam *et al*. (2025) show that destructive fishing in Maluku is influenced by economic pressure, weak surveillance, low legal awareness, and limited enforcement capacity. These findings justify placing compliance between legitimacy, governance capacity, violations, and conflict in the CLD.

The seventh variable is zoning and permit violations. This variable captures activities that deviate from zoning rules or permit requirements. Violations may include unauthorized coastal use, illegal fishing practices, spatial-use deviation, incompatible land use, or activities conducted without adequate approval. Adam *et al*. (2025) similarly show how destructive fishing practices persist when enforcement capacity and socio-economic alternatives are limited. In the model, violations are treated as a stock because they may accumulate and generate unresolved legal, social, and ecological consequences.

The eighth variable is governance and control capacity. This refers to the ability of institutions to coordinate, monitor, enforce, resolve disputes, manage data, and respond to change. Adam *et al*. (2025) show that law enforcement in coastal areas may be constrained by geography, limited investigators, insufficient surveillance infrastructure, and weak institutional capacity. Frohlich *et al*. (2022) also suggest that adaptive coastal management requires legal and governance arrangements capable of responding to dynamic coastal conditions. Governance capacity is therefore positioned as a stock that can strengthen or weaken over time.

The ninth variable is investment and development pressure. Coastal areas often attract investment in ports, reclamation, tourism, aquaculture, settlements, infrastructure, and special economic zones. Development pressure may increase spatial-use intensity and generate environmental and social impacts. Kunyati et al. (2024) show that economic factors encourage coastal land use for settlements, tourism, and aquaculture. Coffman et al. (2025) also show that coastal governance decisions may be influenced by infrastructure, property interests, and political pressure. In the model, development pressure acts as an external driver that can activate the reinforcing loop of conflict.

The tenth variable is coastal environmental pressure. This includes pollution, habitat degradation, wetland conversion, abrasion, sedimentation, flooding, mangrove loss, or decline in ecosystem quality. Guo *et al*. (2021) show that anthropogenic activities can reduce natural wetlands and increase artificial or non-wetland areas. Ebeler *et al*. (2025) show that mangrove management is closely tied to ecological health, livelihoods, and institutional arrangements. Environmental pressure is therefore positioned as an intermediate variable linking development intensity to livelihood vulnerability and conflict.

The eleventh variable is livelihood vulnerability and dissatisfaction. This variable refers to the socio-economic exposure of coastal communities to declining environmental quality, reduced access to resources, loss of income, unequal benefit distribution, or exclusion from decision-making. Cramer *et al*. (2023) highlight the importance of coastal economic sectors for community resilience, while Ebeler *et al*. (2025) show that mangrove restoration and conservation may support livelihoods but also generate governance challenges when benefits

and rules are unevenly distributed. In the CLD, livelihood vulnerability increases the likelihood of dissatisfaction and legal conflict.

The final policy variable is effectiveness of dispute resolution. This refers to the speed, accessibility, fairness, and credibility of mechanisms used to resolve coastal legal conflict. These mechanisms may include administrative settlement, mediation, customary forums, litigation, arbitration, or diplomatic mechanisms at the maritime scale. Madacky (2017) discuss the relevance of System Dynamics in dispute resolution, while Tyas (2023) shows that maritime conflict resolution may involve international legal mechanisms, diplomacy, and negotiation. In the CLD, effective dispute resolution directly reduces accumulated conflict.

Table 10. Systemic variables extracted from the SLR

Code	Variable	Meaning in the model
A1	Consistency between MSP, spatial plans, and permits	Alignment among planning, zoning, and licensing instruments
A2	One data / one map	Integration of permit, zoning, boundary, ecological, and activity data
A3	Investment and development pressure	Economic and physical pressure on coastal space
P1	Spatial-use intensity	Level of coastal and marine space utilization
S2	Zoning and permitting certainty	Clarity and predictability of zoning and permit rules
S1	Coastal legal conflict	Accumulated disputes, complaints, protests, or legal uncertainty
S6	Public legitimacy and trust	Public acceptance of coastal governance processes and outcomes
S3	Compliance with spatial-use rules	Actor behavior in following zoning and permit rules
V1	Zoning and permit violations	Deviations from zoning or permitting rules
S4	Governance and control capacity	Institutional ability to coordinate, monitor, enforce, and respond
A5	Strength of control and sanctions	Consistency and enforceability of sanctions and monitoring
A4	Effectiveness of dispute resolution	Capacity to resolve conflict quickly, fairly, and credibly
S5	Coastal environmental pressure	Decline in ecosystem quality due to coastal activities
L1	Livelihood vulnerability and dissatisfaction	Socio-economic vulnerability of coastal communities

The extracted variables show that coastal legal conflict is not only a legal outcome but also a systemic outcome. It is influenced by the quality of legal rules, the capacity of institutions, the behavior of actors, the condition of ecosystems, and the lived experience of coastal communities.

