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Policy Network Analysis on Forest and Land Fire at Pelalawan Regency

Adiwijoyo, Heri Purnomo, Suria Darma Tarigan

Natural Resources and Environmental Management, Graduate School, IPB, Bogor, Jawa Barat

Corresponding Author Email: wijoyo.adi89.adiwijoyo@apps.ippb.ac.id

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ABSTRACT

Forest and land fires in Pelalawan Regency, Riau Province, represent a persistent and multidimensional environmental governance challenge shaped not only by ecological factors, but also by land-use change dynamics, plantation expansion, and the complexity of cross-sectoral and multi-level policy networks. This study aims to examine the interrelationships among land cover change, hotspot dynamics, and the structural configuration of the forest and land fire control policy network in Pelalawan Regency. The research integrates spatial analysis assessing land cover change (1996 – 2022) using KLHK data and hotspot distribution (2000 – 2022) using MODIS Terra and Aqua satellite data at ≥50% confidence, with policy network analysis applying Social Network Analysis (SNA) to 53 regulatory instruments across national, provincial, and regency levels, measuring degree, betweenness, closeness, and eigenvector centrality. Natural forest declined by 61.1% from 857,922 to 333,443 hectares between 1996 and 2022, while plantation expanded by 240.2%. The findings reveal a structural centrality-implementation gap, although Law No. 32/2009 occupies the most central network position, hotspot surges prior to 2016 coincided paradoxically with peak regulatory expansion. The post-2016 reduction of approximately 94% in hotspot frequency resulted from institutional alignment rather than regulatory proliferation. This study concludes that fire governance effectiveness depends on policy network coherence, vertical coordination, and local implementation capacity rather than regulatory density.

INTRODUCTION

Forest and land fires in Indonesia, particularly in Pelalawan Regency, Riau Province, constitute one of the most complex and recurrent environmental challenges. Forest and land fires cannot be understood as a simple environmental issue, as they involve a wide range of actors, including local communities, large corporations, and political-economic actors such as governors, regents, and local companies (Saharjo, 2022). The use of fire for land clearing is widely recognized as a rapid and low-cost method commonly practiced in Africa, Latin America, and Asia, including Indonesia, and has become one of the primary drivers of deforestation and land degradation (Purnomo et al., 2021). Several interrelated factors accelerate deforestation and land degradation, including social, economic, political, cultural, and technological drivers operating across multiple scales (Kissinger et al., 2012).

The continued decline in forest cover has profound implications for environmental sustainability and biodiversity conservation. Watershed areas, for instance, are recommended to maintain at least 30% forest cover, while plantation areas should not exceed 40% of total land use in order to sustain ecosystem services, particularly hydrological regulation (Tarigan et al., 2018).

Investment growth in the palm oil industry has been strongly encouraged since the signing of the Letter of Intent between the International Monetary Fund (IMF) and the Government of Indonesia in 1998, which aimed to address the national economic crisis at that time, including by liberalizing plantation investment in Indonesia (Purnomo et al., 2018). This period coincided with the severe transboundary haze crisis of 1997–1998, during which large-scale forest fires were extensively used for plantation land preparation, particularly on peatlands (Applegate et al., 2002). Historically, the use of fire has not been limited to large corporations; smallholders, independent farmers, and transmigrants have also relied on fire-based land preparation practices (Suvanto et al., 2004).

In 1997, large-scale forest and land fires across Southeast Asia generated severe transboundary haze, prompting ASEAN member states to establish regional cooperation through the ASEAN Agreement on Transboundary Haze Pollution (AATHP). This agreement obliges signatory countries to ratify and integrate its provisions into their respective national regulatory frameworks.

As global demand for palm oil continues to increase, pressure on the availability of cultivable land has intensified, while suitable land resources have become increasingly limited. Palm oil plantation expansion progressed relatively slowly during the period 1990–2005, before accelerating significantly between 2005 and 2016. One of the key drivers of this acceleration was the One Million Hectare Palm Oil Program (Amalia et al., 2019). Large-scale expansion of palm oil plantations in Indonesia has generated substantial negative impacts on forests, biodiversity, and carbon stocks, with corporate-driven expansion exerting more severe effects than smallholder expansion (Lee et al., 2014).

From a public policy perspective, the dynamics of forest and land fire prevention and control reflect the existence of a policy network comprising institutions and actors from central and local governments, the private sector, and civil society (Alamsyah et al., 2019; Yuliani, 2023). This network is shaped by patterns of coordination, collaboration, and conflicts of interest in both policy formulation and implementation processes (Gronow et al., 2020; Kammerer et al., 2021). Policy networks are understood as a complex architecture of relationships among actors and institutions involved in policy-making and governance processes (Kenis & Schneider, 1991; Thompson & Pforr, 2005).

To analyze the structure and dynamics of such governance arrangements, Social Network Analysis (SNA) provides a robust methodological framework for policy network analysis. SNA enables the identification of relational patterns, power distribution, and levels of influence among actors and policy instruments, offering empirical insights into central actors, dominant policies, and coordination mechanisms within governance systems (Bodin & Crona, 2009; Borgatti et al., 2018; Wasserman & Faust, 1994).

In Pelalawan Regency, forest and land fire control policies are governed by a wide range of regulations spanning national to local levels, including Law No. 41/1999 on Forestry, Law No. 32/2009 on Environmental Protection and Management, as well as local regulations governing land management and fire prevention. However, overlapping permits and inconsistencies among institutional land-use maps have weakened policy implementation in both the palm oil plantation sector and industrial forest plantations (Wibowo et al., 2019), In addition, weak inter-agency coordination and entrenched political–economic interests in the palm oil and industrial plantation sectors have frequently undermined policy effectiveness (Cisneros et al., 2021; Pramudya et al., 2018; Sitanggang et al., 2022). As a region with a high risk of fire occurrence, Pelalawan Regency demonstrates that interactions among government, private sector, and community actors remain suboptimal in forest and land fire prevention and suppression efforts.

