Environmental and Sustainability Indicators 31 (2026) 101451

Contents lists available at ScienceDirect

Environmental and Sustainability Indicators

journal homepage: www.sciencedirect.com/journal/environmental-and-sustainability-indicators

An Actor-Interest-Power (AIP) governance indicator framework for operationalising the Actor-Centred Power approach

Preeyaphat Chaiklang [a,b,*], Daniel Karthe [b,c,d], Lukas Giessen [a,e], Carsten Schusser [a]

[a] Chair of Tropical and International Forestry, Faculty of Environmental Sciences, Technische Universität Dresden, Germany
[b] The United Nations University Institute for Integrated Management of Material Fluxes and of Resources, Dresden, Germany
[c] Faculty of Environmental Sciences, Technische Universität Dresden, Germany
[d] Faculty of Engineering, German-Mongolian Institute for Resources and Technology, Nalaikh, Mongolia
[e] Chair of Forest Policy and Land Use Governance, Faculty of Forest Sciences and Forest Ecology, Georg-August-Universität Goettingen, Germany

ARTICLE INFO

Keywords:
Interest analysis
Power-interest mapping
Governance indicators
Principal component analysis
Sustainability governance
Decision support tools
Natural resource management

ABSTRACT

Systematic analysis of complex social relations in environmental governance requires clear identification of actors, their interests, power distribution, and interactions. While the Actor-Centred Power (ACP) approach provides a theoretical foundation for analysing governance processes, its application has remained predominantly qualitative, limiting transparency, comparability, and reproducibility across governance contexts. This study develops a structured Actor-Interest-Power (AIP) analytical framework that operationalises the ACP approach by integrating actor interests and power distribution within a transparent and comparable analytical procedure. The framework combines structured actor-interest scoring, power assessment, and Principal Component Analysis (PCA) to enable systematic exploration and comparison of governance configurations. Drawing on empirical data from mangrove forest management in Thailand, a subset of actors and interests is reanalysed to demonstrate the application of the framework. To further illustrate its analytical utility, six conceptually constructed AIP typologies representing contrasting governance configurations are developed, ranging from aligned high-power structures to fragmented and asymmetric arrangements. Together, the empirical application and conceptual typologies demonstrate how different Actor-Interest-Power (AIP) configurations can be systematically represented and compared within a consistent analytical framework. By operationalising Actor-Interest-Power relationships into a structured analytical framework, this study advances the practical application of the ACP approach and contributes to the development of transparent, reproducible, and configuration-based governance indicators for comparative sustainability assessment and planning.

1. Introduction

Understanding how power is distributed among actors and how interests interact is central to explaining decision-making and resource outcomes in environmental governance (Leach et al., 1999; Ostrom, 2009). Although the Actor-Centred Power (ACP) approach provides a robust conceptual lens for analysing coercion, incentives, and dominant information (Aurenhammer, 2016; Krott et al., 2014), its empirical applications have remained largely qualitative. As a result, systematic measurement, transparent visualisation, and cross-case comparability of actor configurations remain limited. Efforts to operationalise ACP have linked power and interests through mixed-method approaches, including the Powerful Interest Desired Outcome framework (Schusser et al., 2015). While these approaches advance the integration of interests and power, they rely substantially on interpretative judgment and do not provide a structured multivariate representation of actor constellations. Comparable challenges are evident in related actor-based governance frameworks, where translating qualitative assessments into reproducible and comparable quantitative configurations remains methodologically unresolved.

Similarly, stakeholder analysis, importance-influence grid, and Social Network Analysis (SNA) provide valuable perspectives for examining governance processes but each emphasises different dimensions of actor relationships. Stakeholder analysis is useful for identifying relevant actors and their interests (Brugha and Varvasovszky, 2000; Campos Fernandes et al., 2025), whereas the importance-influence grid provides

* Corresponding author. Chair of Tropical and International Forestry, Faculty of Environmental Sciences, Technische Universität Dresden, Germany.
E-mail address: preeyaphat.chaiklang@mailbox.tu-dresden.de (P. Chaiklang).

https://doi.org/10.1016/j.indic.2026.101451
Received 2 March 2026; Received in revised form 24 July 2026; Accepted 2 August 2026
Available online 3 August 2026
2665-9727/© 2026 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

a simplified representation of stakeholder positions based on relative importance and influence (Opoku et al., 2025). SNA focuses on the structure of relationships and patterns of interaction among actors (Campos Fernandes et al., 2025; Mafaziya Nijamdeen et al., 2022; Prell et al., 2009; Radosavljevic et al., 2025). In contrast, the proposed AIP framework operationalises the Actor-Centred Power (ACP) approach by systematically integrating multidimensional actor interests with power elements within a structured analytical procedure. Rather than replacing existing approaches, the AIP framework provides a complementary perspective for exploring, visualising, and comparing governance configurations across different contexts.

To address this gap, this study develops a structured Actor-Interest-Power (AIP) configuration framework and integrates it with Principal Component Analysis (PCA) as a projection tool. Actor evaluations are organised into a configuration matrix that enables systematic measurement and visualisation of power distributions and interest alignments in multidimensional analytical space. This approach makes actor constellations analytically transparent, comparable, and potentially reproducible. Rather than introducing a new theory of governance, the proposed AIP framework represents an operational extension of the Actor-Centred Power (ACP) approach. Its methodological contribution lies in systematically integrating actor interests, power elements, structured scoring, and PCA visualisation within a single analytical workflow that produces comparable Actor-Interest-Power (AIP) configurations for governance analysis.

Using empirical data from mangrove forest governance in Thailand, the framework is applied to demonstrate how distinct AIP configurations generate differentiated spatial patterns when projected through PCA. In addition, six theoretically constructed AIP typologies are developed to explore how alternative power-interest distributions produce structurally distinct configurations. These conceptual typologies are intended to illustrate how the proposed framework differentiates alternative governance arrangements. By formalising actor-interest-power relations into a transparent and visualisable analytical architecture, the study contributes to the development of structured governance indicators for sustainability assessment and decision support.

This study contributes both theoretically and practically. Theoretically, it operationalises the ACP approach through a transparent procedure for integrating actor interests, power assessment, and PCA-based multivariate visualisation, thereby extending existing actor-based governance approaches with a potentially reproducible configuration framework. Practically, the proposed AIP framework provides a systematic tool for comparing governance configurations, supporting stakeholder analysis, identifying potential governance challenges, and informing environmental decision-making across different governance contexts.

2. Theoretical framework

2.1. Forest governance

Forest governance refers to the constellation of actors, institutions, and decision-making processes that shape forest use, management, and conservation. It extends beyond a state-centric perspective by recognising that formal regulations, informal norms, and power relations interact across scales to influence resource outcomes (Broekhoven et al., 2012; Larson and Petkova, 2011). Giessen and Buttoud (2014), identify four core elements: actors, institutional arrangements, interactions among actors, and interactions between actors and institutions. Together, these elements structure governance outcomes.

Governance outcomes emerge from structured actor interactions rather than isolated decisions. Analysing forest governance, therefore, requires attention to how interests are articulated, how influence is exercised, and how power asymmetries shape collective outcomes. This relational perspective situates actor configurations at the centre of governance analysis and provides the conceptual entry point for applying the Actor-Centred Power (ACP) approach in the next section.

2.2. The Actor-Centred Power (ACP) Approach

Following Krott et al. (2014) Actor-Centred Power is defined as a social relationship in which one actor can alter the behaviour of another without recognising the latter's will. Power is relational and actor-specific, depending on available resources and the issue at stake. Within broader governance systems, such relations form structured power networks among actors (Devkota, 2010). The Actor-Centred Power (ACP) approach provides a systematic theoretical foundation for analysing how power operates within these networks.

Actors are understood as individuals or collective entities with distinct interests and the capacity to influence policy processes (Krott, 2005). ACP conceptualises power through three core mechanisms: coercion, which changes the behaviour of another actor by force; (dis) incentives, which change the behaviour of another actor by providing advantages (or disadvantages); and dominant information, which another actor's behaviour due to his accepting information without verifying it (Krott et al., 2014; Schusser et al., 2015). Power exists when behavioural change occurs through these mechanisms. Importantly, these elements are linked to observable factors such as authority, financial resources, and privileged access to information, enabling empirical investigation.