Causal Structure of Coastal Legal Issues

The causal structure developed from the SLR shows four main pathways: the legal certainty pathway, the legitimacy and compliance pathway, the enforcement and control pathway, and the development–environment–livelihood pathway. These pathways interact with one another and form the basis of the CLD (Figure 7).

The first pathway is the legal certainty pathway. In this pathway, consistency between MSP, spatial plans, and permits strengthens zoning and permitting certainty. Data integration through one data / one map also strengthens certainty because it reduces fragmented information and conflicting interpretations of zoning, permits, boundaries, and activities. In turn, zoning and permitting certainty reduces coastal legal conflict. This pathway is supported by Frohlich *et al*. (2022), who emphasize the importance of legal certainty in adaptive coastal management, and by De Rooy *et al*. (2021), who highlight regulatory synchronization as a condition for legal certainty in coastal conservation areas.

The second pathway is the legitimacy and compliance pathway. Zoning and permitting certainty increases public legitimacy because clear and predictable rules make coastal governance more understandable and credible. Public legitimacy then strengthens compliance with spatial-use rules. When compliance increases, zoning and permit violations decrease. Lower violations reduce coastal legal conflict. This pathway is supported by Van Rooij (2023), who argues that law and behavior should be understood holistically, and by Ebeler *et al*. (2025), Letortu *et al*. (2023), and Kunyati *et al*. (2024), who show the importance of participation, trust, community relevance, and livelihood considerations in coastal governance. The third pathway

is the enforcement and control pathway. Governance and control capacity improves compliance and reduces violations. Stronger sanctions also reduce violations when they are applied consistently and credibly. However, the relationship is not one-directional (Venegas et al., 2023; Hendijani, 2021; Stave *et al*., 2021; Pluchinotta *et al*., 2024)

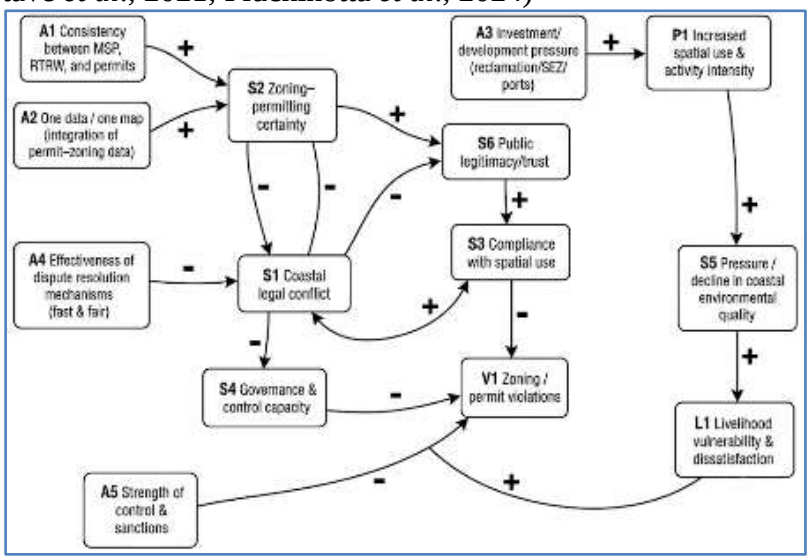


Figure 7. Core Causal Loop Diagram (CLD) of coastal legal conflict

When legal conflict becomes high, governance capacity may be weakened because institutions must spend more resources dealing with complaints, disputes, protests, legal uncertainty, and political pressure. This pathway is strongly supported by Mabin & Cavana (2024) and Adam *et al*. (2025), who show that coastal enforcement is constrained not only by the availability of legal rules, but also by surveillance capacity, human resources, geography, legal awareness, and socio-economic pressure.

