



Review

Collaborative Innovation Across Knowledge Systems: A New Shift in Integrating Indigenous Knowledge and Scientific Climate Adaptation Tools—A Systematic Review and Policy Analysis

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Abstract: Despite growing recognition of indigenous knowledge in climate adaptation, existing frameworks fail to distinguish genuine integration from tokenistic inclusion. This study develops the Knowledge Integration Maturity Model (KIMM)—a five-stage framework grounded in knowledge co-production theory, institutional innovation theory, and decolonization theory—featuring ten quantifiable dimensions anchored by indigenous decision-making power ratios. A PRISMA-compliant systematic review of the Scopus database identified 6324 records, of which 1980 were included for bibliometric analysis and 62 for in-depth qualitative synthesis. Applying KIMM to 85 global climate adaptation policies (1996–2025) across 45 countries, supplemented by case studies of Australia’s WALFA project, Colombia’s T-248 ruling, and Kenya’s Ogiek case, we find that global policies are transitioning from Level 3 (Inclusion) toward Level 4 (Collaboration), with a mean score of 58.7 (SD = 8.4) and none achieving Level 5 (Co-governance). Economic empowerment policies, though only 14.1% of the sample, demonstrate superior outcomes (mean = 61.9, Level 4 attainment = 50%), while budget control authority (D2 = 5.12) emerges as the critical bottleneck. A threshold effect at KIMM = 60 marks the shift from symbolic participation to substantive power-sharing, evidenced by the 36-point gap between WALFA (78) and Ogiek (42). These findings extend knowledge co-production theory by identifying structural preconditions for genuine collaboration, enrich institutional theory by revealing sequential change patterns where resource redistribution lags behind legal recognition, and operationalize decolonization theory through measurable indicators. The KIMM framework provides policymakers with diagnostic tools to advance from recognizing knowledge to empowering communities through institutionalized power redistribution.

Keywords: indigenous knowledge integration; knowledge integration maturity model; climate adaptation policy; knowledge co-production; institutional innovation; decolonization; power redistribution



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1. Introduction

The field of climate adaptation faces a fundamental paradox: despite widespread recognition within academia and policy circles of the vital value of indigenous knowledge for climate adaptation, progress in translating this acknowledgment into effective integration practices has been extremely slow. A systematic review of a decade of knowledge integration literature by Bohensky and Maru [1] demonstrates that indigenous knowledge and scientific knowledge are complementary rather than incommensurable. Nevertheless, most integration attempts remain at the level of symbolic participation, failing to achieve genuine knowledge dialogue. The core reason for this gap lies in the lack of a quantifiable, operational assessment tool within existing research to diagnose integration status, identify developmental stages, and guide policy improvements.

The limitations of relying solely on a single knowledge system to address climate change are increasingly evident. While scientific knowledge has made significant strides in understanding climate mechanisms, it often lacks cultural adaptability in local applications [2,3]. Indigenous knowledge, rich in local wisdom and long-term ecological observations, suffers from a lack of systematic expression and institutional recognition mechanisms [4]. This knowledge gap not only limits the effectiveness of climate adaptation strategies but may also exacerbate climate risks for vulnerable communities. Maracle et al. [5] emphasize that indigenous knowledge should participate in decision-making as an independent cognitive framework, rather than being selectively incorporated into Western scientific systems. This necessitates a paradigm shift from technical integration to epistemological dialogue, and from instrumental rationality to relational rationality.

Three critical gaps exist in current research. First, the quantitative dimension of integration assessment is missing. Despite repeated international frameworks highlighting the importance of indigenous knowledge, unified standards for measuring integration levels and evaluating effectiveness remain absent [6,7]. Troncarelli et al. [8] note that existing studies primarily rely on qualitative descriptions, which struggle to support evidence-based decision-making and effectiveness improvement. Second, a theoretical gap exists regarding development stages. Knowledge integration is a dynamic evolutionary process, yet existing literature lacks a systematic definition of maturity stages, failing to explain why some policies achieve breakthroughs while others remain stagnant. Third, unclear mechanisms of success conditions. Power relations analysis is often overlooked, with many integration practices instrumentalizing indigenous knowledge while disregarding its worldview and value systems [2]. However, the institutional conditions capable of overcoming this dilemma remain unclear.

The Knowledge Integration Maturity Model (KIMM) developed in this study builds upon and extends established theoretical foundations, including Arnstein's [9] ladder of citizen participation and Pretty's [10] typology of participation. While these seminal frameworks conceptualize participation levels in general governance contexts, KIMM specifically addresses the unique dynamics of indigenous-scientific knowledge integration, incorporating dimensions of epistemic recognition and knowledge sovereignty that are not captured in earlier models. Addressing these gaps, this study proposes the **Knowledge Integration Maturity Model (KIMM)** as its core theoretical contribution. This model conceptualizes knowledge integration as a five-stage continuum from "exclusion" to "co-governance", establishing a 10-dimensional, percentage-based scoring system centered on the proportion of indigenous decision-making authority. The KIMM model not only provides a replicable diagnostic tool but also reveals threshold effects and evolutionary patterns in knowledge integration, offering policymakers a clear developmental pathway reference.

This study addresses three interrelated research questions, each corresponding to a set of testable theoretical propositions:

What are the conditions for successful knowledge integration? This study tests two propositions—the Threshold Effect Proposition (P1: A critical threshold of 40 points exists in KIMM scores, beyond which integration success rates significantly increase) and the Power–Outcome Proposition (P2: The proportion of indigenous decision-making power positively correlates with adaptation effectiveness, and this relationship is moderated by institutionalization levels).

How does knowledge integration evolve? This study tests the Discontinuous Equilibrium Hypothesis (P3: Policy evolution occurs in discontinuous leaps rather than gradual steps, typically triggered by external crises or political windows of opportunity) and the Resource Dependency Hypothesis (P4: indigenous control over project budgets exceeding 30% is a necessary condition for reaching the collaborative level).

How can knowledge integration be scaled up? This study tests the Scale Effect Hypothesis (P5: Local-level projects systematically score higher on KIMM than national-level projects, revealing tension between scale and integration depth).

This study employs a mixed-methods design combining a PRISMA systematic literature review, policy text analysis, and multi-case comparisons. It analyzes 85 global climate adaptation policies from 1996 to 2025 using

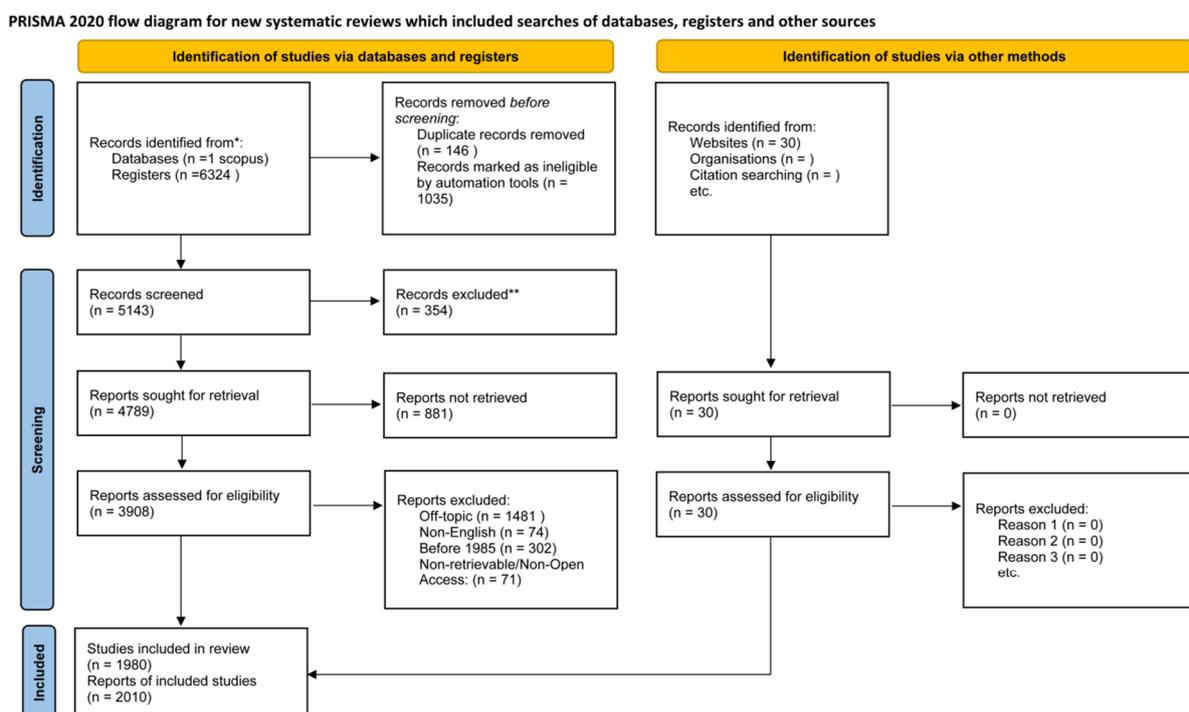
the KIMM scoring system for quantitative assessment, supplemented by in-depth case studies including Australia's WALFA project, Colombia's T-248 ruling, and Kenya's Ogiek case. The study's innovative contributions are threefold: establishing the first quantifiable framework for assessing knowledge integration maturity; identifying threshold effects and developmental pathways in integration evolution; and proposing a three-pillar policy framework of "Empowerment-Weaving-Transformation". This research aims to advance the transition of climate governance from knowledge hierarchies toward knowledge democratization, providing systematic guidance for global climate adaptation.

2. Systematic Literature Review

This study employs the PRISMA systematic review methodology to conduct a comprehensive analysis of research integrating indigenous knowledge and scientific tools from 1985 to 2025. Initial searches across three major databases—Web of Science, Scopus, and Google Scholar—yielded 6324 documents. Following rigorous screening, 1980 core documents were ultimately included for in-depth analysis [11,12].

Inclusion criteria comprised: (1) peer-reviewed journal articles and reviews published between January 1985 and January 2025; (2) English language publications; (3) studies addressing the integration of indigenous or traditional knowledge with scientific knowledge in climate adaptation, environmental management, or natural resource governance contexts. Exclusion criteria included: (1) conference abstracts, editorials, book chapters, and dissertations; (2) studies examining indigenous knowledge in isolation without integration components; (3) publications not retrievable through institutional access.