Interests form a central component connecting actor behaviour and power relations. Following Krott (2005) interests are defined as action-oriented preferences held by individuals or groups that represent the benefits they expect from a specific object, such as a forest. These interests shape cross-scale interactions within governance systems, as actors pursue expected benefits through strategic linkages. Interests may be formally articulated in policies and regulations or expressed informally through practices and implicit preferences (Scharpf, 2018). Moreover, interests are dynamic and can be reinforced, reshaped, or marginalised through dominant ideas, information, and institutional structures (Angelsen et al., 2012).

ACP has been widely applied in environmental and forest governance research, including forest management, land-use planning, value chain governance, and community-based resource governance (Hintz et al., 2025; Giessen et al., 2016; Maryudi and Krott, 2012; Schusser et al., 2015; Movuh and Schusser, 2012; Schusser, 2013b). While these applications demonstrate the analytical strength of ACP in examining power distributions, the operationalisation of actor interests has largely relied on qualitative interpretation. Interests are typically inferred from descriptive actor characteristics rather than structured measurement, which limits systematic comparison and visualisation of complex actor-interest-power constellations. Hence, empirical applications often rely on case-specific interpretations, making comparisons across governance contexts difficult and reducing analytical transparency and potentially reproducibility. In recent years, sustainability assessment has increasingly emphasised the use of multidimensional governance indicators and integrated analytical frameworks to capture the complexity of social-ecological systems while supporting transparent and comparable decision-making (Georgescu et al., 2025; Georgescu et al., 2025). Previous studies have also demonstrated the value of classification and typology approaches for interpreting complex sustainability processes and facilitating cross-case comparison (Georgescu et al., 2025). This perspective is consistent with the development of the six conceptual AIP typologies proposed in this study, which are intended to support the interpretation and comparison of alternative governance configurations. More broadly, these developments reflect a transition towards governance assessment frameworks that integrate multiple dimensions of sustainability and can be adapted across governance contexts, including circular economy transitions (Georgescu et al., 2025). Consequently, despite the conceptual precision of ACP approach, a methodological gap remains in translating actor interests into measurable configurations that allow potentially

reproducible mapping and dimensional differentiation. Addressing this gap forms a central motivation for the Actor-Interest-Power (AIP) configuration framework developed in this study.

3. Methods

In this study, governance is not represented by a single composite indicator. Instead, it is represented through structured and standardised governance configurations based on combinations of actors, interests, and power distributions. These governance configurations provide comparable analytical units for assessing governance structures across cases, while Principal Component Analysis (PCA) serves solely as a visualisation technique to facilitate interpretation of the resulting configurations.

3.1. Actor-Interest-Power (AIP) Analysis

This study advances the operationalisation of the Actor-Centred Power (ACP) approach by integrating it with Principal Component Analysis (PCA). An illustrative case from mangrove governance in Thailand is used to demonstrate the analytical workflow and reproducibility of the Actor-Interest-Power (AIP) configuration process. The empirical application draws on document analysis, semi-structured interviews, participatory workshops, and field observations to identify actors and assess their interests and power distributions. The emphasis lies on methodological development rather than on detailed empirical interpretation, which is presented in a separate study. For transparency and potential reproducibility, the complete empirical Actor-Interest-Power (AIP) input matrix used in this illustrative application is provided in Supplementary Table S1.

3.1.1. Actor identification and power assessment

Actor identification was conducted through semi-structured interviews with representatives from governmental organisations, non-governmental organisations, donor agencies, and local communities involved in mangrove governance in Thailand. A snowball sampling approach was applied to ensure comprehensive identification of actors identified by multiple respondents as relevant to governance processes. Actor-Power relations were subsequently assessed using the dominance degree analysis proposed by (Schusser, 2013a; Schusser et al., 2012) which enables systematic identification of potentate and subordinate relationships within actor networks. Assessments were based on triangulated evidence from semi-structured interviews, policy documents, and field observations.

Power assessment followed a sequential mixed-methods design (Schusser et al., 2012) that integrated triangulated qualitative and quantitative evidence. In line with the ACP approach (Krott et al., 2014; Schusser et al., 2012, 2015), power was evaluated across three elements: coercion, incentives, and dominant information. Following the dominance degree and sequential design of the ACP approach, each power element was coded dichotomously (2 = powerful; 1 = less powerful), reflecting whether an actor was able to exercise a particular power mechanism rather than the magnitude of that power. This operationalisation follows the original sequential design, in which each power element is classified as either powerful or less powerful after triangulating quantitative and qualitative evidence (Schusser, 2013a; Schusser et al., 2012).

This binary coding ensured consistency with the original ACP operationalisation and provided a transparent decision rule for translating qualitative evidence into structured power indicators. The combined score across the three power elements therefore ranged from 3 to 6, representing actors' relative capacity to exercise power within the operationalised framework. As an operational representation of relational power, the aggregated score facilitates comparative analysis across actors while recognising that it does not capture the direction, reciprocity, or temporal dynamics of power relations. This approach also improves the reproducibility of the coding process by minimising ambiguity associated with assigning intermediate levels of power. Accordingly, binary coding was selected to operationalise the ACP approach rather than to measure incremental differences in power intensity.

3.1.2. Interest identification and operationalisation

Actor interests were analysed through a sequential integration of qualitative and quantitative approaches. Participatory tools derived from the Climate Vulnerability and Capacity Analysis (CVCA) framework (Daze et al., 2009), including hazard mapping, seasonal calendars, vulnerability matrices, and Venn diagrams, were used to generate context-specific insights into social-ecological vulnerabilities and to elicit both formal and informal actor interests. The CVCA approach integrates local and scientific knowledge, thereby supporting systematic clarification of actor roles, adaptive capacities, and governance linkages within the ACP approach. The CVCA framework integrates local and scientific knowledge and has been applied in diverse socio-ecological contexts (Adem et al., 2017; Ketsomboon & von der Dellen, 2013), supporting its suitability for structured interest identification within the ACP approach.

Interest analysis followed four analytical stages designed to systematically structure and operationalise Actor-Interest-Power (AIP) relationships. An illustrative case of mangrove forest conservation in Thailand was used to demonstrate the application of this procedure:

1. *Content analysis*: formal and informal interests were identified through document analysis, interview transcripts, historical timelines, and field observations. Formal interests were derived from policies, regulations, and official mandates, while informal interests emerged from narratives, practices, and implicit benefit orientations.
2. *Thematic analysis*: identified interests were qualitatively coded and categorised. Formal interests reflected regulatory and policy-based objectives. Informal interests were structured using the benefit typology proposed by King & Walker (1992). Informal interests were grouped into four categories: ***Professional benefit*** (advancing careers or maintaining their professional standing), ***Material benefit*** (tangible or economic benefits), ***Solidary benefit*** (social belonging and collective support), and ***Purposive benefit*** (commitment to shared goals or long-term causes). This step transformed diverse expressions of interest into analytically consistent categories.
3. *Scoring and triangulation:* to enable systematic comparison, interests were translated into quantitative indicators. Each actor received a score ranging from 0 (no interest) to 3 (high interest) per theme. Scores were assigned based on triangulated evidence from documents, interviews, and field observations, ensuring reproducibility and reducing subjective bias.

To improve transparency and consistency, explicit decision rules adapted from Schusser (2013a) were developed to guide score assignment based on triangulated qualitative evidence. The operational coding criteria are presented in Table 1.

4. *Dimensional integration through PCA:* standardised interest scores were integrated with power indicators using Principal Component Analysis (PCA). This step enabled the visualisation and interpretation of Actor-Interest-Power (AIP) configurations, revealing structural alignments and divergences across actors. For demonstration purposes, five actor groups were included: governmental agencies, non-governmental organisations (NGOs), donors, local communities, and sub-district and district-level organisations (e.g., local administrations). Six key interests were incorporated to illustrate the analytical process, covering both formal interests (monetary benefits, conservation, livelihood well-being, climate mitigation, biodiversity) and informal interests (professional and solidary benefits). All statistical analyses were performed using R version 4.3.0 (R Core Team, 2023),

Table 1
Interest scoring decision rules used for the operationalisation of actor interests.