The fourth pathway is the development–environment–livelihood pathway. Investment and development pressure increase spatial-use intensity. Higher spatial-use intensity increases coastal environmental pressure, especially when development is poorly regulated or weakly monitored. Environmental pressure then increases livelihood vulnerability and dissatisfaction. When communities experience reduced access, income loss, ecosystem degradation, or unfair benefit distribution, the likelihood of legal conflict increases. This pathway is supported by Guo *et al*. (2021), who show how anthropogenic activity transforms coastal landscapes; Ebeler *et al*. (2025), who connect mangrove governance with livelihoods and institutions; and Cramer *et al*. (2023), who emphasize the importance of coastal economic sectors for community resilience.

These pathways are not independent. They interact through feedback loops. For example, conflict may reduce public trust, weaken compliance, and increase violations, which then increases conflict again. Conflict may also weaken zoning certainty and institutional capacity. This means that once conflict begins to accumulate, it can become self-reinforcing unless balancing mechanisms are strong enough.

The causal structure shows that legal conflict is both an outcome and a driver. It is an outcome because it is produced by violations, vulnerability, legal uncertainty, and environmental pressure. But it is also a driver because it can reduce legitimacy, weaken governance capacity, and undermine certainty. This dual role makes coastal legal conflict difficult to manage through simple linear policy responses. A simplified representation of the causal structure is shown below.

This figure illustrates the causal structure of coastal legal conflict by linking regulatory consistency, data integration, zoning–permitting certainty, public legitimacy, compliance, violations, governance capacity, dispute resolution, development pressure, environmental decline, and livelihood vulnerability. Positive signs indicate variables moving in the same direction, while negative signs indicate opposite-direction effects. Overall, the diagram shows that coastal legal conflict is shaped by both balancing mechanisms, such as legal certainty and enforcement, and reinforcing pressures, such as development-driven environmental degradation and livelihood dissatisfaction.

Reinforcing and Balancing Loops in the CLD

The CLD reveals that coastal legal issues are shaped by both balancing and reinforcing feedback loops. This distinction is important because it helps explain why some policy interventions may stabilize the system, while others may fail to stop conflict escalation. The first balancing loop, B1, links zoning and permitting certainty, public legitimacy, compliance, violations, coastal legal conflict, and back to zoning and permitting certainty. When zoning and permitting certainty increases, public legitimacy tends to increase. Higher legitimacy strengthens compliance. Stronger compliance reduces violations. Lower violations reduce coastal legal conflict. Reduced conflict then helps maintain zoning and permitting certainty. This loop represents a stabilizing mechanism. It shows that legal certainty can reduce conflict not only directly, but also indirectly through legitimacy and compliance.

The second balancing loop, B2, links governance capacity, compliance, violations, conflict, and governance capacity. Strong governance capacity improves compliance and reduces violations. Lower violations reduce conflict. Lower conflict helps preserve institutional capacity. However, this loop can weaken when conflict becomes too high. High conflict may burden institutions, reduce their ability to monitor and enforce rules, and create a cycle where weak capacity leads to more violations and more conflict. This explains why strengthening enforcement capacity must be combined with conflict prevention and dispute resolution.

The third balancing loop, B3, centers on dispute resolution. Effective dispute resolution reduces conflict. Lower conflict helps restore legitimacy, which improves compliance and reduces violations. Lower violations then further reduce conflict. This loop shows that dispute resolution is not only a reactive mechanism. It can also help stabilize the broader governance system if it is timely, accessible, and perceived as fair.

The first reinforcing loop, R1, moves through development pressure, spatial-use intensity, environmental pressure, livelihood vulnerability, conflict, legitimacy, compliance, violations, and back to conflict. This loop explains how development pressure can generate a spiral of conflict when not matched by strong governance. Increased development pressure raises spatial-use intensity. Higher intensity increases environmental pressure. Environmental pressure increases livelihood vulnerability and dissatisfaction. Dissatisfaction increases conflict. Conflict reduces legitimacy, weakens compliance, increases violations, and then further increases conflict.

The second reinforcing loop, R2, focuses on the relationship between conflict, legitimacy, compliance, violations, and conflict. When conflict increases, legitimacy declines. Lower legitimacy weakens compliance. Weaker compliance increases violations. Higher violations then increase conflict. This loop captures the social dimension of legal conflict: once trust declines, legal compliance may become harder to sustain, and formal rules may lose practical effectiveness.