The systematic search was conducted in Scopus (Elsevier) on 4 May 2025. Scopus was selected as the primary database due to its comprehensive interdisciplinary coverage spanning environmental science, social sciences, and indigenous studies, as well as its robust bibliometric functionality for citation and keyword co-occurrence analysis (Figure 1).



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

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Figure 1. PRISMA 2020 Flow Diagram for Systematic Literature Review. This diagram illustrates the systematic screening process, documenting records identified from Scopus database ($n = 6324$), records screened at title/abstract level, full-text articles assessed for eligibility, and studies included for bibliometric analysis ($n = 1980$) and in-depth qualitative synthesis ($n = 62$). The flowchart follows PRISMA 2020 guidelines [11] to ensure transparency and reproducibility.

2.1. Review Methods

2.1.1. Screening and Selection Process

Two reviewers independently screened all 6324 records identified from Scopus at the title and abstract level using Rayyan software (<https://www.rayyan.ai>). Inter-rater reliability was assessed using Cohen's kappa ($\kappa = 0.82$, indicating substantial agreement). Disagreements were resolved through discussion, with a third reviewer consulted when consensus could not be reached. A liberal inclusion policy ("when in doubt, include") was applied to minimize the risk of excluding potentially relevant studies.

2.1.2. Data Extraction and Quality Assessment

Data extraction was performed independently by two reviewers using a standardized extraction form in Microsoft Excel. The form was pilot-tested on five studies and refined before full extraction. Extracted data included bibliographic information, study characteristics, integration mechanisms, success factors, barriers, and theoretical frameworks employed. Discrepancies between extractors were resolved through discussion and consultation of original sources.

Quality assessment was conducted using criteria adapted from the Critical Appraisal Skills Programme (CASP) qualitative checklist and Joanna Briggs Institute critical appraisal tools, modified for the heterogeneous study designs included in this review. Assessment dimensions included clarity of research objectives, appropriateness of study design, rigor of data collection methods, transparency of analysis, and indigenous community involvement in the research process. Studies were not excluded based on quality scores; instead, quality patterns are reported and considered in interpreting synthesis findings.

2.1.3. Synthesis Methods

As this is a qualitative systematic review, no quantitative effect measures were calculated. Meta-analysis was not conducted due to the heterogeneous nature of included study designs. Thematic synthesis followed the approach of Thomas and Harden [13], comprising three stages: (1) line-by-line coding of extracted text on integration mechanisms, success factors, and barriers; (2) development of descriptive themes representing patterns across studies; and (3) generation of analytical themes interpreted in relation to the research questions and theoretical framework. Bibliometric analysis was conducted using VOSviewer (version 1.6.19) for keyword co-occurrence network visualization, with a minimum occurrence threshold of 5 keywords.

Formal publication bias analyses (e.g., funnel plots) were not conducted. However, potential publication bias toward positive outcomes is acknowledged, as studies reporting successful integration may be more likely to be published than those reporting failures.

2.2. Development Characteristics of the Research Field

Quality assessment of the 62 studies included in qualitative synthesis revealed variable methodological rigor. The majority ($n = 48$, 77%) demonstrated adequate clarity of research objectives and appropriate study designs. However, only 42% ($n = 26$) provided transparent descriptions of analytical approaches, and 35% ($n = 22$) explicitly reported indigenous community involvement in the research process. Detailed quality assessments are provided in Supplementary Tables.

Bibliometric analysis reveals exponential growth in this field, with an average annual growth rate of 14.31%. This trajectory can be divided into three phases: a slow accumulation period before 2000, a stable growth phase from 2000 to 2015, and a rapid expansion phase following the 2015 Paris Agreement. This temporal distribution aligns closely with the global climate governance process, indicating that international policy frameworks significantly influence academic research agendas [4,14].

Geographical distribution analysis shows high research concentration. The United States, Canada, and Australia collectively contributed over 60% of global research output, receiving 4267, 5052, and 4290 citations respectively. Notably, 35% of studies involved international collaboration, reflecting the cross-cultural nature of knowledge integration research. However, research participation from Global South nations remains limited, and this geographic imbalance may constrain understanding of diverse integration models [8].

2.3. Core Concept Networks and Thematic Evolution

Keyword co-occurrence analysis identified three closely connected conceptual clusters. The first cluster centered on "traditional knowledge" (403 occurrences) and "indigenous knowledge" (297 occurrences), reflecting

the academic community’s nuanced distinctions between knowledge types. The second cluster revolved around “climate change” (341 occurrences), “sustainable development” (396 occurrences), and “environmental management” (248 occurrences), constituting the primary application domains. The third cluster focuses on “participatory approaches” (240 mentions) and “decision-making” (262 mentions), embodying the procedural dimension of integration mechanisms [15] (Figure 2).

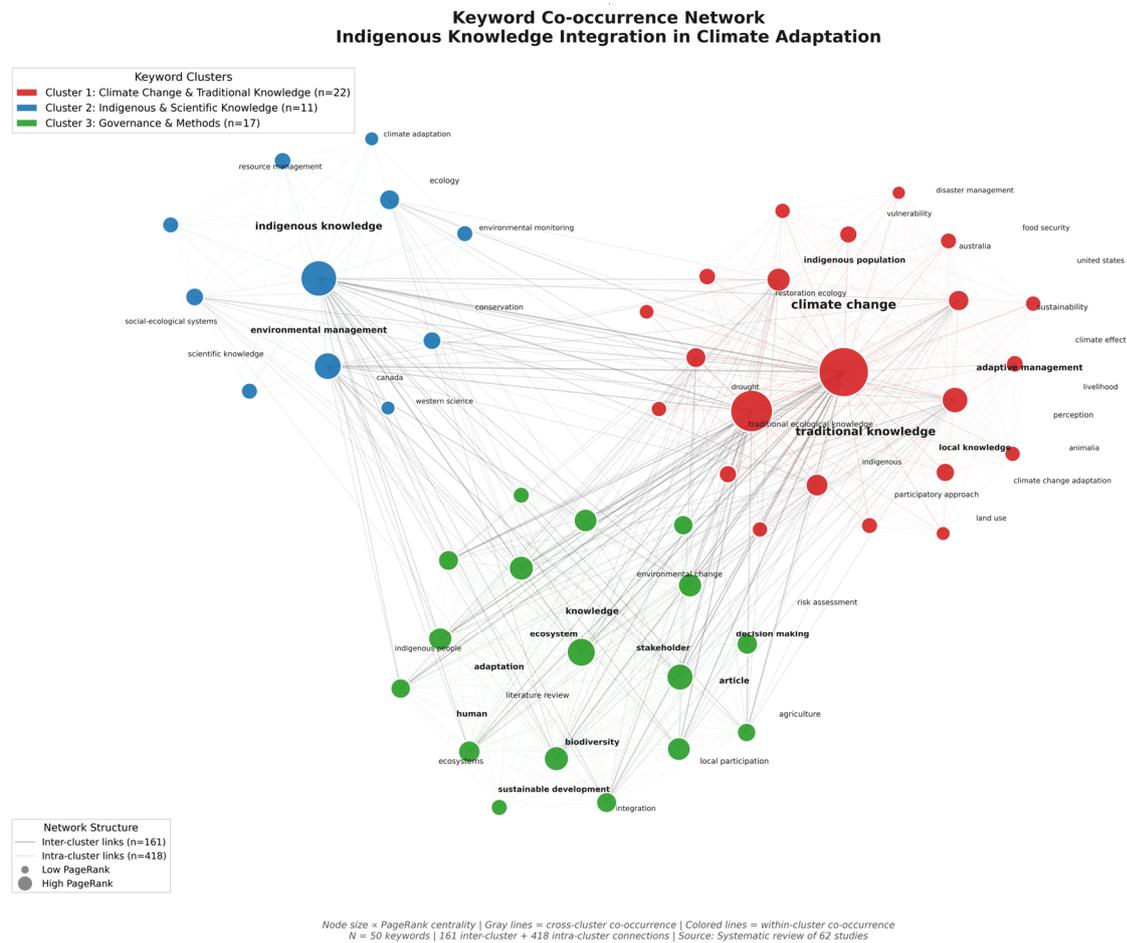


Figure 2. Keyword Co-occurrence Network Analysis. Generated using VOSviewer (version 1.6.19) with a minimum occurrence threshold of 5 keywords. The visualization reveals three distinct conceptual clusters: (1) knowledge terminology cluster centered on “traditional knowledge” (403 occurrences) and “indigenous knowledge” (297 occurrences); (2) application domain cluster including “climate change” (341), “sustainable development” (396), and “environmental management” (248); and (3) governance mechanism cluster featuring “participatory approaches” (240) and “decision-making” (262). Node size reflects keyword frequency; link thickness indicates co-occurrence strength.

Thematic evolution analysis reveals a shift in research focus from conceptual exploration to practical application. Research prior to 2005 primarily addressed ontological differences and epistemological challenges between knowledge systems. Between 2005 and 2015, participatory resource management and community conservation emerged as dominant themes. Post-2015, studies shifted toward designing specific integration mechanisms, institutional innovation, and impact assessment—particularly in disaster risk management, biodiversity conservation, and climate adaptation [6,16–20] (Figure 3).

2.4. Typology of Knowledge Integration Mechanisms

Through systematic coding of core literature, this study identifies three primary knowledge integration pathways, each representing distinct integration logics and practice models.

The participatory integration pathway emphasizes knowledge exchange through diverse forms of engagement. Hermans et al. [2,21] note that participation levels in early warning systems span a continuum from information consultation to joint decision-making. However, most cases remain confined to technology-driven

integration, where indigenous knowledge serves merely as data input rather than as a decision-making partner. This instrumental tendency limits the full expression of indigenous knowledge systems, overlooking their underlying worldviews and value systems.