Score	Interest Level	Operational decision rules
3	High	The interest is explicitly identified as a primary objective or priority and is consistently supported by multiple sources of evidence (e.g., official documents, interview data, and observed practices).
2	Medium	The interest is clearly recognised but is not consistently prioritised. It is supported by some evidence from policies, interviews, or observed practices but receives less emphasis than primary interests.
1	Low	The interest is mentioned only occasionally or indirectly and is supported by limited qualitative evidence.
0	None	No evidence of the interest was identified from documents, interviews, or field observations.

ensuring computational reproducibility of the PCA-based AIP configuration.

3.2. Dimensional mapping through Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was used solely as a visualisation technique to identify structural patterns in actor interest profiles and to facilitate the interpretation of Actor-Interest-Power (AIP) configurations. It was not intended to statistically validate the conceptual framework. PCA reduces the dimensionality of the interest indicators by transforming correlated variables into orthogonal principal components that successively maximise explained variance (Jolliffe and Cadima, 2016). In social and environmental research, PCA is widely used to explore latent association structures among governance indicators (Abdi and Williams, 2010; Fischer et al., 2020, 2021). Mathematically, each principal component is a linear combination of the original variables (Jolliffe, 2004):

$$Z_i = a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{ip}x_p$$

where.

- Z_i = the i-th principal component,
- $x_1, x_2, \ldots, x_p$ = standardized variables (e.g., interest scores for each actor), and
- a_{ij} = the loading or weight of variable j on component i.

The first component (PC1) captures the maximum possible variance in the dataset, while each subsequent component captures the remaining variance orthogonal to the previous components. Eigenvalues (λ) represent the variance explained by each component, and eigenvectors (the a coefficients) define the direction of maximum variance.

$$Var(Z_i) = \lambda_i$$

In this study, standardised interest scores were analysed using the correlation matrix to ensure comparability across variables. The first principal component (PC1) captures the largest share of variance in actor interest alignment, while subsequent components explain the remaining orthogonal variance. Eigenvalues were used to assess component relevance, and the first two components (PC1 and PC2) were retained for visual interpretation. In governance-related datasets characterised by social complexity and heterogeneous actor motivations, PCA commonly yields moderate explained variance (Abdi and Williams, 2010). Therefore, components accounting for approximately 40-70% of total variance can still provide meaningful insight into dominant structural association patterns among actors, interests, and power relations.

The PCA biplot integrates actors and interests within a shared dimensional space. Actors are represented as points and interests as vectors (arrows). Vector direction indicates increasing expression of a given interest, while vector length reflects its relative contribution to the extracted components. Within the PCA ordination, the relative positions of actors and interest vectors provide an indicative visual representation of structural associations among variables.

3.3. Actor-Interest-Power (AIP) typologies design and PCA demonstration

To demonstrate the proposed Actor-Interest-Power (AIP) framework under contrasting governance conditions, six conceptual AIP typologies were constructed within the Actor-Centred Power (ACP) approach. These typologies represent contrasting governance configurations characterised by systematic variation in actor interest intensity and power distribution. They function as structured analytical scenarios that illustrate how different predefined AIP configurations are represented in PCA space and facilitate comparison with the empirical application.

Actor characterisation draws on established concepts from power-interest mapping and stakeholder typologies (Eden and Ackermann, 2001; Reed et al., 2009), adapted to the adaptive governance perspective of the ACP framework. The typologies vary along two principal dimensions: (1) the aggregate level and distribution of interests across actors, and (2) the concentration and asymmetry of power. This dimensional logic ensures analytical consistency while allowing meaningful contrast among configurations.

The six typologies (Table 2) were selected to capture core AIP relationship patterns relevant to the ACP approach, ranging from high-high alignment to low-low disengagement and mixed asymmetric constellations. While some configurations may be less frequently observed empirically, they remain analytically valuable for assessing structural differentiation in governance arrangements and for examining potential adaptive capacity pathways. Each typology was subsequently examined using Principal Component Analysis to visualise its structural positioning within the AIP dimensional space, facilitating comparison among governance configurations.

3.4. Operationalising AIP relationship typologies

Principal Component Analysis (PCA) enables the quantitative operationalisation of the Actor-Centred Power (ACP) framework by

Table 2
Conceptual summary of AIP relationship typologies.

Typologies of AIP Relations	Interest Level	Power Level	Characteristics
1. Empowered	High	High	All actors exhibit uniformly high interest and power, indicating strong collective motivation and influence capacity.
2. Negligible	Low	Low	Weak engagement and minimal influence, with all actors exhibiting uniformly low interest and power, indicating limited motivation and very low capacity to shape outcomes.
3. Dominant	Mixed[a]	High	A few powerful actors hold diverse or competing interests, resulting in concentrated influence and potential contestation.
4. Fragmented	Mixed	Low	Actors exhibit diverse interests but limited overall influence, resulting in weak coordination and fragmented governance.
5. Disengaged	Low	Mixed	Predominantly low interest despite variation in power; limited mobilisation capacity.
6. Asymmetric	Mixed	Mixed	Unequal distribution of both interest and power; partial alignment and structural imbalance.

[a] Mixed indicates variation in actor interest or power levels (low, medium, and high).

transforming triangulated actor-interest and power assessments into a structured numerical Actor-Interest-Power (AIP) matrix. This integration enhances analytical transparency, structural consistency, and comparability across governance configurations. The overall analytical workflow of the proposed AIP framework is summarised in Fig. 1. PCA contributes to the operationalisation of the AIP framework by:

1. Revealing structural clustering of actors based on similarity in interest intensity and power positioning.
2. Quantifying the relative contribution of interest and power attributes through component loadings and vector magnitudes.
3. Integrating actors and attributes within a shared dimensional space that enables systematic visual comparison.

The six AIP relationship typologies were parameterised using standardised categorical scales (interests: 0 = none, 1 = low, 2 = medium, 3 = high; power: 1 = less powerful, 2 = powerful). These structured configurations were then analysed using PCA to examine how variation in interest distribution and power concentration affects actor positioning within the dimensional space. To ensure interpretive consistency, Table 2 summarises the structural logic underlying each typology and its expected configuration in the PCA biplot. PCA outputs are not interpreted as behavioural measurements but as dimensional representations of relational structure, synthesising qualitative insights into a reproducible analytical form. The resulting biplots illustrate how different AIP typologies manifest as distinct spatial patterns, highlighting shifts in actor alignment, interest orientation, and relative power balance within adaptive governance contexts.

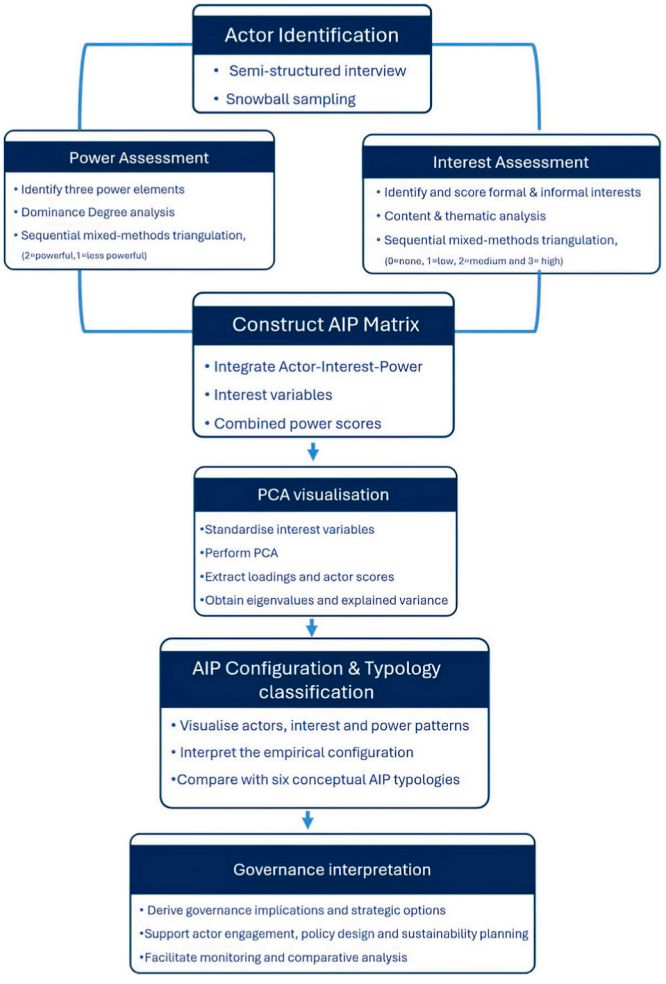

Fig. 1. Workflow of the proposed Actor-Interest-Power (AIP) framework and analytical procedure.