The feedback structure shows that coastal legal governance must work on two fronts at the same time. It must strengthen balancing loops and weaken reinforcing loops. Strengthening

balancing loops requires legal certainty, institutional capacity, fair dispute resolution, and public legitimacy. Weakening reinforcing loops requires controlling development pressure, reducing environmental degradation, protecting livelihoods, and preventing violations from accumulating.

This is why a narrow enforcement-only approach is unlikely to be sufficient. Enforcement is important, but it cannot work effectively if zoning remains uncertain, data are fragmented, communities do not trust the process, and development pressure continues to harm coastal livelihoods. A systemic policy response must therefore combine regulatory harmonization, data integration, governance capacity, sanctions, dispute resolution, participation, and livelihood protection.

Table 11. Main feedback loops in the CLD

Loop Code	Pathway	Type	Interpretation
B1	S2 → S6 → S3 → V1 → S1 → S2	Balancing loops	Legal certainty strengthens legitimacy and compliance, reduces violations, and helps lower conflict
B2	S4 → S3 → V1 → S1 → S4	Balancing loops	Governance capacity reduces violations and conflict, but high conflict may weaken capacity.
B3	A4 → S1 → S6 → S3 → V1 → S1	Reinforcing loops	Effective dispute resolution interrupts conflict escalation and helps restore compliance.
R1	A3 → P1 → S5 → L1 → S1 → S6 → S3 → V1 → S1	Reinforcing loops	Development pressure may trigger environmental stress, livelihood vulnerability, declining legitimacy, violations, and escalating conflict.
R2	S1 → S6 → S3 → V1 → S1	Reinforcing loops	Conflict reduces legitimacy, weakens compliance, increases violations, and further increases conflict.

Translation from CLD to SFD

The translation from the CLD to the SFD was carried out to move the model from a qualitative causal map toward a more operational dynamic structure. The CLD helps explain how variables are connected through causal relationships and feedback loops. However, it does not distinguish between variables that accumulate over time, processes that change those accumulations, and supporting variables that influence the rate of change. For this reason, the SFD was developed to identify stocks, flows, and auxiliary variables (Figure 8).

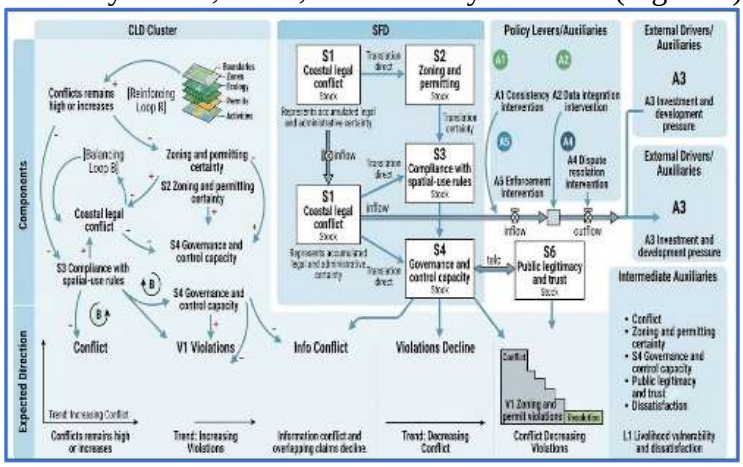


Figure 8. Translation of CLD variables into SFD structure

In this study, several variables were treated as stocks because they represent conditions that build up, decline, or persist over time. These include zoning and permitting certainty, public legitimacy, compliance with spatial-use rules, zoning and permit violations, coastal legal conflict, and governance and control capacity. These variables do not change instantly. Legal certainty is gradually built through regulatory harmonization, data integration, and consistent

implementation. Public legitimacy grows or declines through repeated experiences of fairness, participation, transparency, and responsiveness. Compliance changes through legal awareness, trust, enforcement, and socio-economic conditions. Violations and conflicts may accumulate when they remain unresolved. Governance capacity may strengthen through institutional investment, but it may also decline when institutions are overwhelmed by conflict.