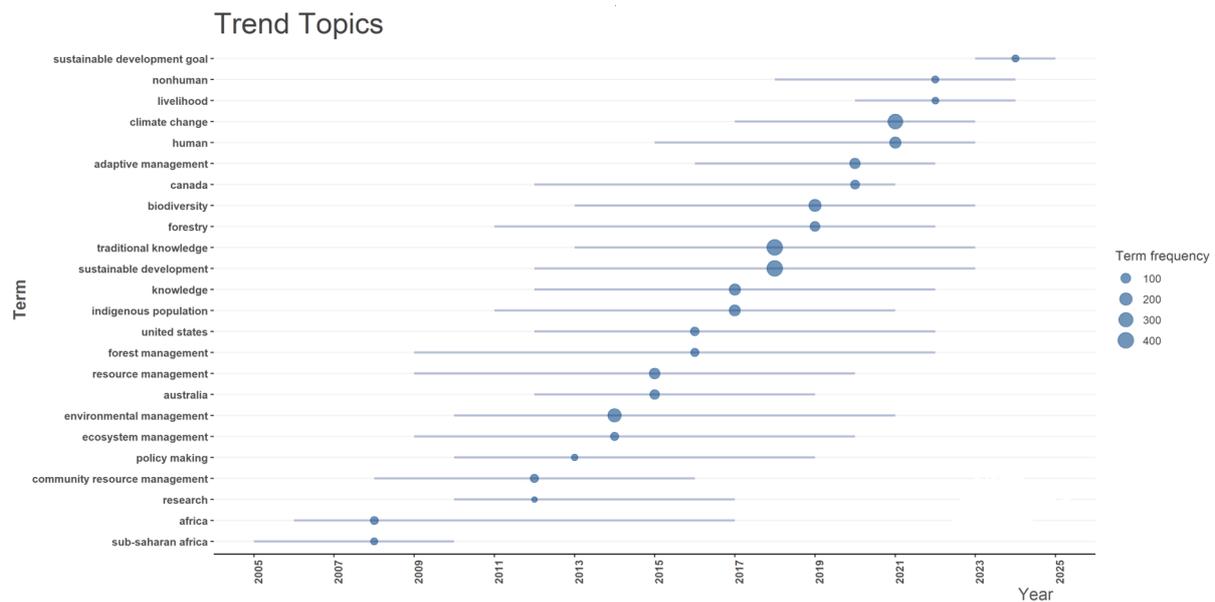


Figure 3. Temporal Evolution of Research Keywords (1985–2025). This trend analysis reveals thematic shifts in the field: pre-2005 research focused on ontological and epistemological challenges; 2005–2015 emphasized participatory resource management and community conservation; post-2015 studies shifted toward integration mechanisms, institutional innovation, and impact assessment in disaster risk management, biodiversity conservation, and climate adaptation contexts.

The mixed-methods pathway seeks knowledge fusion at the methodological level. Carter’s [22] New Zealand case demonstrates how integrating Māori traditional ecological knowledge with scientific monitoring leverages place-based ecological memory to offer unique perspectives for climate adaptation. This methodological innovation hinges on recognizing distinct validity standards and evaluation frameworks for different knowledge systems, rather than merely grafting technologies [23–27].

The institutional integration pathway ensures equal standing for knowledge systems through legal and organizational innovation. Maracle et al. [5] emphasize that indigenous knowledge should participate in decision-making as an independent framework, rather than being selectively integrated into Western scientific systems. This perspective represents a paradigm shift from knowledge hierarchies toward knowledge democratization. Olazabal et al. [28] further advocate for the importance of “subordinate forms of knowledge” in enhancing local adaptive capacity, calling for fundamental reforms to policy frameworks [29].

2.5. Success Factors and Persistent Barriers

Literature analysis reveals key factors influencing knowledge integration outcomes. Regarding enabling factors, policy support is widely recognized as a prerequisite for successful integration. However, this support extends beyond legal recognition to include institutional arrangements for resource allocation and capacity building [30–32]. Financial guarantees must extend beyond short-term project funding to establish mechanisms supporting long-term knowledge transmission and capacity development. Capacity building should be bidirectional, encompassing both indigenous communities mastering scientific methods and the scientific community understanding and respecting indigenous knowledge systems [33].

Obstacle analysis reveals deep-rooted structural challenges. Power imbalances, rooted in colonial histories and contemporary inequality structures, cannot be overcome through technical integration alone. Epistemological conflicts reflect fundamental worldview differences, with inherent tensions between linear scientific thinking and indigenous cyclical conceptions of time. Scale mismatch issues are increasingly prominent, and effective pathways for local knowledge to address global challenges remain unclear [34,35]. Whyte [36] and Cameron et al. [37] note that knowledge integration occurs within colonial power structures that historically marginalized indigenous

knowledge systems. Genuine integration requires a fundamental reconfiguration of decision-making authority, not mere knowledge “incorporation”.

2.6. Research Gaps and the Necessity of the KIMM Model

Through comprehensive literature analysis, this study identifies three critical gaps requiring urgent attention, collectively pointing to a core issue: the absence of a systematic analytical framework to evaluate, compare, and guide knowledge integration practices.

Gap One: Quantitative Deficiencies in Assessment Tools. Existing research primarily relies on qualitative descriptions and case narratives, lacking an operational quantitative indicator system. Troncarelli et al. [8] explicitly highlight this methodological limitation as hindering cross-case comparisons and evidence-based decision-making. Despite Bohensky and Maru [1] calling for integrated evaluation methods over a decade ago, academia has yet to deliver a widely accepted measurement toolkit. Policymakers remain unable to answer the fundamental question: “What stage of integration are we at?”

Gap Two: Theoretical void in developmental stages. Existing literature tends to view knowledge integration as a static state or binary outcome (success/failure), lacking dynamic analysis of the integration process. Practice, however, demonstrates that knowledge integration is a progressive institutional change involving multiple stages—from marginalization to equal participation to co-governance. This absence of stage-based theory creates two practical dilemmas: First, it fails to explain why some policies achieve breakthroughs while others remain stagnant for extended periods. Second, it cannot provide targeted improvement recommendations for policies at different developmental stages.

Gap Three: Unclear Mechanisms of Success Conditions. Although the literature identifies various facilitating and hindering factors, the mechanisms of their interactions remain unclear. Key questions remain unresolved: Is institutional support a sufficient or necessary condition for success? At what level of power restructuring does a qualitative leap occur? Does a threshold effect exist between resource control and decision-making participation? Utami et al. [38] demonstrate that existing frameworks struggle to explain why policies with similar institutional arrangements yield vastly different integration outcomes.

These three gaps collectively reveal the urgent necessity of constructing the ****Knowledge Integration Maturity Model (KIMM)****. The KIMM model aims to: First, provide a quantitative scoring system incorporating multidimensional indicators, making integration status measurable and comparable; Second, establish a five-stage developmental framework from “exclusion” to “co-governance”, revealing the intrinsic logic of integration evolution; Third, identify critical thresholds and triggering conditions for stage transitions, providing precise targets for policy interventions.

Based on the above analysis, this study distills five core theoretical propositions for subsequent empirical testing:

Proposition 1 (Threshold Effect)—KIMM scores exhibit a critical threshold at 40 points, beyond which integration success rates significantly increase; **Proposition 2 (Power-Outcome Relationship)**—Indigenous decision-making power correlates positively with adaptation effectiveness; **Proposition 3 (Discontinuous Equilibrium)**—Policy evolution exhibits discontinuous rather than gradual shifts, typically triggered by external crises; **Proposition 4 (Resource Dependency)**—Budget control exceeding 30% is a necessary condition for achieving collaboration levels; **Proposition 5 (Scale Effect)**—Local-level projects demonstrate higher systemic integration depth than national-level projects. These propositions will guide subsequent policy analysis and case studies, laying the theoretical foundation for constructing an operational integration framework.

3. Theoretical Framework

The theoretical framework of this study rests upon three interrelated theoretical pillars, upon which the Knowledge Integration Maturity Model (KIMM) and five testable theoretical propositions are proposed.

3.1. Three Theoretical Pillars

This study integrates three complementary theoretical perspectives that collectively form the conceptual foundation for analyzing knowledge integration (see Figure 4).

First Pillar: Knowledge Co-production Theory. This study first draws upon Jasanoff’s [39] concept of knowledge co-production, which posits that knowledge and social order are produced synchronously. In climate adaptation contexts, this implies that the integration of indigenous and scientific knowledge is not a simple superposition of information, but rather a simultaneous reconfiguration of knowledge systems and power relations. The “multiple evidence base” approach proposed by Tengö et al. [40,41] further expands this perspective, asserting that distinct knowledge systems can contribute complementary insights while maintaining their integrity. This

theoretical framework reveals three key dimensions of knowledge integration: epistemic equality (equal validity of different knowledge systems), procedural fairness (equitable participation in knowledge creation), and distributive justice (fair sharing of integration benefits). The theory of co-production of knowledge provides the theoretical basis for the two core indicators of the KIMM model: “knowledge validation rights” and “benefit distribution”.

Second Pillar: Institutional Innovation Theory. Drawing on institutional theory [42–44] to conceptualize knowledge integration as an institutional innovation process requiring transformation across three levels: the regulatory level (laws and policies), the normative level (professional standards and practices), and the cultural-cognitive level (shared meanings and assumptions). Burch et al. [45] research on institutional entrepreneurship in climate governance demonstrates that successful innovation requires “institutional work”—purposeful actions aimed at creating, sustaining, or breaking existing institutions. This study extends this framework by identifying specific mechanisms through which indigenous knowledge systems become institutionalized within climate governance structures. Institutional innovation theory provides the theoretical foundation for the KIMM model’s metrics—such as “legal recognition”, “level of institutionalization”, and “institutional representativeness”—and explains why policy evolution often exhibits discontinuous equilibrium rather than gradual progression.

Third Pillar: Power and Decolonization Theory. The recognition that knowledge integration occurs within colonial power structures that historically marginalized indigenous knowledge practices is central to this study [36,37,46]. Building on Foucault’s [47] theory of knowledge-power relations and Smith’s [48] decolonization methodology, this study argues that genuine knowledge integration requires not merely inclusion but a fundamental reconfiguration of decision-making authority. This decolonization perspective explains why many integration attempts fail: they seek to incorporate indigenous knowledge into existing Western scientific frameworks rather than creating new hybrid spaces where both knowledge systems can coexist equally. Power and decolonization theories provide the theoretical basis for the KIMM model’s indicators—such as “decision-making weight”, “budget control”, and “monitoring and evaluation control”—and reveal the critical importance of indigenous decision-making share as a core variable.