4. AIP typologies and PCA illustration

The PCA visualisations of the six AIP typologies illustrate contrasting configurations of Actor-Interest-Power relationships. Each typology represents an analytically constructed configuration derived from systematic variation in interest intensity and power distribution and is interpreted as an ideal-typical governance structure rather than an empirical prediction. Across the six configurations, differences in collective interest alignment and power distribution are reflected in distinct spatial patterns in the PCA biplots. These patterns facilitate comparison of actor clustering, interest orientation gradients, and relative power positioning (Tables S1–S4). Rather than validating governance configurations, the conceptual typologies provide an analytical framework for comparing alternative Actor-Interest-Power structures. They support systematic interpretation of potential differences in governance configurations, including variation in actor alignment, power asymmetry, and interest diversity, and may assist discussions of actor engagement, institutional capacity, and context-specific governance strategies.

4.1. Empirical PCA configuration

The first two principal components explained 75.4% of the total variance (PC1 = 47.7%, PC2 = 27.7%), indicating that the two-dimensional PCA representation captured most of the variation in the empirical Actor-Interest-Power (AIP) configuration (Fig. 2). NGOs were positioned closer to the vectors representing conservation and climate mitigation interests, whereas local communities were located nearer the solidarity and monetary benefit vectors and exhibited the highest aggregated ACP power scores. Government and sub-district administrative organisations occupied intermediate positions within the PCA space, while donors were positioned on the opposite side of the dominant interest vectors and displayed comparatively lower aggregated ACP power scores. Overall, the PCA revealed a heterogeneous distribution of actor interests and unequal distributions of power across actors. Based on qualitative comparison of the distributions of actor interests, aggregated power scores, and the overall spatial arrangement of actors in the

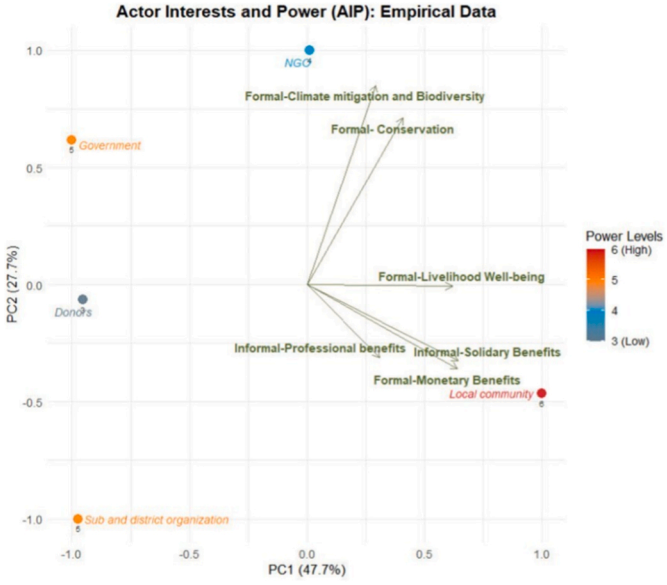

Fig. 2. PCA biplot of Actor-Interest-Power (AIP) relationships derived from empirical data on community-based mangrove governance. (Actors are shown as points, coloured by power level and annotated with numeric power scores to ensure colour-blind accessibility. Interest variables are represented by arrows, with arrow length reflecting their correlations with the principal components.)

PCA biplot, the empirical configuration most closely resembled the conceptual Asymmetric (Typology 6) scenario.

4.2. Conceptual AIP typologies Illustrations

The following subsections present six conceptual PCA configurations corresponding to the AIP typologies defined in Table 2. Unlike the empirical case presented in Section 4.1, these configurations are analytically constructed simulations based on systematic variation in interest intensity and power distribution.

Their purpose is not to predict empirical outcomes but to visualise how different structural arrangements of actor-interest-power relationships manifest within the ACP dimensional space. By holding the scoring logic constant while varying interest and power parameters, the PCA biplots reveal how shifts in alignment, concentration, and asymmetry reshape actor clustering and interest gradients. These illustrations therefore function as comparative structural scenarios, enabling clearer interpretation of the underlying logic of each AIP typology.

4.2.1. AIP typology 1: empowered (high interest, high power)

In AIP Typology 1 (Empowered), all actors were assigned uniformly high interest and power scores. Consequently, the dataset exhibited negligible variance, and PCA did not produce meaningful structural differentiation among actors (Fig. 3). Accordingly, no interpretation of actor-interest proximity or vector orientation is intended for this configuration. Rather than representing a conventional PCA configuration, this typology is presented as a conceptual reference condition that illustrates the absence of structural variation. It therefore serves as a baseline against which the remaining AIP typologies can be compared, demonstrating how increasing heterogeneity in actor interests and power generates progressively more differentiated PCA configurations.

4.2.2. AIP typology 2: negligible (low interest, low power)

Based on the conceptual configuration of AIP Typology 2 (Negligible), the first two principal components (PC1 = 44.1%, PC2 = 35.9%) jointly explain 80.0% of total variance (Fig. 4). The relatively short interest vectors suggest limited differentiation in the multivariate interest patterns represented by the PCA. Actors cluster closely around the origin, reflecting relatively similar PCA scores under this conceptual configuration rather than pronounced separation among actors. Consistent with the predefined scenario, power levels remain uniformly low across actors, representing a governance configuration characterised by limited influence and weak collective engagement.

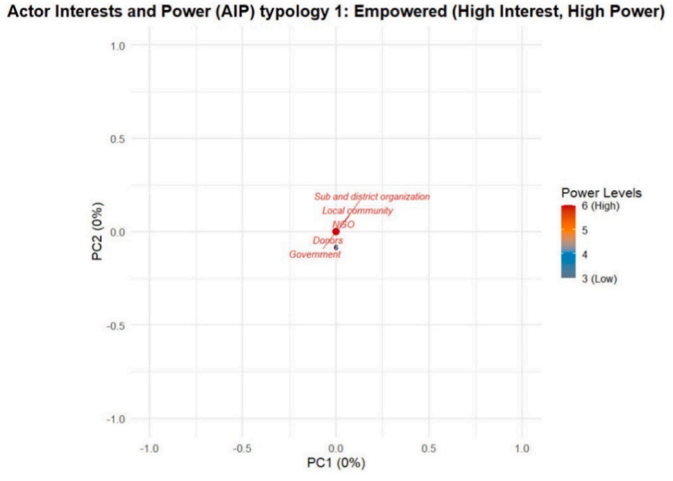

Fig. 3. Conceptual reference case (boundary condition) representing AIP typology 1: Empowered (High Interest, High Power). (Actors are shown as points, coloured by power level and annotated with numeric power scores to ensure colour-blind accessibility. Interest variables are represented by arrows, with arrow length reflecting their correlations with the principal components.)