The system is anchored by six interconnected stocks that define the dynamics of coastal spatial governance. The first stock, zoning and permitting certainty (S2), reflects the accumulated level of clarity and predictability in coastal management (Frohlich *et al*., 2022; Mabin & Cavana, 2024). Its inflow is the formation of certainty, which is directly enhanced by policy levers such as consistency interventions between MSP, spatial plans, and permits (A1), as well as "one data / one map" integration (A2). Conversely, its outflow represents the decline of certainty, occurring when permits overlap, data becomes fragmented, or legal interpretations turn inconsistent, weakening confidence in the regulatory framework. This structural foundational certainty closely influences public legitimacy and trust (S6), the second stock, which represents the accumulated level of public acceptance toward coastal governance. The inflow of legitimacy is nurtured by transparent data, meaningful participation, and fair dispute resolution, while its erosion is driven by unaddressed violations, community exclusion, or unfair development pressures. This structure is supported by studies emphasizing participation, community relevance, local wisdom, and livelihood protection in coastal governance (Letortu *et al*., 2023; Ebeler *et al*., 2025; Kunyati *et al*., 2024).

In turn, this public trust directly shapes the third stock, compliance with spatial-use rules (S3), which represents the collective behavior of actors toward zoning and permit regulations. Compliance accumulates through stronger public legitimacy, institutional capacity, and credible enforcement sanctions, but it declines when poor monitoring, weak trust, or economic pressures incentivize non-compliance. When compliance drops, it triggers the inflow of the fourth stock, zoning and permit violations (V1), which captures the accumulated deviations from legal and spatial-use rules. While violations naturally spike under heavy investment and development pressure (A3) or weak surveillance, they are reduced through active enforcement interventions (A5), administrative corrections, and the restoration of lawful practices. When violations are left unaddressed or compliance fails (Van Rooij, 2023; Adam *et al*., 2025), it feeds directly into the fifth stock, coastal legal conflict (S1). This stock represents the accumulated disputes, protests, jurisdictional tensions, and unresolved legal disagreements within the coastal zone. Treating conflict as a stock is crucial because legal disputes can persist, accumulate, and reproduce themselves if not actively managed. The emergence of this conflict is heavily accelerated by socio-economic and ecological pathways, including livelihood vulnerability (L1) and coastal environmental pressure (S5). However, conflict is mitigated through the outflow of effective dispute resolution interventions (A4), which facilitate faster, fairer mediation and administrative settlements.

Finally, the capacity to balance all these shifting forces resides in the sixth stock, governance and control capacity (S4), which represents the accumulated institutional ability to coordinate, monitor, enforce, and manage data. This capacity is continuously built up through institutional investments, technological support, and better data systems, but it can face erosion if the institutions become overloaded by escalating legal conflicts or fragmented authority. Together, these six stocks, driven by targeted policy levers and external variables, form a dynamic quantitative structure that simulates how policy interventions can successfully steer the system away from conflict escalation and toward sustainable coastal governance (Langemeyera & Connolly, 2020; Adam *et al*., 2025).

Auxiliary variables were also included in the SFD. These include investment and development pressure, spatial-use intensity, coastal environmental pressure, livelihood vulnerability, strength of control and sanctions, and effectiveness of dispute resolution. These variables influence the flows between stocks. For example, development pressure increases spatial-use intensity, which increases environmental pressure. Environmental pressure then contributes to livelihood vulnerability, which may accelerate the emergence of conflict. Sanctions and control mechanisms influence the reduction of violations, while dispute resolution influences the reduction of conflict. Through this translation, the SFD becomes a bridge between conceptual understanding and future simulation. It does not yet represent a fully calibrated quantitative model. Rather, it provides an operational structure that can later be assigned indicators, initial values, parameters, time delays, and equations. This is why the SFD is treated as part of the first-year output of the research roadmap, while calibration and empirical validation are positioned as the next stage.

Conceptual Policy Scenario Simulation

The SFD structure was then used to formulate a conceptual policy scenario simulation. The purpose of this simulation was not to predict the exact number of conflicts in the future. Instead, it was designed to visualize how the system may behave under different policy assumptions. The simulation uses a hypothetical index from 0 to 100, where 0 indicates very low coastal legal conflict and 100 indicates very high coastal legal conflict.

Six scenarios were developed (Figure 9). The first scenario is S0 Business as Usual, where no major policy change is introduced. This scenario assumes that existing weaknesses in legal certainty, data integration, enforcement, dispute resolution, and public participation remain largely unchanged. The second scenario is S1 Regulatory Harmonization, which focuses on improving consistency between MSP, spatial plans, and permits. The third scenario is S2 One Data / One Map, which focuses on integrating spatial, zoning, permit, boundary, ecological, and activity data. The fourth scenario is S3 Strengthened Enforcement, which focuses on improving governance capacity, monitoring, and sanctions. The fifth scenario is S4 Dispute Resolution, which focuses on creating faster, fairer, and more accessible mechanisms for resolving coastal legal conflicts. The sixth scenario is S5 Integrated Policy Package, which combines regulatory harmonization, data integration, strengthened enforcement, dispute resolution, and public participation.