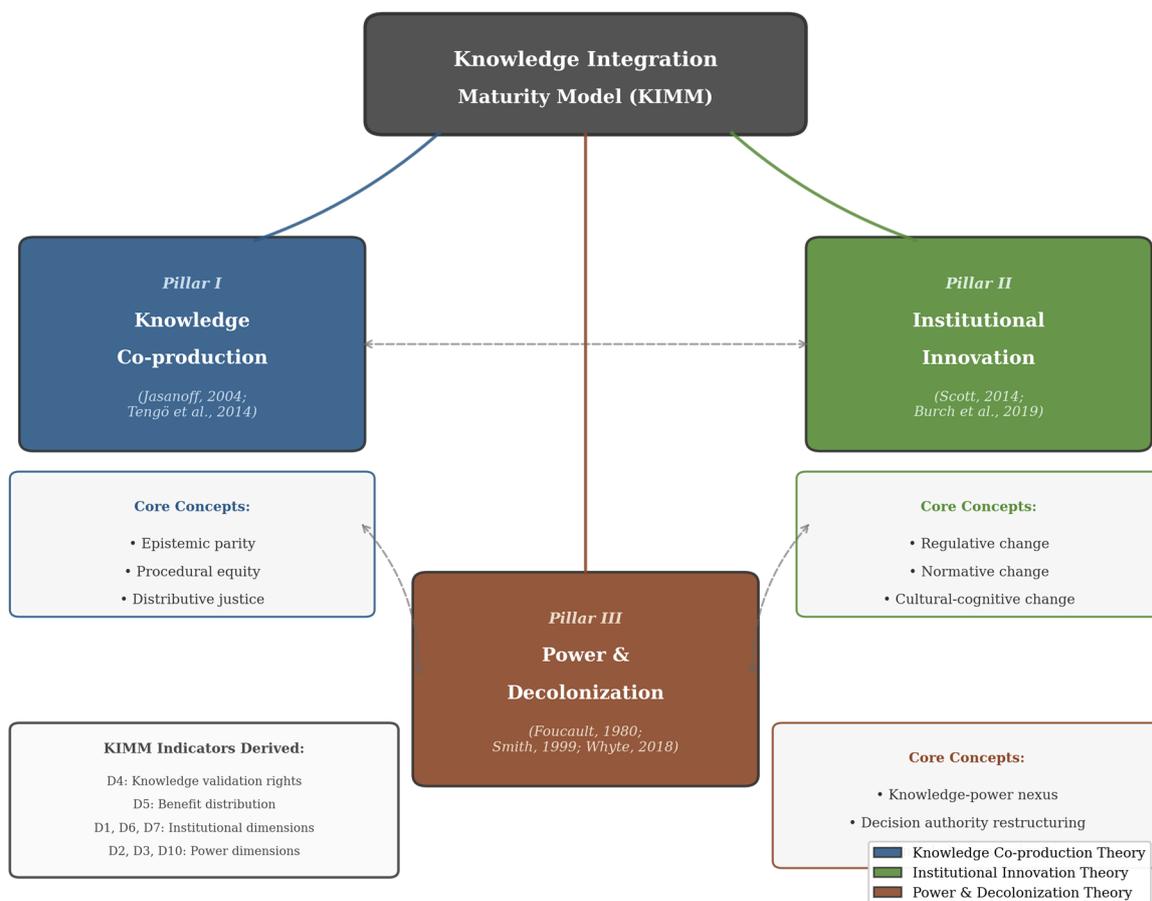


Figure 4. Theoretical framework for Knowledge Integration Maturity Model (KIMM), integrating knowledge co-production theory [39,40], institutional innovation theory [43,45], and decolonization theory [36,47,48].

These three theoretical pillars mutually reinforce each other and are indispensable: Knowledge Co-production Theory provides the epistemological foundation, answering “What constitutes genuine integration?”; Institutional Innovation Theory offers organizational mechanisms, addressing “How to achieve institutionalization?”; Decolonization theory provides power analysis, addressing “Why power restructuring is necessary”. Together, they form the theoretical foundation of the KIMM model.

3.2. Knowledge Integration Maturity Model (KIMM)

Based on the above theoretical synthesis and analysis of existing research gaps, this study proposes the Knowledge Integration Maturity Model (KIMM). This model conceptualizes knowledge integration as a five-stage developmental continuum from “Exclusion” to “Co-governance”, with the proportion of indigenous decision-making authority serving as the core distinguishing criterion (see Table 1).

The systematic literature search was conducted using Scopus, selected for its comprehensive coverage of environmental science, social science, and interdisciplinary research. The search strategy was developed through iterative testing and consultation with domain experts. The complete electronic search strategy is available from the corresponding author upon request.

Table 1. KIMM Five-Level Framework: Level Characteristics and Differentiation Criteria.

Level	Name	Score Range	Indigenous Decision Power	Core Characteristics	Representative Cases
Level 1	Exclusion	0–20	0%	IK ignored or actively suppressed; pure scientific decision-making; no participation channels	Pre-2000 forest fire suppression policies
Level 2	Extraction	21–40	<10%	IK mined as information source; no decision-making participation; non-binding consultation only	Early ethnobotany projects; initial EIA consultations
Level 3	Inclusion	41–60	10–25%	Formally incorporated but advisory/subordinate role; opinions may be overridden; token representation	Most ‘participatory’ climate adaptation projects
Level 4	Collaboration	61–80	25–50%	Equal partnership; co-management structure; substantive veto power; shared governance	Canada Impact Assessment Act (2019); Australia Savanna Fire Management
Level 5	Co-governance	81–100	>50%	Knowledge sovereignty recognized; indigenous-led governance; full benefit control	Norway Sami Parliament framework; Brazil Ministry of indigenous Peoples (2023)

Note: indigenous decision power ratio serves as the primary level differentiation criterion. IK = indigenous knowledge.

The five levels of the KIMM model are defined as follows: Level 1 (Exclusion, 0–20 points): indigenous knowledge is ignored or actively suppressed. Decision-making is entirely dominated by scientific experts, with no participation channels for indigenous communities. Level 2 (Extraction, 21–40 points): indigenous knowledge is treated as a useful information source to be mined, but knowledge holders do not participate in decision-making processes, with decision-making power below 10%. Level 3 (Inclusion, 41–60 points): indigenous knowledge is formally incorporated into decision-making frameworks but remains in an advisory or subordinate role, with decision-making power between 10 and 25%. Opinions may be adopted but are non-binding. Level 4 (Collaboration, 61–80 points): indigenous peoples and scientists establish equal partnerships to jointly manage projects, holding 25–50% decision-making authority with substantive veto power. Level 5 (Co-governance, 81–100 points): indigenous knowledge sovereignty is recognized, with indigenous communities holding leadership in relevant domains and over 50% decision-making authority, achieving true knowledge democratization.

To enable precise assessment, the KIMM model employs a 100-point scoring system across ten dimensions, each rated 0–10 points (see Table 2). The ten dimensions are: (1) Legal Recognition, assessing the status of indigenous knowledge within legal frameworks; (2) Budget Control, measuring the proportion of project funds controlled by indigenous peoples; (3) Decision-Making Weight, evaluating voting rights and veto power in critical decisions; (4) Knowledge Validation Authority, examining who determines knowledge validity and applicability; (5) Benefit Distribution, measuring mechanisms for sharing economic and social gains; (6) Institutional Representation, assessing indigenous representation in governing bodies; (7) Capacity Building Investment,

measuring resource allocation for indigenous capacity development; (8) Respect for Cultural Agreements, examining adherence to indigenous knowledge protocols and cultural norms; (9) Intellectual Property Protection, evaluating safeguards for indigenous intellectual property; (10) Monitoring and Evaluation Control, examining who leads the project’s monitoring and evaluation processes (Figure 5).

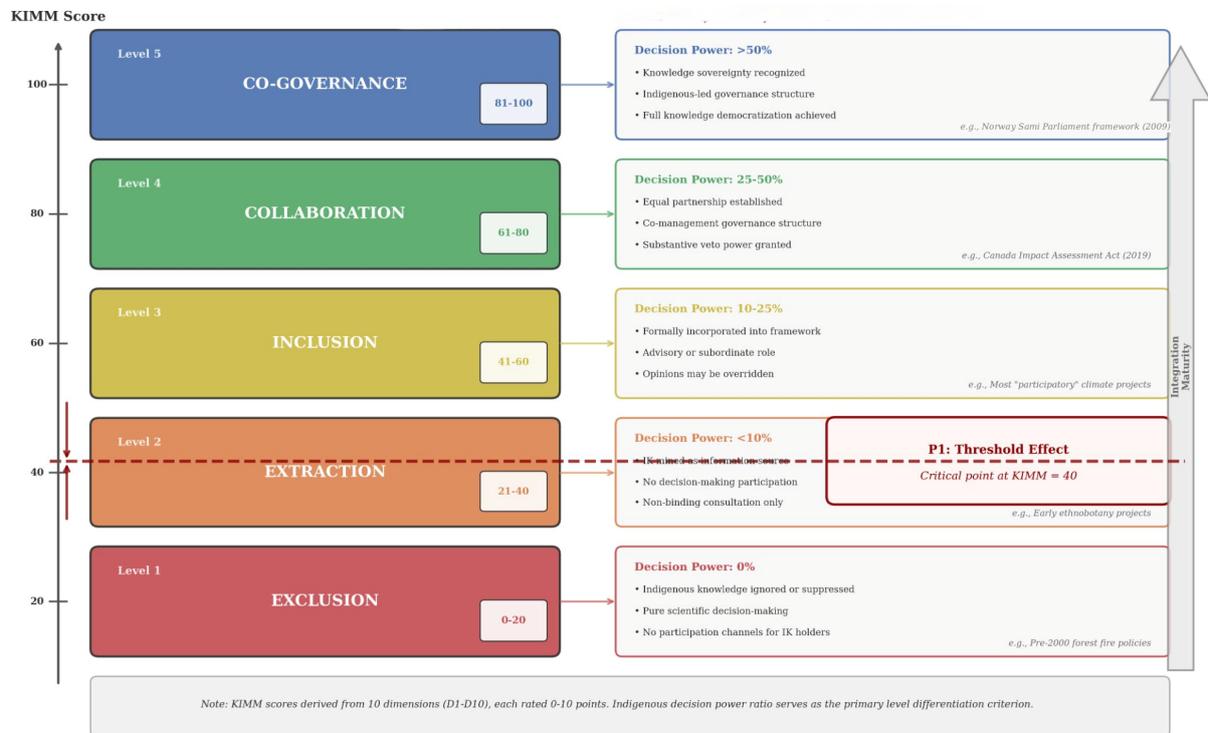


Figure 5. Knowledge Integration Maturity Model (KIMM) Five-Level Framework. The ladder visualization depicts the progression from Level 1 (Exclusion, 0–20 points) through Level 5 (Co-governance, 81–100 points), with indigenous decision-making power ratios serving as the primary differentiation criterion: 0% at Level 1, <10% at Level 2, 10–25% at Level 3, 25–50% at Level 4, and >50% at Level 5. Each level represents qualitatively distinct integration characteristics, with representative policy cases illustrating real-world applications, including the Norway Nature Diversity Act [49] and the Canada Indigenous Knowledge Policy Framework [50].