4.2.3. AIP typology 3: dominant (mixed interest, high power)

In this typology, the first two principal components explain 80.1% of total variance, indicating that the two-dimensional PCA representation captures the major variation in this conceptual configuration (Fig. 5). High-power actors are widely dispersed across the PCA space, suggesting heterogeneous multivariate interest patterns rather than a single shared orientation. Government and sub-district organisations are positioned in the same general direction as the Informal Professional Benefits vector, suggesting relative similarity in the multivariate interest pattern represented by the PCA. In contrast, local communities occupy the opposite region of the PCA space, suggesting a different multivariate interest pattern associated with Conservation and Climate Mitigation. The relatively long and multidirectional interest vectors suggest that multiple competing interest dimensions contribute to the component structure. Consistent with the predefined scenario, this typology represents a power-concentrated governance configuration in which influential actors pursue differentiated and potentially competing priorities, resulting in limited structural convergence.

4.2.4. AIP typology 4: fragmented (mixed interest, low power)

Fig. 6 presents the first two principal components (PC1 = 51.4%, PC2 = 36.0%), which together explain 87.4% of the total variance. The PCA biplot shows a dispersed spatial configuration, indicating heterogeneous multivariate interest patterns despite uniformly low power levels. Government, local communities, sub-district organisations, NGOs, and donors occupy different regions of the PCA space, suggesting relative differences in their dominant interest profiles. The interest vectors extend in multiple directions, reflecting contributions from several interest dimensions rather than a single dominant pattern. The configuration suggests a fragmented governance structure characterised by differentiated interests combined with limited power across actors, rather than demonstrating direct governance relationships or causal alignment.

4.2.5. AIP typology 5: disengaged (low interest, mixed power)

The first two principal components (PC1 = 52.3%, PC2 = 29.4%) explain 81.7% of total variance (Fig. 7). The configuration reveals uniformly low interest intensity across actors, combined with uneven power distribution. Most actors cluster near the origin, reflecting weak alignment with the dominant interest dimensions. While Government and Sub-district organisations display comparatively higher power scores, their proximity to the origin indicates limited substantive engagement with core interest gradients. NGOs and Local Communities occupy more distant but weakly defined positions, suggesting positional variation without strong directional alignment. Structurally, this pattern differs from typology 2 by exhibiting power asymmetry despite low overall motivation. Accordingly, AIP typology 5 represents a disengaged governance configuration characterised by limited interest mobilisation and uneven, but weakly activated, influence structures.

4.2.6. AIP typology 6: asymmetric (mixed interest, mixed power)

In this configuration, the first two principal components explain 82.9% of total variance, indicating a clearly differentiated yet structurally imbalanced arrangement of interests and power (Fig. 8). High-power actors, including Government and Donors, align primarily with Formal Monetary, Livelihood, and Professional Benefit dimensions, positioning them along dominant decision-making gradients. In contrast, Local Communities and Sub-district Organisations associate more strongly with Informal Solidary Benefits and Climate-Biodiversity interests, occupying distinct regions of the dimensional space. NGOs appear in an intermediate position, bridging elements of both formal and informal interest orientations.

The long and multidirectional vectors indicate that multiple interest dimensions contribute substantially to the component structure,

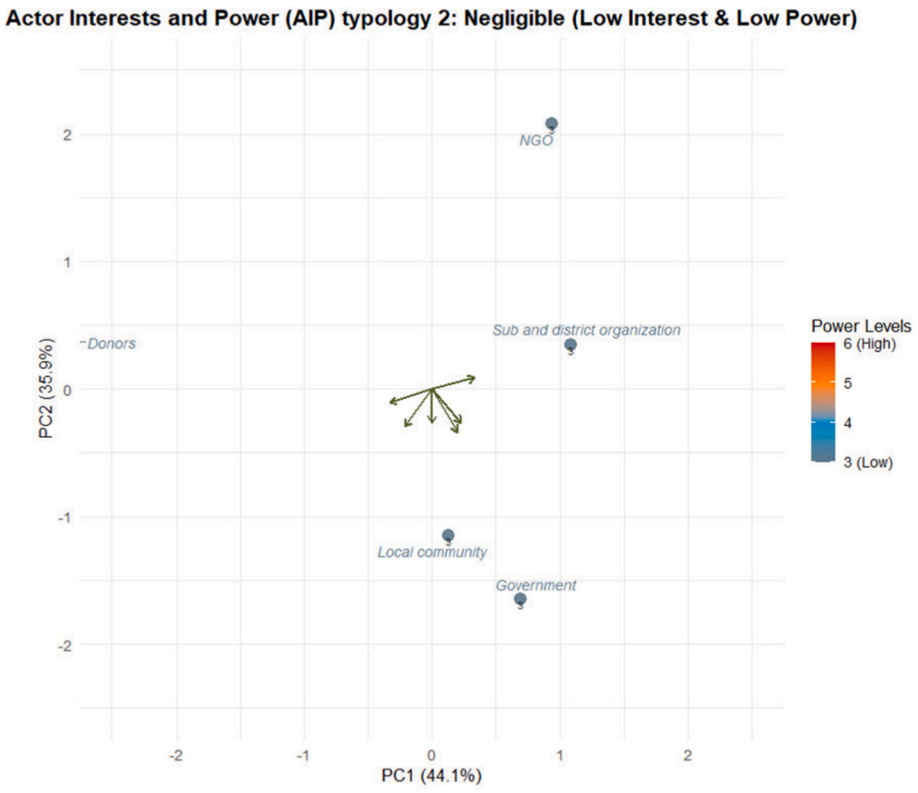

Fig. 4. PCA biplot of AIP typology 2: Negligible (Low Interest, Low Power). (Actors are shown as points, coloured by power level and annotated with numeric power scores to ensure colour-blind accessibility. Interest variables are represented by arrows, with arrow length reflecting their correlations with the principal components.)

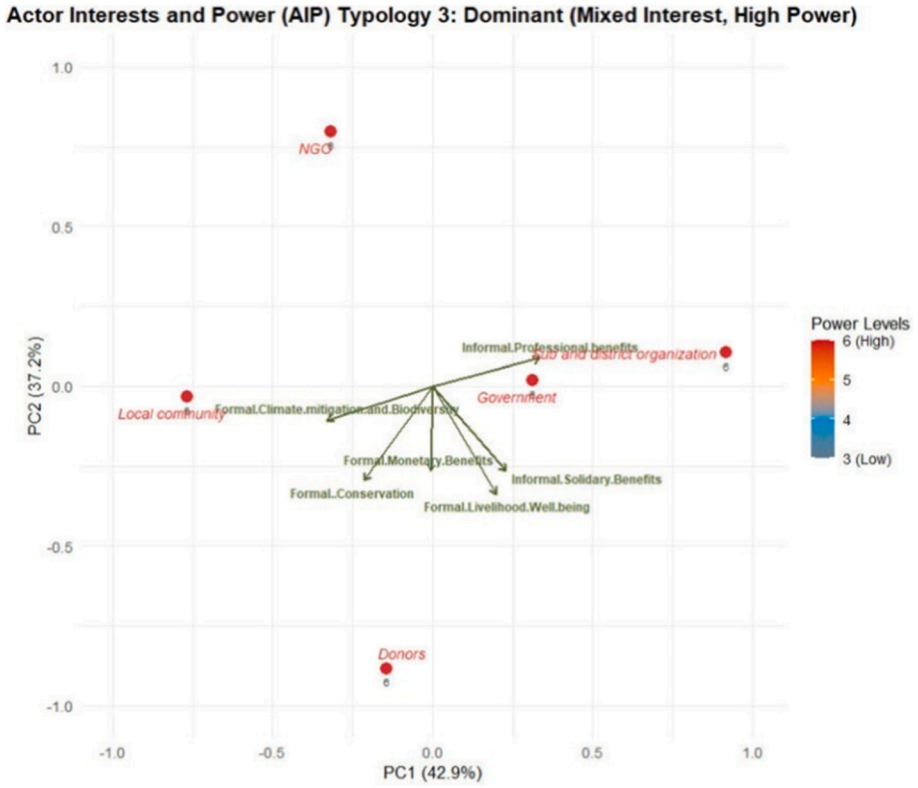

Fig. 5. PCA biplot of AIP typology 3: Dominant (High Power and Mixed Interest). (Actors are shown as points, coloured by power level and annotated with numeric power scores to ensure colour-blind accessibility. Interest variables are represented by arrows, with arrow length reflecting their correlations with the principal components.)