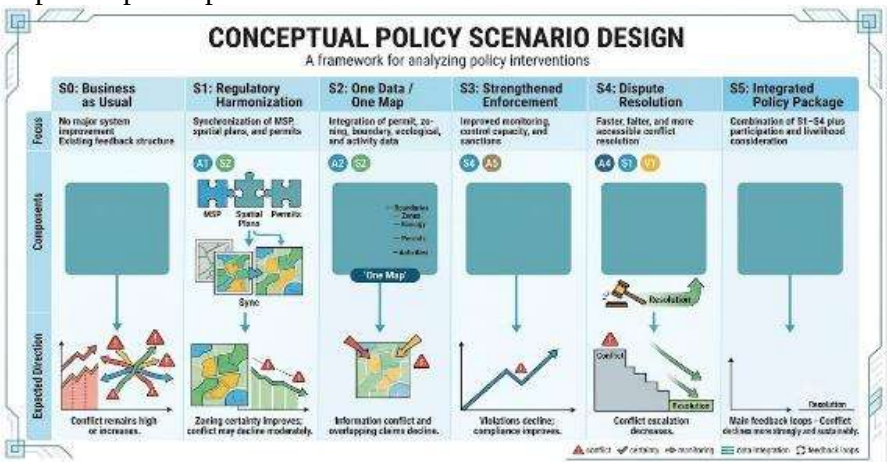


Figure 9. Six conceptual policy scenarios in testing the possible course of coastal legal conflict under various intervention options.

The scenarios were developed based on the leverage points identified in the CLD and SFD. Each scenario targets different flows within the model. Regulatory harmonization and data integration increase the formation of zoning and permitting certainty. Strengthened enforcement increases compliance and accelerates the reduction of violations. Dispute resolution accelerates conflict resolution. Public participation strengthens legitimacy and supports compliance. The integrated policy package combines these mechanisms and is therefore expected to produce the strongest stabilizing effect.

The conceptual simulation reflects an important idea from System Dynamics (Akhavan, & Jalali, 2024): policy effects depend not only on the strength of one intervention, but also on how interventions interact within the system. A single intervention may improve one part of the model, but it may not be strong enough to change the overall behavior of the system if other reinforcing loops continue to operate. For example, stronger sanctions may reduce violations, but if zoning remains uncertain and legitimacy is low, conflict may still continue. Similarly, data integration may reduce ambiguity, but if dispute resolution is weak and development pressure remains high, conflict may still accumulate.

For this reason, the simulation places special attention on the integrated policy package. The integrated scenario is expected to work better because it strengthens several balancing mechanisms at the same time: legal certainty, public legitimacy, compliance, institutional capacity, violation reduction, and conflict resolution. It also helps weaken the reinforcing conflict loop by reducing uncertainty, improving trust, and controlling violations.

Discussion of the 2D and 3D Simulation Results

The 2D simulation visualizes the direction of coastal legal conflict over a ten-year period under the six scenarios. The results show that Business as Usual leads to an increase in the conflict index. This suggests that if legal uncertainty, weak data integration, limited enforcement, slow dispute resolution, and low legitimacy remain unaddressed, coastal legal conflict may continue to accumulate. The BAU pattern reflects the reinforcing loop in the CLD, where conflict weakens legitimacy, weaker legitimacy reduces compliance, reduced compliance increases violations, and violations further increase conflict.

The partial scenarios—regulatory harmonization, data integration, strengthened enforcement, and dispute resolution—show more limited effects when implemented separately. Each scenario improves one part of the system, but none of them fully interrupts the reinforcing loop. Regulatory harmonization improves zoning and permitting certainty, but its effect may be limited if enforcement capacity remains weak. Data integration reduces information fragmentation, but it may not be enough if violations continue or if disputes are not resolved. Strengthened enforcement may reduce violations, but it may face resistance if public legitimacy is low. Dispute resolution may reduce accumulated conflict, but it may not prevent new conflict if zoning uncertainty and environmental pressure remain high.