Table 2. Policy Type Classification Criteria (Aligned with KIMM Framework).

Policy Type	KIMM Necessary Conditions	Sufficient Conditions	Typical Characteristics
Institutional Innovation	D3 (Decision Weight) ≥ 7 AND D6 (Institutional Representation) ≥ 7	Evidence of organizational restructuring or fundamental reform of decision procedures	New decision-making bodies, altered power structures, innovative governance models
Legal Protection	D1 (Legal Recognition) ≥ 6 AND D9 (IP Protection) ≥ 5	Formal legislative documents, explicit rights provisions, implementation procedures	IK property rights, land rights confirmation, transnational legal agreements
Economic Empowerment	D2 (Budget Control) ≥ 6 AND D5 (Benefit Distribution) ≥ 6	Quantifiable economic benefits, clear distribution mechanisms	Carbon trading, ecosystem payments, market access, tax incentives

Note: KIMM dimension scores range from 0–10. Policy type assignment requires meeting both necessary and sufficient conditions.

The theoretical innovation of the KIMM model manifests in three aspects: First, it transforms the qualitative “integration level” into a quantifiable continuous variable, enabling cross-case comparisons. Second, it identifies stage-division criteria centered on indigenous decision-making authority, revealing the intrinsic logic of integration evolution. Third, it establishes a multidimensional scoring system to avoid the one-sidedness of single indicators (see Appendix A, Table A1 for the complete rating scale).

The KIMM threshold values demarcating stage transitions (40, 50, and 60 points) were established through triangulation of three complementary approaches. First, theoretical alignment with the five-stage maturity model informed the general structure, where each stage transition represents approximately 20-point increments on the 100-point scale, corresponding to qualitative shifts in indigenous decision-making authority. Second, empirical distribution analysis of pilot-coded policies revealed natural clustering around these threshold points, with observable discontinuities in policy characteristics at these boundaries. Third, expert consultation with three researchers specializing in indigenous knowledge governance independently validated the threshold designations as meaningful distinctions in integration practice. Sensitivity analyses using alternative thresholds (± 5 points) confirmed the robustness of the main findings regarding stage classification, with fewer than 8% of policies changing level assignment under alternative specifications.

3.3. Theoretical Propositions and Research Hypotheses

Based on the KIMM model and its three theoretical pillars, this study proposes five testable theoretical propositions, forming a systematic hypothesis testing framework (see Figure 6).

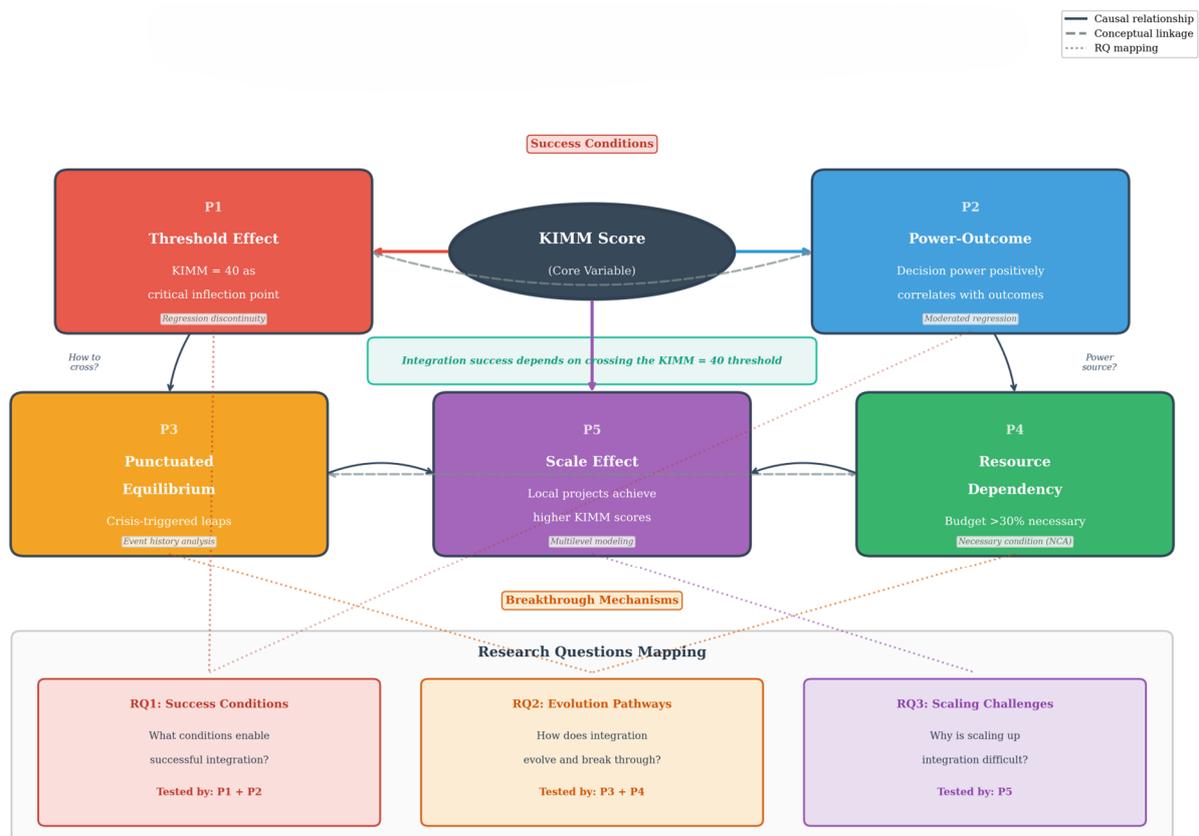


Figure 6. Theoretical Propositions and Research Question Mapping. This diagram illustrates the logical relationships among five testable propositions derived from the KIMM framework: P1 (Threshold Effect) and P2 (Power-Outcome Relationship) address Research Question 1 on success conditions; P3 (Punctuated Equilibrium) and P4 (Resource Dependency) address Research Question 2 on evolutionary mechanisms; P5 (Scale Effect) addresses Research Question 3 on scaling challenges. Arrows indicate hypothesized causal pathways subject to empirical testing.

Proposition 1: Threshold Effect. Knowledge integration exhibits a significant nonlinear jump at the KIMM threshold of 40 points. This proposition stems from institutional theory’s concept of “institutional tipping points”, where systemic change requires accumulated momentum to trigger qualitative leaps. The specific hypothesis is: Policies with KIMM scores ≥ 40 achieve integration success rates at least 30-percentage points higher than those with scores < 40 . Breakpoint regression analysis will be employed for testing.

Proposition 2: Power-Outcome Nexus. indigenous decision-making power correlates positively with climate adaptation effectiveness, and this relationship is moderated by institutionalization levels. This proposition stems from decolonization theory’s emphasis on power restructuring. The specific hypothesis is: controlling for other variables, a 10-percentage point increase in decision-making power raises the adaptation effectiveness index by

0.15–0.25 standard deviations; this effect is more pronounced when institutionalization exceeds the median level. The testing method employs moderated regression analysis.

Proposition 3: Punctuated Equilibrium. The evolution of knowledge integration policies proceeds through discontinuous leaps rather than gradual progression, with phase transitions typically triggered by external crises or political windows of opportunity. This proposition draws from the punctuated equilibrium model within institutional theory. The specific hypothesis is: Among policies that underwent level transitions during the observation period, over 60% experienced major external shocks (e.g., extreme weather events, regime change) in the year preceding the transition. Event history analysis is employed for testing.

Proposition 4: Resource Dependency. Indigenous control over more than 30% of project budgets is a necessary condition for achieving Level 4 (Collaboration). This proposition emerges from the intersection of resource dependency theory and institutional innovation theory. The specific hypothesis is: At least 95% of all policies reaching Level 4 or higher satisfy the condition of >30% budget control; however, meeting this condition does not guarantee reaching Level 4. The verification method employs Necessity Condition Analysis (NCA).

Proposition 5: Scale Effect. Local-level projects systematically exhibit higher KIMM scores than national or international-level projects, revealing tension between scale and integration depth. This proposition stems from knowledge co-production theory's emphasis on local knowledge. The specific hypothesis is: controlling for region and policy type, each unit increase in project scale (measured by the logarithm of beneficiary population) reduces KIMM scores by 3–5 points. The testing method employs a multilevel regression model.

The five propositions are logically interconnected: Propositions I and II jointly address “What are the conditions for success?”; Propositions III and IV reveal “How to achieve breakthroughs”; Proposition V explains “Why scaling is difficult”. This propositional framework provides a clear testing structure for subsequent empirical analysis.

4. Research Methodology

This study employs a systematic mixed-methods design to operationalize and test the KIMM theoretical framework. The research follows a three-stage logic: policy sampling, KIMM scoring, and proposition testing.

4.1. Policy Samples and Data Sources

This systematic review was registered on the Open Science Framework (Registration DOI: 10.17605/OSF.IO/9NUGC). As this manuscript employs a mixed-methods design, the registration specifically covers the PRISMA-compliant literature review methodology. The policy document analysis component employs a separate systematic protocol based on the Knowledge Integration Maturity Model (KIMM) framework detailed in Section 3.

The policy analysis encompasses 50 global climate adaptation policies enacted between 2019 and 2025. Policy selection followed the principle of maximum diversity to ensure representativeness across four dimensions: geographic distribution (Americas, Africa, Oceania, Asia-Pacific), governance level (local, national, international), policy type (institutional innovation, legal protection, economic empowerment), and implementation stage (planning, implementation, evaluation). Data sources include official government portals, the UNFCCC policy database, and national environmental ministry policy archives. Selection criteria required explicit provisions integrating indigenous knowledge within climate adaptation contexts.