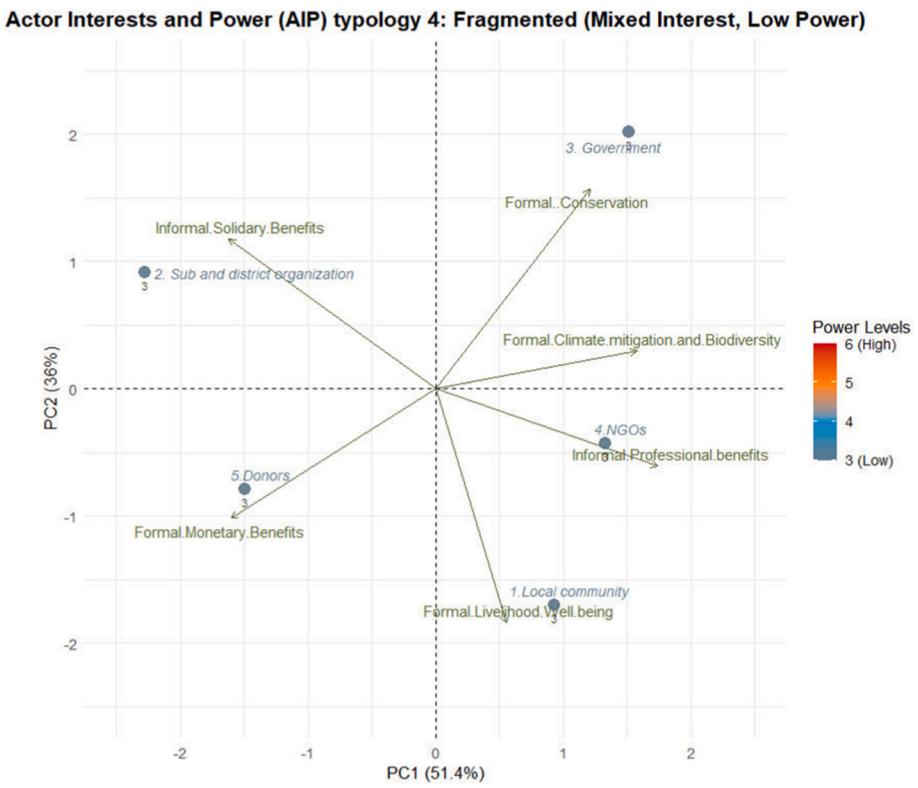

Fig. 6. PCA biplot of AIP typology 4: Fragmented (Mixed Interest, Low Power). (Actors are shown as points, coloured by power level and annotated with numeric power scores to ensure colour-blind accessibility. Interest variables are represented by arrows, with arrow length reflecting their correlations with the principal components.)

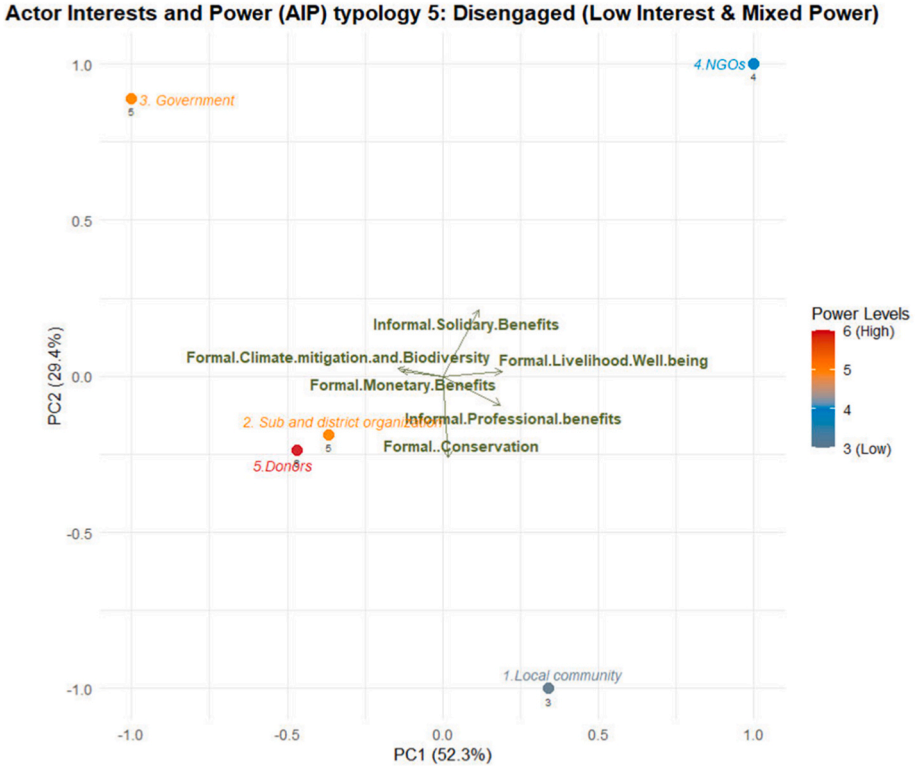

Fig. 7. PCA biplot of AIP typology 5: Disengaged (Low Interest, Mixed Power). (Actors are shown as points, coloured by power level and annotated with numeric power scores to ensure colour-blind accessibility. Interest variables are represented by arrows, with arrow length reflecting their correlations with the principal components.)

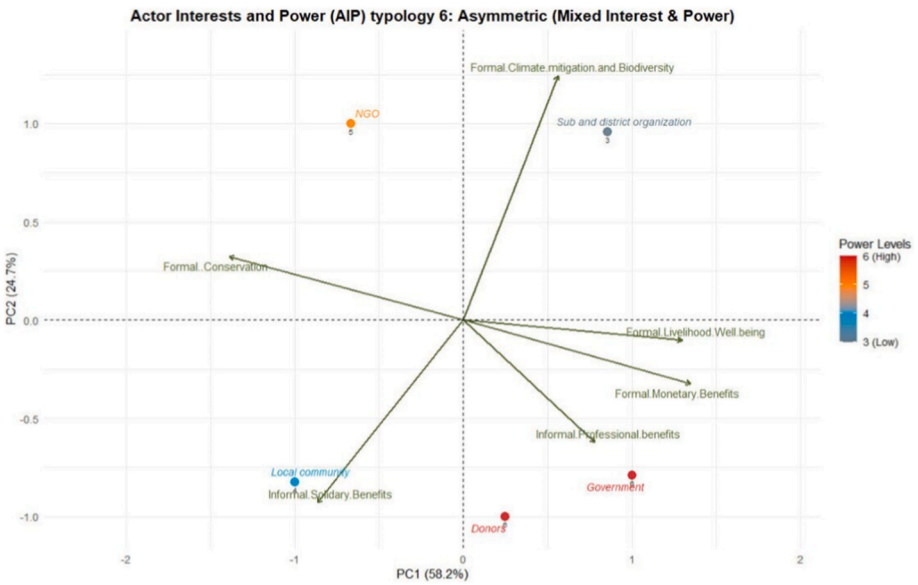

Fig. 8. PCA biplot of AIP typology 6: Asymmetric (Mixed Interest, Mixed Power). (Actors are shown as points, coloured by power level and annotated with numeric power scores to ensure colour-blind accessibility. Interest variables are represented by arrows, with arrow length reflecting their correlations with the principal components.)

reflecting the coexistence of diverse priorities within an uneven power landscape. Accordingly, AIP Typology 6 represents an asymmetrical governance configuration in which differentiated motivations persist under imbalanced influence distribution, yet without complete structural fragmentation.