By contrast, the integrated policy package shows the strongest reduction in the conflict index. This result is consistent with the CLD and SFD structure. The integrated scenario works through multiple leverage points at once. It improves certainty, strengthens data integration, supports enforcement, accelerates dispute resolution, and builds legitimacy. As a result, it strengthens the balancing loops while weakening the reinforcing conflict loop (Tabel 12)..

The 3D simulation adds another layer of interpretation. It shows the interaction between two groups of interventions: legal certainty and data integration on one axis, and enforcement and dispute resolution on the other. The surface indicates that conflict remains high when both groups of interventions are weak. Conflict begins to decline more clearly when both groups are strengthened together. This pattern supports the argument that policy interaction matters.

Table 12. Interpretation of the 2D simulation results

Scenario	Main pattern in the 2D simulation	Interpretation
S0	Conflict increases over time	Existing reinforcing loops remain active and conflict accumulates
S1	Limited improvement	Legal certainty improves, but enforcemen and legitimacy may still be weak
S2	Limited improvement	Information clarity improves, but violations and conflict may persist
S3	Limited improvement	Violations may decline, but legitimacy and zoning certainty still matter
S4	Limited improvement	Conflict resolution improves, but new conflict may still emerge
S5	Strongest conflict reduction	Multiple leverage points are strengthened simultaneously

In practical terms, the 3D visualization suggests that legal certainty alone is not enough. If rules are clear but enforcement is weak, violations may continue (Figure 10) . Enforcement alone is also not enough. If sanctions are strong but rules are unclear or perceived as unfair, public legitimacy may decline. Data integration alone is not enough if institutions cannot act on the information. Dispute resolution alone is not enough if the system continues to generate new conflict. The strongest effect emerges when certainty, data, enforcement, and dispute resolution work together.

The 2D (Figure 11) and 3D (Figure 12) simulations should not be read as empirical forecasts. They are exploratory visualizations based on a conceptual SFD. The numerical values are hypothetical and intended to show direction rather than prediction. Their main contribution is to make the system behavior easier to see. They show why partial interventions may not be enough and why integrated policy design is more consistent with the systemic nature of coastal legal conflict.

Policy interaction		Expected conflict level	Interpretation
	Low certainty/data + low enforcement/dispute resolution	High conflict	The system lacks both clarity and control
S1	Low certainty/data + low enforcement/dispute resolution	High conflict	The system lacks both clarity and control
S2	High certainty/data + low enforcement/dispute resolution	Moderate to high conflict	Rules and data improve, but violations may continue
S3	Low certainty/data + high enforcement/dispute resolution	Moderate to high conflict	Enforcement improves, but unclear rules may reduce legitimacy
S4	High certainty/data + high enforcement/dispute enforcement/dispute resolution	Low conflict	Legal clarity, information integration, control, and resolution mechanisms reinforce each other

Figure 10. Interpretation of the 3D simulation results

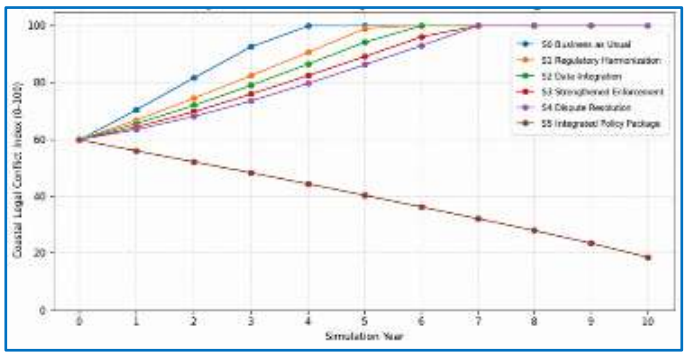


Figure 11. 2D conceptual simulation of coastal legal conflict under six policy scenarios.

The graph shows the direction of the coastal legal conflict index over a ten-year conceptual simulation period. Business as usual and partial interventions tend to produce limited improvement, while the integrated policy package shows the strongest reduction in conflict. Furthermore, Figure 12 shows a surface graph showing the combined effects of legal certainty and data integration, law enforcement and dispute resolution, and the conflict index at the end of the simulation period. Conflict remains high when both policy dimensions are weak and decreases when both are strengthened together.