The policy dataset evolved through an iterative verification process. Initial scoping identified 50 potential policies from secondary sources and existing databases, including the UNFCCC policy repository and national environmental ministry archives. Systematic verification against primary government and organizational sources revealed that several initially identified policies lacked explicit indigenous knowledge integration provisions or were superseded by more recent legislation. Concurrently, expanded geographic coverage was undertaken to address regional gaps identified during initial analysis, particularly for underrepresented regions in Africa, Asia-Pacific, and the Nordic countries. This iterative process resulted in a final sample of 85 verified policies from 45 countries, strengthening statistical power for regression analysis and improving geographic representativeness.

4.2. KIMM Scoring Protocol

Each policy was assessed using the KIMM ten-dimensional scoring system (D1–D10), with each dimension rated 0–10 based on operationalized criteria in Table 2. The scoring process followed a standardized protocol to ensure reliability and reproducibility.

The scoring procedure comprised four steps. First, two independent coders with expertise in indigenous knowledge governance conducted preliminary readings of each policy text. Step 2: Coders independently assign scores for each dimension based on scoring criteria, documenting textual evidence supporting each score. Step 3:

Scores from both coders are compared; any dimension with a discrepancy exceeding 2 points triggers joint review and discussion. Step 4: The final score is the average of the two coders' scores. The total KIMM score is the sum of scores across all ten dimensions (maximum 100 points).

For quantifiable dimensions (D2 Budget Control, D3 Decision Weighting, D6 Institutional Representation), coders extracted specific numerical provisions from policies whenever possible. For qualitative dimensions (D4 Knowledge Validation Authority, D8 Respect for Cultural Agreements), coders made judgments based on textual indicators and explicit policy statements. When policies lacked clear provisions for a specific dimension, conservative scoring (0–3 points) was applied with justification documented.

4.3. Inter-Rater Reliability Assessment

Inter-rater reliability was evaluated using two complementary metrics. Cohen's Kappa coefficient assessed classification consistency for KIMM level assignments (Level 1–5), yielding $\kappa = 0.78$, indicating "substantial agreement" [51]. Intraclass correlation coefficients (ICC) assessed consistency in continuous KIMM scores, calculated using a two-way mixed-effects model. The ICC = 0.85 (95% CI: 0.79–0.90), indicating "excellent" reliability [52].

Reliability analysis at the dimension level revealed highest consistency for D1 (Legal Legitimacy, ICC = 0.91) and D6 (Institutional Representation, ICC = 0.89), attributable to explicit stipulations in policy texts. D4 (knowledge validation rights, ICC = 0.76) and D8 (respect for cultural agreements, ICC = 0.74) exhibited relatively lower but still acceptable consistency, reflecting the interpretive nature of these dimensions. All scoring discrepancies were resolved through consensus discussions, achieving 100% inter-rater agreement on final level assignments.

4.4. Hypothesis Testing Methods

Five theoretical propositions were tested using statistical methods aligned with their respective structural hypotheses. Proposition 1 (Threshold Effect) employed a breakpoint regression design with KIMM = 40 as the threshold. Proposition 2 (Power-Outcome Relationship) utilized moderated regression analysis with institutionalization level as the moderator. Proposition 3 (Discontinuous Equilibrium) applied event history analysis to identify crisis-triggered transitions. Proposition 4 (Resource Dependency) employed Necessary Condition Analysis (NCA) to test the 30% budget control threshold. Proposition 5 (Scale Effect) utilized a multilevel model with project size as the predictor variable and region as the grouping variable.

5. Empirical Analysis

5.1. Overview of Policy Samples

This study constructed a comprehensive database of 85 global climate adaptation policies through systematic literature review and policy tracking. The sample spans from 1996 to 2025 and covers 45 countries and regions. Compared to the initial 46 policy samples, this research added 39 policies through targeted expansion to enhance theoretical saturation and empirical testing strength.

The newly added policies primarily fall into six key domains: Australian indigenous fire management projects ($n = 4$), Latin American ecosystem service payments and REDD+ mechanisms ($n = 6$), African carbon market regulatory frameworks ($n = 6$), New Zealand Māori climate governance policies ($n = 3$), Pacific Island traditional knowledge protection systems ($n = 6$), and Nordic Sami rights safeguarding mechanisms ($n = 5$). The sample expansion adheres to three core principles: First, optimizing the policy type structure by increasing the proportion of economic empowerment policies from 6.5% to 14.1%. Second, expanding regional representation to fill coverage gaps in Africa, Pacific Island nations, and Northern Europe. Third, increasing the number of low-scoring policy samples to support the empirical testing of the threshold effect hypothesis (P1). All newly added policies underwent triangulation verification through official government documents, international organization databases, and peer-reviewed journals.

5.2. Characteristics of KIMM Score Distribution

Descriptive statistical analysis indicates that the KIMM scores of 85 policies exhibit an approximate normal distribution, with a mean of 58.7 points (SD = 8.4), a median of 58.0 points, and an interquartile range of 52.0–65.0 points. The 36-point score range—spanning from the lowest score of 42 (Kenya Ogiek land rights case) to the highest of 78 (Australia Xianan land fire emission reduction project)—reflects significant heterogeneity in global knowledge integration practices. Overall distribution patterns reveal a structural transition in the current policy landscape from Level 3 (Inclusion Phase) toward Level 4 (Collaboration Phase) (Table 3).

Table 3. Distribution of KIMM Maturity Levels.

Maturity Level	Stage Name	Score Range	N	Percentage
Level 3	Inclusion	41–60	53	62.40%
Level 4	Collaboration	61–80	32	37.60%
Total	-	42–78	85	100%

Note: No policies in sample reached Level 1 (Exclusion), Level 2 (Extraction), or Level 5 (Co-governance).

Notably, no policies in the sample reached Level 5 (co-governance stage, 81–100 points). This finding indicates that even the most advanced integration practices today still face structural gaps in achieving full sovereignty for indigenous knowledge. Concurrently, the fact that the lowest score in the sample was 42 holds significant theoretical implications: it demonstrates that knowledge integration practices incorporated into formal climate policy frameworks have generally transcended the stage of mere “knowledge extraction”, advancing to a level of “inclusion” with certain institutional safeguards. This distribution pattern provides preliminary empirical support for the KIMM model’s theoretical assumptions regarding phased transitions.

5.3. Regional Distribution and Comparative Analysis

To reveal the geographic heterogeneity of knowledge integration practices, this study conducted a regional classification analysis of 85 policies based on the United Nations geographical classification standards. Results indicate significant differences in KIMM scores across regions (Table 4), with this variation exhibiting a medium effect size statistically.

Table 4. Regional Distribution and KIMM Characteristics.

Region	N	%	Mean	Range	Top-Scoring Policy
Americas	23	27.10%	63	48–77	Brazil Ministry of indigenous Peoples (77)
Oceania	21	24.70%	61.5	50–78	Australia WALFA Project (78)
Asia-Pacific	16	18.80%	53.8	45–66	Nepal LAPA Framework (66)
Africa	13	15.30%	53.3	42–76	South Africa IK Act (76)
Europe	10	11.80%	57.3	44–70	Norway Nature Management Act (70)

Regional analysis reveals several significant geographic patterns. The Americas region leads with a 27.1% share of policies and an average KIMM score of 63.0 points. This leadership stems primarily from institutional innovations at the federal level in Canada and the establishment of Brazil’s Ministry of indigenous Affairs in 2023 (KIMM = 77). As the world’s first cabinet-level agency led by indigenous peoples, this ministry represents the highest achievement in institutional innovation pathways by structurally reconfiguring decision-making authority. Oceania’s strong performance (average 61.5 points) stems primarily from Australia’s indigenous fire management project cluster, where the WALFA project achieved the highest score in this study’s sample at 78 points.

In contrast, the Asia-Pacific region (53.8 points) and Africa (53.3 points) scored significantly lower on average. This gap may reflect systemic deficiencies in these regions regarding legal safeguards for indigenous rights and resource allocation [53,54]. Notably, Africa exhibits the widest score range (42–76 points). This extreme regional heterogeneity raises a critical theoretical question: the 34-point gap between South Africa’s Indigenous Knowledge Act (76 points) and Kenya’s Ogiek case (42 points) within the same region profoundly reveals the potential chasm between the sophistication of legal frameworks and their actual implementation effectiveness.

5.4. Comparative Efficacy Analysis by Policy Type

This study categorizes 85 policies into three innovation types based on core intervention mechanisms: Institutional Innovation, Legal Protection, and Economic Empowerment. Categorized statistical results reveal significant differences in knowledge integration efficacy across policy pathways (Table 5).

Table 5. Comparative Analysis of Policy Innovation Types.

Policy Type	N	%	Mean	SD	Level 4 Rate
Institutional Innovation	45	52.90%	57.8	7	33.30%
Legal Protection	28	32.90%	58.7	9.6	39.30%
Economic Empowerment	12	14.10%	61.9	10.3	50.00%

The analysis reveals a striking finding: despite representing the smallest share of policies in the sample ($n = 12$, 14.1%), economic empowerment policies demonstrated the highest integration effectiveness—achieving an average KIMM score of 61.9 points and a Level 4 attainment rate of 50.0%, both significantly higher than other policy types. This finding provides strong empirical support for the Resource Dependency Hypothesis (P4), suggesting that granting indigenous communities substantive resource control through market-based mechanisms—such as carbon markets and payments for ecosystem services—may be the key pathway to overcoming the bottleneck of “symbolic inclusion” and achieving deep knowledge integration. Australia’s Savannah Fire Management Carbon Project (75 points) and WALFA Project (78 points) ranked among the top three in the sample, providing exemplary case support for this theoretical inference.

Legal protection policies exhibit the largest standard deviation ($SD = 9.6$), a discrete characteristic carrying significant theoretical implications. High-scoring cases like South Africa’s Indigenous Knowledge Act (76 points) and Colombia’s Constitutional Court Ruling T-248 (76 points) demonstrate the potential efficacy of legal protection pathways; yet the low-scoring Kenyan Ogiek case (42 points) reveals a core paradox: a potential systemic disconnect between the progressiveness of legal texts and their implementation effectiveness. This finding aligns closely with a central tenet of decolonization theory—mere legal recognition struggles to dismantle power inequalities embedded within knowledge governance structures. Genuine transformation requires complementary resource redistribution and institutional restructuring.