5. Discussion

The combined empirical and conceptual analyses demonstrate how governance configurations in mangrove management shift according to the distribution of actor interests and power. Operationalising the Actor-Interest-Power (AIP) framework through Principal Component Analysis (PCA) enabled qualitative relational data to be translated into structured spatial configurations, revealing patterns of alignment, divergence, and asymmetry. The empirical case exhibited an asymmetrical configuration in which government agencies and donors were primarily associated with formal and material interests, while local communities and NGOs aligned more closely with ecological and social priorities. The empirical configuration most closely resembles AIP Typology 6 (Asymmetric) based on qualitative comparison of the distributions of actor interests, aggregated power scores, and the overall spatial arrangement of actors in the PCA biplot. This comparison is interpretive and is not derived from a formal statistical classification procedure.

The six conceptual AIP typologies deepen the analysis by demonstrating how systematic shifts in interest intensity and power distribution generate distinct spatial patterns within the operationalised ACP framework. By contrasting conditions of homogeneity, dominance, fragmentation, disengagement, and asymmetry, they clarify the structural sensitivity of PCA to alternative governance arrangements. This comparative coherence supports the proposed operationalisation of the ACP approach and demonstrates its ability to distinguish different governance configurations.

Methodologically, integrating PCA into the ACP approach advances actor-based governance analysis by linking qualitative interpretation with multivariate structure. The approach converts narrative actor relations into reproducible and comparable configurations, enhancing analytical transparency. Beyond descriptive mapping, it provides both diagnostic insight into existing governance structures and an exploratory means of examining how changes in actor interests and power relations may influence governance configurations.

The empirical findings are broadly consistent with previous studies showing that governance outcomes are shaped by interactions between formal institutional objectives, informal actor interests, and unequal power relations (Krott et al., 2014; Schusser et al., 2015). Rather than contradicting previous applications, the proposed AIP operationalisation complements them by integrating systematic interest analysis with power distributions, enabling governance configurations to be visualised and compared within a single analytical procedure. It also complements conventional stakeholder analysis and governance assessment approaches by combining qualitative evidence, explicit scoring procedures, and visualisation in a transparent workflow. This enables governance configurations to be compared systematically across cases while preserving the contextual interpretation of qualitative governance evidence.

Beyond illustrating governance configurations, the proposed AIP operationalisation support a practical decision-support framework for environmental governance and sustainability planning. The resulting AIP configurations can help identify potential conflicts arising from divergent interests and asymmetric power relations, allowing decision-makers to recognise where negotiation may be required. The framework can also support environmental management and policy formulation by identifying actors with complementary or competing interests, thereby helping prioritise institutional interventions, actor engagement strategies, and resource allocation. When applied repeatedly over time, the methodology can further assist in monitoring changes in governance configurations, evaluating the effectiveness of policy reforms and institutional changes, and supporting adaptive governance in complex socio-ecological systems.

Although demonstrated using mangrove forest governance, the proposed analytical procedure is not limited to this context. Because it focuses on actor interests and power distributions rather than sector-specific variables, it can be adapted to other governance settings where multiple actors negotiate competing objectives. Its application is most appropriate in governance contexts involving multiple interacting actors, identifiable interests, and observable power relationships. Potential applications include water governance, protected area management, spatial planning, climate change adaptation, circular economy initiatives, and other sustainability planning contexts where actor interactions influence environmental decision-making. While the specific actors, interests, and governance objectives differ across sectors, the

underlying procedure for identifying actors, structuring interests, assessing power, and comparing governance configurations remains applicable. Applying the methodology across different governance domains would further evaluate its transferability and refine its implementation under diverse institutional and socio-ecological conditions.

Several limitations should be acknowledged. The proposed framework relies on actor–interest scores derived from triangulated qualitative sources, including policy documents, field observations, and interviews; therefore, the interpretation of qualitative evidence inevitably involved researcher judgement, particularly when identifying informal interests. Although explicit coding criteria and triangulation were applied to improve consistency, alternative coding strategies or weighting schemes may produce different results. The numerical scores should therefore be interpreted as structured analytical representations rather than precise measurements of complex social processes. Similarly, aggregating power distributions into actor-level scores provides a simplified representation of relational power and does not capture the direction, reciprocity, or temporal dynamics of interactions among actors. In addition, the use of standardised 0-3 scales may compress variation, reducing sensitivity to subtle differences among actors. PCA was applied primarily as an exploratory visualisation tool rather than for inferential testing; accordingly, variance thresholds were interpreted in relation to configurational clarity rather than statistical optimisation. Given the limited number of actor groups included in the illustrative application, the PCA results should be interpreted as exploratory representations of governance configurations rather than statistically generalisable multivariate structures. Finally, the conceptual typologies were intentionally simplified to examine the interpretability of the proposed methodology and do not capture temporal dynamics or the full complexity of governance systems. Future research should also examine the sensitivity of the framework under alternative coding and weighting schemes, as well as different actor compositions and interest variables, and apply the framework to larger longitudinal and cross-case datasets.

6. Conclusion

This study developed and demonstrated an operational Actor-Interest-Power (AIP) framework that operationalises the Actor-Centred Power (ACP) approach and applies Principal Component Analysis (PCA) to analyse governance configurations in environmental management. The framework translates qualitative information on actor interests and power distribution into structured and comparable governance configurations, while PCA serves as a visualisation technique for interpreting and comparing these configurations. In this way, the study extends from a qualitative analytical framework to a potentially reproducible methodology capable of generating configuration-based governance indicators for comparative governance analysis.

From a theoretical perspective, the study contributes to the literature on Actor-Centred Power and governance indicators by providing a transparent procedure for identifying actors, structuring formal and informal interests, assessing power elements, and integrating these dimensions into a single analytical framework. The empirical application and six conceptual AIP typologies illustrate how the methodology can distinguish different governance configurations while preserving the contextual interpretation of qualitative evidence. The proposed approach therefore offers a systematic means of comparing governance arrangements across cases while enhancing analytical transparency and reproducibility. From a practical perspective, the AIP framework provides a decision-support tool for analysing governance systems in complex socio-ecological contexts. The resulting governance configurations can support researchers and practitioners in identifying potential conflicts among actors, understanding how interests and power shape governance outcomes, prioritising actor engagement, and monitoring changes in governance arrangements over time. Although demonstrated using mangrove forest governance, the methodology can be adapted to other multi-actor governance settings.

More broadly, this study contributes to sustainability indicator research by demonstrating that governance can be represented through structured governance configurations rather than a single composite index. The proposed configuration-based governance indicators provide comparable analytical units for examining governance structures while retaining the complexity of actor relationships. Future research should evaluate the approach across longitudinal and cross-case applications to further assess its transferability, applicability, and usefulness for sustainability assessment and governance decision-making.

CRediT authorship contribution statement

Preeyaphat Chaiklang: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. **Daniel Karthe:** Conceptualization, Resources, Supervision, Writing – review & editing. **Lukas Giessen:** Conceptualization, Resources, Supervision, Writing – review & editing. **Carsten Schusser:** Conceptualization, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank the German Academic Exchange Service (DAAD), Germany, for funding the EPOS NEXtra project (grant number 309812), which provided a scholarship to Preeyaphat Chaiklang.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.indic.2026.101451.

Data availability

Data will be made available on request.

References

Abdi, H., Williams, L.J., 2010. Principal component analysis. WIREs Comput. Stat. 2 (4), 433–459. https://doi.org/10.1002/wics.101.

Adem, A., Deering, K., Molla, S., 2017. Building adaptive communities through integrated programming: CARE Ethiopia's experience with climate vulnerability and capacity analysis (CVCA). In: Leal Filho, W., Belay, S., Kalangu, J., Menas, W., Munishi, P., Musiyiwa, K. (Eds.), Climate Change Adaptation in Africa. Springer International Publishing, pp. 217–234. https://doi.org/10.1007/978-3-319-49520-0_14.

Angelsen, A., Verchot, L., Brockhaus, M., Sunderlin, W.D., 2012. Center for International Forestry Researchissuing body. Analysing REDD+: Challenges and Choices. Center for International Forestry Research.

Aurenhammer, P.K., 2016. Network analysis and actor-centred approach—A critical review. For. Pol. Econ. 68, 30–38. https://doi.org/10.1016/j.forpol.2014.12.010.