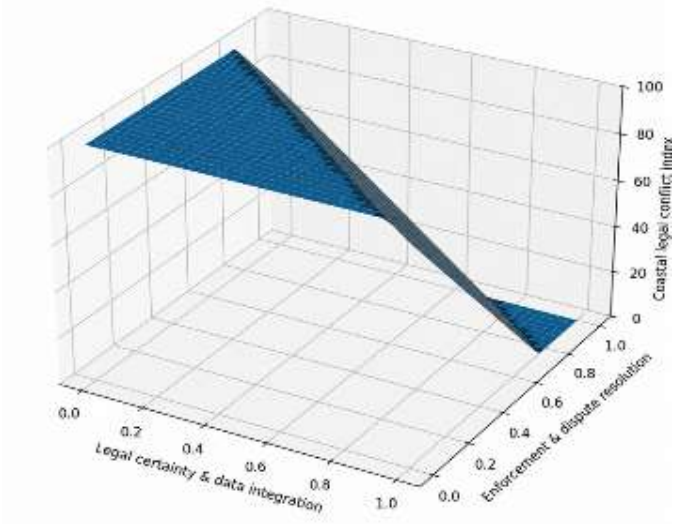


Figure 12. 3D conceptual simulation of policy interaction effects on coastal legal conflict.

This finding is consistent with Malbon and Parkhurst (2023), who argue that System Dynamics can support evidence-informed policymaking by helping policymakers understand feedback, interaction, and unintended consequences. It also aligns with Naugle et al. (2024), who emphasize the need to distinguish between conceptual and quantitative System Dynamics modeling. At this stage, the simulation remains conceptual. In the next phase of the roadmap, the model should be parameterized, calibrated, and validated using empirical data.

Overall, the simulation results reinforce the main argument of this article: coastal legal conflict cannot be reduced sustainably through one-dimensional policy responses. Legal certainty, data integration, enforcement, dispute resolution, participation, environmental control, and livelihood protection must be treated as parts of one system. The integrated policy package is therefore not only a policy preference, but a logical implication of the feedback structure revealed by the CLD and SFD.

CONCLUSION AND RECOMMENDATION

Conclusion

This study shows that coastal legal issues cannot be understood as isolated or linear legal problems. They are shaped by a wider system of interacting factors, including zoning and permitting certainty, consistency between marine spatial planning, spatial plans, and permits, data integration, public legitimacy, compliance with spatial use rules, zoning and permit violations, governance capacity, development pressure, coastal environmental quality, and the vulnerability of coastal livelihoods. In this sense, coastal law should not be seen only as a set of formal rules, but as part of a dynamic socio-ecological governance system.

The CLD developed in this study reveals both balancing and reinforcing loops within coastal legal dynamics. The balancing loops work through legal certainty, legitimacy, compliance, governance control, and dispute resolution, all of which can help reduce legal

conflict. In contrast, the reinforcing loop operates through development pressure, increasing spatial use intensity, declining environmental quality, livelihood vulnerability, weakening legitimacy, violations, and escalating conflict. This structure suggests that coastal legal conflict is not driven only by weak enforcement, but also by overlapping rules, fragmented data, declining trust, and socio-ecological pressures.

The translation from CLD to SFD, together with the conceptual policy scenario simulation, indicates that partial interventions are unlikely to reduce coastal legal conflict in a sustainable way. Regulatory harmonization, data integration, stronger enforcement, and dispute resolution are all important, but their effects remain limited when implemented separately. The integrated policy package appears to be the most reasonable option because it works across several leverage points at the same time, including legal certainty, data integration, institutional capacity, sanctions, dispute mechanisms, public participation, and the protection of coastal livelihoods.

Recommendations

Following the planned three-year research roadmap, this study should be developed in stages. In the first year, the main outputs—SLR–PRISMA, evidence map, CLD, initial SFD design, and policy scenarios—need to be finalized and validated through expert review involving coastal law, spatial planning, marine governance, and System Dynamics specialists. In the second year, the model should be advanced into a quantitative SFD by defining indicators, setting parameters, calibrating the model with secondary and local data, validating both structure and behavior, running policy simulations, and conducting sensitivity analysis. In the third year, the simulation results should be translated into an adaptive policy package, policy briefs, implementation guidelines, and a monitoring and evaluation framework, with possible replication in other coastal areas so that the recommendations become not only conceptually sound, but also practically useful for strengthening coastal legal governance in Indonesia.

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