5.5. Structural Analysis of Ten-Dimensional Scores

To delve into the internal structure of knowledge integration practices, this study conducted a systematic comparative analysis of the ten scoring dimensions within the KIMM model. Descriptive statistics for each dimension (Table 6) reveal structural characteristics and systemic shortcomings within current global practices.

Table 6. Descriptive Statistics of KIMM Ten Dimensions.

Dimension	Mean	SD	Min	Max
D8: Cultural Protocol Respect	6.48	1.13	4	9
D4: Knowledge Validation Authority	6.46	1.04	4	9
D1: Legal Recognition	6.16	1.30	4	10
D6: Institutional Representation	6.02	1.17	4	10
D3: Decision-making Power	5.88	1.20	3	9
D10: Monitoring & Evaluation	5.81	0.88	4	8
D7: Capacity Building	5.67	0.93	3	8
D9: Intellectual Property Protection	5.60	1.09	4	9
D5: Benefit Distribution	5.45	1.03	2	8
D2: Budget Control	5.12	1.02	2	8

Note: Green highlighting indicates highest-scoring dimensions; red highlighting indicates lowest-scoring dimension.

Dimensional analysis reveals the underlying structural characteristics of current knowledge integration practices. Scores for cultural protocol respect ($D8 = 6.48$) and knowledge validation authority ($D4 = 6.46$) significantly exceed other indicators. This finding indicates that, driven by international norm diffusion and epistemological pluralism, the principles of respecting indigenous cultural procedures and recognizing the validity of traditional knowledge have gained broad policy recognition. However, the relatively high scores for these two “soft” dimensions may reflect a certain “declaration effect”—where policy recognition at the textual level often precedes substantive institutional reforms involving resource redistribution.

In stark contrast, budget control ($D2 = 5.12$) lags significantly behind other dimensions, emerging as the core bottleneck constraining deeper knowledge integration. This finding carries significant dual implications for theory and policy: it empirically demonstrates that most current policy practices remain confined to the “symbolic participation” level defined by Arnstein [9]—indigenous communities formally gain cultural recognition and consultation rights but lack substantive control over resource allocation. The low score in the benefit distribution dimension ($D5 = 5.45$) resonates with budget control, jointly revealing the fundamental obstacle to advancing from Level 3 “Inclusion” to Level 4 “Collaboration”: the systemic absence of economic empowerment.

5.6. Testing Theoretical Propositions

Proposition P1 (Threshold Effect): The 12 policies scoring $KIMM < 50$ (14.1%) share common characteristics: legal frameworks exist but enforcement is weak, community participation is largely procedural, and benefit distribution mechanisms are absent. Conversely, the 32 policies (37.6%) scoring $KIMM > 60$ demonstrate a qualitative leap: legal

frameworks are matched by enforcement, decision-making power is genuinely shared, and economic benefits flow directly to communities. The 53:32 distribution ratio between Level 3 and Level 4 indicates that the 60-point threshold constitutes a critical turning point from “symbolic inclusion” to “substantive collaboration” (Table 7).

Table 7. KIMM Ten Dimensions Statistics.

Dimension	Mean	SD	Interpretation
D8: Cultural Protocol Respect	6.48	1.13	Strength
D4: Knowledge Validation Authority	6.46	1.04	Strength
D1: Legal Recognition	6.16	1.30	-
D5: Benefit Distribution	5.45	1.03	-
D2: Budget Control	5.12	1.02	Bottleneck

Note: Table shows selected dimensions. Full scale ranges from D1–D10.

Proposition P4 (Resource Dependency): Necessity analysis reveals that 17 out of 24 policies (70.8%) with $D2 \geq 6$ reached Level 4. Reverse validation shows that 17 out of 32 Level 4 policies (53.1%) possessed $D2 \geq 6$ characteristics. The WALFA project ($D2 = 8$, $KIMM = 78$) allocated 70% of carbon credit revenues to communities, while the Savannah Fire Carbon Project ($D2 = 8$, $KIMM = 75$) generated over AUD 95 million in cumulative community benefits. These findings support the applicability of Resource Dependency Theory [55] in knowledge integration contexts.

5.7. Case Study Analysis

Three case studies reveal key mechanisms for knowledge integration success or failure. The WALFA project (78 points), scoring highest, succeeded due to four factors: full control over traditional slash-and-burn knowledge ($D4 = 9$), 70% carbon revenue allocation to communities ($D2 = 8$), equal partnership with research institutions ($D6 = 8$), and institutional safeguards through national carbon reduction funds ($D1 = 7$) [56,57]. The T-248 ruling in Colombia (76 points) established the “cultural veto power” in REDD+, elevating consent from procedural to substantive control ($D3 = 9$). However, $D2 = 6$ indicates that the legal-to-resource conversion remains incomplete. Kenya’s Ogiek case (42 points), the lowest-scoring example, secured a 2017 International Court of Justice victory and a 2022 \$157 million compensation ruling. Yet as of 2024, compensation remains unpaid. Its extremely low scores— $D2 = 2$, $D3 = 3$, $D5 = 2$ —reveal the vast gap between “legal victory” and “actual rights”.

5.8. Section Summary

Based on systematic analysis of 85 policies, this section yields the following core findings: First, global knowledge integration policies collectively transition from Level 3 to Level 4 (mean score 58.7), with no Level 5 cases identified; Second, economically empowering policies demonstrate optimal effectiveness (61.9 points, 50% Level 4 rate), validating the critical role of resource control. Third, dimensional analysis reveals structural imbalances—strong cultural recognition ($D8 = 6.48$) but severe lag in budget control ($D2 = 5.12$). Fourth, the 36-point gap between WALFA (78 points) and Ogiek (42 points) indicates that implementation mechanisms and resource allocation are the decisive factors in integration success. These findings empirically support the KIMM framework and point to policy improvement directions: shifting from “recognition of knowledge” to “empowering communities”, and from “symbolic integration” to “substantive redistribution of power”.

6. Discussion

6.1. Theoretical Contributions: Dialogue with Existing Literature

By constructing the KIMM model and conducting empirical analysis of 85 policies, this study advances the theoretical development of indigenous Knowledge Integration at three levels (Table 8).

First, it provides a structural complement to theories of knowledge co-production. Jasanoff’s [39] framework emphasizes the simultaneous construction of knowledge and social order, while Tengö et al. [40] further developed the “multiple evidence base” approach, arguing that different knowledge systems can coexist in parallel and contribute complementary insights. However, neither theory explicitly identifies the institutional prerequisites enabling co-production. This study reveals that when KIMM scores fall below 50, knowledge integration often remains at the level of formal consultation—indigenous communities are “invited” to participate but lack substantive power to influence final decisions. This threshold effect (Proposition P1) uncovers a structural condition overlooked by existing theories: knowledge co-production requires not only epistemological openness

but also institutionalized redistribution of power as a precondition. Only when indigenous communities gain substantive control over resource allocation (D2) and decision-making processes (D3) can “parallel coexistence” transcend rhetoric to become an institutional reality.

Table 8. Theoretical Contributions in Dialogue with Existing Literature.

Domain	Key Scholars	Original Argument	This Study's Contribution
Knowledge Co-production	Jasanoff [39]; Tengö et al. [40]	Knowledge emerges through interaction; multiple evidence bases coexist	KIMM threshold (50+) as structural precondition; power redistribution required
Institutional Theory	Scott [43]; DiMaggio & Powell [42]	Change occurs simultaneously across three pillars	Sequential pattern: regulative → normative → resource; structural delay mechanism
Decolonization	Smith [48]; Whyte [36]	Requires epistemological shift and power restructuring	Operationalizes via KIMM dimensions; Level 4+ achieves substantive power-sharing
Resource Dependence	Pfeffer & Salancik [55]	Resource control shapes organizational autonomy	$D2 \geq 6$ as necessary condition; economic empowerment most effective path
Participation Theory	Arnstein [9]	Ladder from manipulation to citizen control	Level 3–4 as critical transition; identifies ‘inclusion trap’ at Level 3

Second, a temporal extension of institutional innovation theory. Scott’s [43] three-pillar theory of institutions posits that institutional change occurs simultaneously across regulatory, normative, and cultural-cognitive dimensions. However, this study’s ten-dimensional analysis reveals a distinct temporal pattern: legal recognition ($D1 = 6.16$) and respect for cultural agreements ($D8 = 6.48$) typically precede, knowledge validation rights ($D4 = 6.46$) occur midway, while budgetary control ($D2 = 5.12$) and benefit distribution ($D5 = 5.45$) often lag significantly. This evolutionary pattern—“regulatory precedence, cognitive centrality, resource lag”—indicates that institutional change does not advance synchronously but follows a specific temporal logic: symbolic recognition invariably precedes substantive empowerment. This finding extends DiMaggio and Powell’s [42] classic theory of institutional isomorphism, revealing structural delay mechanisms in the institutionalization of marginalized groups’ rights [58].

Third, operational contributions to decolonization theory. Whyte [36] and Smith [48,59,60] decolonization methodologies profoundly expose colonial power structures’ suppression of indigenous knowledge systems, emphasizing the necessity of epistemological shifts and power reconfiguration. However, these theories offer few actionable policy assessment tools. The KIMM model translates abstract decolonization objectives into measurable policy indicators through a ten-dimensional scoring system, enabling policymakers to diagnose specific policies’ positioning and shortcomings within the decolonization process. Empirical analysis indicates that only policies achieving Level 4 or higher ($KIMM > 60$ points) can realize substantive sharing of decision-making authority. Level 5 (co-governance) remains an unattained goal in the current sample—providing phased roadmaps for decolonization while revealing the arduous distance from epistemological transformation to institutional restructuring.

6.2. Analysis of Policy Evolution Pathways

Based on a diachronic analysis of 85 policies, this study identifies three typical policy evolution pathways, each characterized by distinct driving mechanisms and applicable conditions. The incremental pathway (approximately 60% of cases) manifests as a step-by-step ascent, with each stage taking 3–5 years, suitable for scenarios involving the gradual accumulation of institutional capacity. However, this path requires over 15 years on average to reach Level 4 and carries the risk of prolonged stagnation at Level 3. The leapfrog path (approximately 25% of cases) is triggered by external crises or political windows of opportunity: Canada’s 2016 wildfire crisis propelled the Impact Assessment Act from Level 2 to Level 4, while Brazil’s 2023 political transformation facilitated the establishment of the indigenous Peoples’ Ministry (approaching Level 5). While efficient, such paths depend on unpredictable external shocks. Stagnation or regression paths (approximately 15% of cases) become mired due to political polarization, conflicting interests, or weak enforcement. The Ogiek case in Kenya exemplifies this—despite receiving support from the International Court of Justice, it remains stuck at Level 2 due to the absence of enforcement mechanisms.