Broekhoven, G., Von, S., Shannon, M., Savenije, H., 2012. Moving Forward with Forest governance—A Synthesis.

Brugha, R., Varvasovszky, Z., 2000. Stakeholder analysis: a review. Health Pol. Plann. 15 (3), 239–246. https://doi.org/10.1093/heapol/15.3.239.

Campos Fernandes, C., Valente, S., Figueiredo, E., Polido, A., 2025. Stakeholder and social network analysis for understanding forest (fires) management – a contribution based on a systematic literature review. For. Pol. Econ. 170, 103396. https://doi.org/10.1016/j.forpol.2024.103396.

Daze, A., Ambrose, K., Ehrhart, C., 2009. Climate vulnerability and capacity analysis handbook. CARE international.

Devkota, R.R., 2010. Interests and Power as Drivers of Community Forestry: a Case Study of Nepal. Univ.-Verl, Göttingen.

Eden, C., Ackermann, F., 2001. *Making Strategy: the Journey of Strategic Management* (Repr). Sage.

Fischer, R., Giessen, L., Günter, S., 2020. Governance effects on deforestation in the tropics: a review of the evidence. Environ. Sci. Pol. 105, 84–101. https://doi.org/10.1016/j.envsci.2019.12.007.

Fischer, R., Tamayo Cordero, F., Ojeda Luna, T., Ferrer Velasco, R., DeDecker, M., Torres, B., Giessen, L., Günter, S., 2021. Interplay of governance elements and their effects on deforestation in tropical landscapes: quantitative insights from Ecuador. World Dev. 148, 105665. https://doi.org/10.1016/j.worlddev.2021.105665.

Georgescu, L.P., Balsalobre-Lorente, D., Zlati, M.L., Fortea, C., Antohi, V., Barbuta-Misu, N., 2025a. Cluster analysis of the transition to climate neutrality in the European Union. Sustain. Dev. 33 (S1), 1498–1519. https://doi.org/10.1002/sd.70064.

Georgescu, L.P., Barbuta Misu, N., Antohi, V.M., Fortea, C., Zlati, M.L., 2025b. Approaches and perspectives on the transition to the circular economy in the European Union. Front. Environ. Sci. 13, 1533776. https://doi.org/10.3389/fenvs.2025.1533776.

Georgescu, L.P., Fortea, C., Antohi, V.M., Balsalobre-Lorente, D., Zlati, M.L., Barbuta–Misu, N., 2025c. Economic, technological and environmental drivers of the circular economy in the European Union: a panel data analysis. Environ. Sci. Eur. 37 (1), 76. https://doi.org/10.1186/s12302-025-01119-4.

Georgescu, L.P., Ionescu, R.-V., Antohi, V.-M., Zlati, M.L., Iticescu, C., 2025d. A new model for quantifying the impact of the social economy on the sustainability of water resources. Water 17 (4), 561. https://doi.org/10.3390/w17040561.

Giessen, L., Buttoud, G., 2014. Defining and assessing forest governance. For. Pol. Econ. 49, 1–3. https://doi.org/10.1016/j.forpol.2014.11.009.

Giessen, L., Sarker, P., Rahman, M., 2016. International and domestic sustainable Forest management policies: distributive effects on power among State agencies in Bangladesh. Sustainability 8 (4), 335. https://doi.org/10.3390/su8040335.

Hintz, K.S., Tham, L.T., Mombo, F., Auch, E., Pretzsch, J., Giessen, L., 2025. Combining established methods for value chain and power analyses: Towards a comprehensive next-generation understanding of value chain governance. MethodsX 15, 103637. https://doi.org/10.1016/j.mex.2025.103637.

Jolliffe, I.T., 2004. Principal Component Analysis, 2. ed. Springer [Nachdr.]).

Jolliffe, I.T., Cadima, J., 2016. Principal component analysis: a review and recent developments. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 374 (2065), 20150202. https://doi.org/10.1098/rsta.2015.0202.

Ketsomboon, B., von der Dellen, K., 2013. Climate vulnerability and capacity analysis report: south of Thailand. CARE Deutschland-Luxemburg e.V. in cooperation with Raks Thai Foundation.

King, D.C., Walker, J.L., 1992. The provision of benefits by interest groups in the United States. J. Polit. 54 (2), 394–426. https://doi.org/10.2307/2132032.

Krott, M., 2005. Forest Policy Analysis. Springer (with European forest institute).

Krott, M., Bader, A., Schusser, C., Devkota, R., Maryudi, A., Giessen, L., Aurenhammer, H., 2014. Actor-centred power: the driving force in decentralised community based forest governance. For. Pol. Econ. 49, 34–42. https://doi.org/10.1016/j.forpol.2013.04.012.

Larson, A.M., Petkova, E., 2011. An introduction to Forest governance, people and REDD + in Latin America: obstacles and opportunities. Forests 2 (1), 86–111. https://doi.org/10.3390/f2010086.

Leach, M., Mearns, R., Scoones, I., 1999. Environmental entitlements: dynamics and institutions in community-based natural resource management. World Dev. 27 (2), 225–247. https://doi.org/10.1016/S0305-750X(98)00141-7.

Mafaziya Nijamdeen, T.W.G.F., Hugé, J., Ratsimbazafy, H.A., Kodikara, K.A.S., Dahdouh-Guebas, F., 2022. A social network analysis of mangrove management stakeholders in Sri Lanka's Northern Province. Ocean Coast Manag. 228, 106308. https://doi.org/10.1016/j.ocecoaman.2022.106308.

Maryudi, A., Krott, M., 2012. Poverty alleviation efforts through a Community Forestry Program in Java, Indonesia. J. Sustain. Dev. 5 (2), p43. https://doi.org/10.5539/jsd.v5n2p43.

Movuh, M.C.Y., Schusser, C., 2012. Power, the hidden factor in development cooperation. An example of community forestry in Cameroon. Open J. For. 2 (4), 240–251. https://doi.org/10.4236/ojf.2012.24030.

Opoku, P., Nsor, C.A., Acquah, E., Akoto, D.A., Weber, N., 2025. Actor and power analysis in urban forests and green spaces management. Insights from the Garden City of West Africa. For. Pol. Econ. 170, 103389. https://doi.org/10.1016/j.forpol.2024.103389.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325 (5939), 419–422. https://doi.org/10.1126/science.1172133.

Prell, C., Hubacek, K., Reed, M., 2009. Stakeholder analysis and social network analysis in natural resource management. Soc. Nat. Resour. 22 (6), 501–518. https://doi.org/10.1080/08941920802199202.

R Core Team, 2023. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing. https://www.R-project.org/.

Radosavljevic, M., Rogelja, T., Masiero, M., Andriollo, E., Glavonjic, B., 2025. Information exchange network on timber legality among key actors in Serbia: an illustrative case study. For. Pol. Econ. 178, 103602. https://doi.org/10.1016/j.forpol.2025.103602.

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. J. Environ. Manag. 90 (5), 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001.

Scharpf, F.W., 2018. Games Real actors play: Actor-Centered institutionalism. In: Policy Research, first ed. Routledge. https://doi.org/10.4324/9780429500275.

Schusser, C., 2013a. Comparative analysis of community forestry: theoretical and methodological requirements. VVB Laufersweiler.

Schusser, C., 2013b. Who determines biodiversity? An analysis of actors' power and interests in community forestry in Namibia. For. Pol. Econ. 36, 42–51. https://doi.org/10.1016/j.forpol.2012.06.005.

Schusser, C., Krott, M., Devkota, R., Maryudi, A., Salla, M., Yufanyi Movuh, M., 2012. Sequence design of quantitative and qualitative surveys for increasing efficiency in Forest Policy research. AFJZ 183 (3/4), 75–83.

Schusser, C., Krott, M., Yufanyi Movuh, M.C., Logmani, J., Devkota, R.R., Maryudi, A., Salla, M., Bach, N.D., 2015. Powerful stakeholders as drivers of community forestry—Results of an international study. For. Pol. Econ. 58, 92–101. https://doi.org/10.1016/j.forpol.2015.05.011.