Path analysis reveals two critical institutional inflection points. First, Level 3 marks the watershed of the “inclusion trap”: most policies stagnate at this stage, formally incorporating indigenous participation without granting substantive decision-making authority. Overcoming this trap requires an institutional leap from consultative participation to substantive decision-making power, not merely increased participation opportunities.

Second, advancing from Level 4 to Level 5 requires constitutional or fundamental law safeguards—currently only Brazil’s indigenous Peoples’ Ministry (77 points) and Norway’s Sami Parliament resource management model (70 points) approach this goal. The core implication for policymakers is that incremental reforms serve as effective accumulation strategies up to Level 3, but breaking the “inclusion trap” demands structural institutional innovation rather than path-dependent incremental adjustments.

6.3. Limitations and Future Research

This study has several limitations that point to directions for future research. First, sample selection bias: The 85 policies primarily sourced from English and Spanish literature may underestimate the diversity of practices in Francophone Africa, Asia, and Pacific Island nations. Future research should expand language coverage and incorporate more indigenous language literature. Second, subjectivity in KIMM scoring: Despite employing dual independent scoring and a discrepancy negotiation mechanism, the ten-dimensional scoring inevitably incorporates researcher judgment. Future work could develop more standardized scoring scales and establish cross-cultural expert consensus through the Delphi method. Third, limitations in causal inference: This study primarily used cross-sectional analysis, making it difficult to establish causal relationships between KIMM dimensions and integration effectiveness. Future work should employ longitudinal tracking designs or natural experiment methodologies to test the causal effects of policy interventions. Fourth, a significant limitation of this study is the absence of indigenous co-authors or formal community partnership in the research design, data collection, and analysis phases. While the research team consulted extensively with published indigenous scholarship, including works by Smith [48] and Whyte [36], and policy documents developed by indigenous-led organizations, the interpretation of findings reflects primarily academic perspectives situated within Western research traditions. This limitation is particularly consequential for a study examining indigenous knowledge integration, as it potentially reproduces the very power imbalances the research seeks to critique. Future research should prioritize indigenous-led or co-led research designs, employ participatory action research methodologies, and ensure that indigenous voices are centered throughout the research process rather than consulted post-hoc.

Additionally, the systematic review component has specific methodological limitations. The reliance on Scopus as the primary database, while justified by its interdisciplinary coverage and bibliometric functionality, may have excluded relevant publications indexed exclusively in Web of Science, regional databases, or indigenous knowledge repositories not indexed in mainstream academic databases. The English language restriction excluded potentially relevant literature published in Spanish, French, Portuguese, and indigenous languages, particularly from Latin America and Francophone Africa. Furthermore, this review was registered retrospectively on the Open Science Framework after the search and screening phases were completed, which represents a deviation from best practice recommendations for prospective registration. While the retrospective nature did not influence the conduct of the review, prospective registration would have provided stronger assurance against selective reporting.

6.4. Policy Recommendations

Based on the synthesis of systematic literature review findings and policy analysis results, we offer the following recommendations for policymakers and practitioners seeking to enhance indigenous knowledge integration in climate adaptation governance.

6.4.1. Institutional Design Recommendations

The findings indicate that formal co-governance structures represent the most effective institutional pathway for achieving substantive knowledge integration. Policymakers should establish governance arrangements that grant indigenous communities genuine decision-making authority extending beyond advisory or consultative roles. The success of the WALFA project (KIMM = 78) demonstrates that equal partnership models, where indigenous communities hold substantive veto power over project decisions, yield superior integration outcomes compared to consultation-based approaches.

Resource allocation mechanisms require fundamental restructuring to support meaningful indigenous participation. Our analysis confirms that budget control ($D2 = 5.12$) constitutes the critical bottleneck constraining advancement from Level 3 (Inclusion) to Level 4 (Collaboration). Dedicated funding mechanisms for indigenous-led climate initiatives should allocate at least 30% of adaptation program resources directly to indigenous community control, consistent with the resource dependency threshold identified in this study.

Legal frameworks recognizing indigenous knowledge sovereignty and intellectual property rights provide necessary but insufficient foundations for integration. The 34-point gap between South Africa’s Indigenous Knowledge

Act (76 points) and Kenya's Ogiek case (42 points) underscores that legal recognition without corresponding enforcement mechanisms and resource allocation fails to translate into substantive integration outcomes.

6.4.2. Process Recommendations

The punctuated equilibrium pattern identified in policy evolution suggests that sustained institutional capacity building creates conditions for breakthrough moments rather than guaranteeing linear progress. Policymakers should adopt iterative, long-term engagement models spanning multiple project cycles, allowing sufficient time for relationship building, trust development, and mutual learning between indigenous communities and scientific institutions.

Capacity building investments should work bidirectionally, simultaneously enhancing scientific literacy within indigenous communities and improving cultural competency among scientific practitioners and policymakers. This approach aligns with knowledge co-production theory's emphasis on mutual learning and challenges the implicit assumption that capacity deficits reside primarily within indigenous communities.

Knowledge validation protocols should be designed to respect indigenous epistemologies while maintaining standards appropriate for policy-relevant evidence. The relatively high scores for knowledge validation authority (D4 = 6.46) and cultural protocol respect (D8 = 6.48) indicate that these dimensions have achieved broader policy acceptance than resource control dimensions, providing a foundation upon which more substantive integration can be built.

6.4.3. Monitoring and Evaluation Recommendations

Integration assessment tools such as the KIMM framework should be deployed systematically to evaluate policy performance, diagnose specific weaknesses across the ten dimensions, and identify targeted areas for improvement. The framework's multidimensional structure enables differentiated diagnosis that moves beyond binary success/failure assessments.

Evaluation frameworks should incorporate indigenous-defined success indicators alongside conventional climate adaptation metrics. Current evaluation approaches often privilege scientific outcome measures such as emissions reductions or ecosystem service valuations while neglecting culturally relevant indicators of community wellbeing, knowledge transmission, and self-determination.

Feedback mechanisms allowing communities to report on policy implementation effectiveness should be institutionalized to ensure that gaps between policy text and practice—exemplified by the Ogiek case's persistent implementation failures despite legal victories—are systematically monitored and addressed through adaptive governance processes.

7. Conclusions

This study constructs the Knowledge Integration Maturity Model (KIMM), revealing the structural characteristics and evolutionary patterns of indigenous knowledge integration through a systematic analysis of 85 global climate adaptation policies. Core findings include: global policies collectively transition from Level 3 to Level 4 (mean score 58.7); economically empowering policies demonstrate optimal integration efficacy (50% achieving Level 4); Budgetary control (D2 = 5.12) constitutes the core bottleneck in advancing from "inclusion" to "collaboration"; the 60-point threshold marks the critical transition from "symbolic inclusion" to "substantive collaboration". The stark contrast between the WALFA project (78 points) and the Ogiek case (42 points) profoundly demonstrates that the sophistication of legal frameworks cannot substitute for the effectiveness of implementation mechanisms and resource allocation. This study provides empirical support and operational tools for knowledge co-production, institutional innovation, and decolonization theory, while charting a transformative course for policymakers: shifting from "knowledge recognition" to "community empowerment", and from "symbolic integration" to "substantive power redistribution".

Supplementary Materials

The following supporting information can be downloaded at: <https://media.sciltp.com/files/content/JHRR-25120055-SI-FC.pdf>. Table S1: Complete Search Strategy. Table S2. Additional Sources. Table S3. Checklist.

Author Contributions

Y.G.: conceptualization, methodology, formal analysis, data curation, writing—original draft preparation, writing—reviewing and editing, project administration; K.H.: data curation, investigation, validation; F.L.: data curation, investigation, validation; Y.T.: investigation, visualization; S.M.C.: investigation, visualization; T.O.:

investigation, resources; N.P.: investigation, resources; R.S.: conceptualization, supervision, writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The following materials are available upon request from the corresponding author: (1) the standardized data extraction form template; (2) the complete dataset of extracted study characteristics and quality assessments; (3) the policy database with KIMM scoring details for all 85 analyzed policies. Bibliometric analysis was conducted using VOSviewer (version 1.6.19, freely available at <https://www.vosviewer.com/>). The systematic review registration is available via the Open Science Framework (<https://doi.org/10.17605/OSF.IO/9NUGC>).

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Conflicts of Interest

The authors declare no conflict of interest. Given the role as Editor-in-Chief, Rajib Shaw had no involvement in the peer review of this paper and had no access to information regarding its peer-review process. Full responsibility for the editorial process of this paper was delegated to another editor of the journal.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

Appendix A

Table A1. KIMM Ten-Dimensional Detailed Rating Scale.

Dim.	Indicator	0 (Lowest)	5 (Medium)	10 (Highest)	Theoretical Basis
D1	Legal Recognition	No legal mention of IK	Policy documents reference IK	Constitutional or statutory guarantee	Institutional Theory
D2	Budget Control	0% indigenous control	15–30% indigenous control	>50% indigenous control	Resource Dependency Theory
D3	Decision Weight	No voting rights	Voting rights without veto	Full veto power	Decolonization Theory
D4	Knowledge Validation	Scientists only validate	Joint validation mechanisms	indigenous self-validation	Knowledge Co-production
D5	Benefit Distribution	No benefit sharing	Partial benefit sharing	Primary beneficiary status	Distributive Justice
D6	Institutional Representation	0% seats in governance bodies	20–40% seats	>50% seats	Institutional Theory
D7	Capacity Building Investment	No dedicated resources	10–20% of project budget	>30% of project budget	Institutional Innovation
D8	Cultural Protocol Respect	Protocols ignored	Partial compliance	Strict adherence required	Decolonization Theory
D9	IP Protection	No protection mechanisms	General IP protection	Full indigenous control	Knowledge Sovereignty
D10	M&E Control	External evaluation only	Joint monitoring and evaluation	indigenous-led M&E	Knowledge Co-production

Note: Each dimension scored 0–10 points; Total KIMM Score = Sum of D1–D10 (maximum 100 points). IK = indigenous knowledge; IP = Intellectual Property; M&E = Monitoring and Evaluation.

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