The body of literature on forest and land fires in Indonesia has expanded substantially, yet existing studies predominantly emphasize ecological impacts, drivers of fire occurrence, and largely descriptive policy assessments (Purnomo, Okarda, et al., 2017; Tacconi, 2016; Varkkey, 2015). Although several studies have highlighted the complexity of actors and interests involved in fire governance (Cisneros et al., 2021; Purnomo et al., 2018), policy analyses have generally focused on individual regulations or institutional roles, rather than examining how policies interact within a broader governance structure.

Empirical research employing quantitative network-based approaches to systematically analyze interrelationships among policies in forest and land fire governance remains highly limited, particularly at the district level. Existing studies have yet to map policy networks or measure the centrality, influence, and dominance of individual regulatory instruments within the fire governance system. Consequently, empirical understanding of policy structures, coordination dynamics, and hidden power relations at the local level, especially in high-risk regions such as Pelalawan Regency, remains insufficient.

Within this context, policy network analysis using an SNA approach offers a robust methodological framework for examining forest and land fire governance at the local level. Through SNA-based policy network analysis, it is possible to identify the most influential policies within the forest and land fire control network (Purnomo, Shantiko, et al., 2017). This analysis is critical for understanding how power relations, coordination mechanisms, and policy implementation are structured in the local context, as well as how network structures can be strengthened to support zero-burning policies and sustainable land management. Accordingly, the findings of this study are expected to contribute to improvements in forest and land fire governance that are more effective, collaborative, and empirically grounded (Borgatti et al., 2018; Purnomo et al., 2018; Wasserman & Faust, 1994). In addition, this study aims to identify the most influential policies within the policy chain governing forest and land fire prevention and control in Pelalawan Regency.

This study makes a dual theoretical and methodological contribution to the literature, on environmental governance and public policy. Theoretically, it introduce the concept of the centrality-implementation gap, the structural disconnect between a regulation's central position within a policy network and its effectiveness in producing measurable governance outcomes, thereby challenging the implicit assumption that regulatory density correlates linearly with implementation performance. This extends existing policy network theory (Kenis & Schneider, 1991; Thompson & Pforr, 2005), by demonstrating that structural centrality alone is insufficient to ensure implementation performance in decentralized governance settings. Methodologically, this study introduces a replicable analytical framework integrating long-term hotspot data with Social Network Analysis of regulatory instruments, an underutilized approach in sub-national fire governance research. The framework operationalizes degree, betweenness, closeness, and eigenvector centrality to diagnose coordination failures and policy coherence deficits, offering a transferable model for environmental governance analysis across fire-prone peatland landscapes in Indonesia and comparable developing country contexts.

While the findings of this study offer meaningful contributions to the literature on forest fire governance, several limitations should be acknowledged in interpreting the results. First, by focusing exclusively on regulatory instruments as network nodes, it does not capture the informal interactions, power asymmetries, and behavioral dynamics among implementing actors that ultimately shape on-the-ground outcomes. Second, the construction of inter-regulatory connections retains an element of interpretive judgment, which may introduce analytical subjectivity. Third, MODIS-derived hotspot data are subject to spatial resolution constraints that may underrepresent fire occurrences in densely vegetated or cloud-covered areas. Future research should integrate policy network analysis with actor-based network analysis to simultaneously examine formal regulatory structures and actor-level coordination dynamics. Incorporating qualitative methods such as elite interviews and participatory mapping would further strengthen the interpretive validity of findings and deepen contextual understanding of implementation failures at the local level.

RESEARCH METHODS

This study was conducted in Pelalawan Regency, Riau Province, employing an integrated methodological approach that combines spatial analysis with policy network analysis (PNA). The spatial analysis examines land cover dynamics and fire hotspot patterns within the study area, while the PNA identifies the structural relationships and interactions among regulatory instruments governing the landscape.

The first spatial analysis focused on land cover change in Pelalawan Regency from 2000 to 2022, using land cover data obtained from the Directorate General of Forestry Planning and Environmental Management of the Ministry of Environment and Forestry. This analysis provides a systematic overview of land cover transitions over time, with particular attention to the conversion of forested and peatland areas into plantation estates and other land uses (Lambin et al., 2003; Margono et al., 2014)

The second spatial analysis involved statistical assessment and spatial pattern analysis of fire hotspots from 2000 to 2022 using Terra and Aqua satellite data recorded by the Moderate Resolution Imaging Spectroradiometer (MODIS), with a confidence level of ⩾50%. Hotspot data were overlaid with land cover maps from the Ministry of Environment and Forestry for the period 2000 – 2022. This overlay analysis enabled the identification of land cover types associated with hotspot occurrences, thereby revealing land cover categories that experienced fire events and were subsequently converted into plantation areas or other land uses.

Policy network analysis was conducted to examine the structure and patterns of policies influencing the action arena, recognizing that policy outcomes are shaped not by one or two individual regulations but by a complex policy network that guides and constrains actor behavior across the landscape. Relevant policies related to forest and land fire prevention and suppression were identified at the national level, the Riau Provincial Government, and the Pelalawan Regency Government.

To synthesize the findings from both domains, the integration of spatial analysis and policy network analysis (PNA) in this study is operationalized through a temporal overlay and periodization analysis. This approach is grounded in three complementary theoretical frameworks. First, the punctuated equilibrium theory (Baumgartner & Jones, 1993) provides the basis for identifying discrete governance phases, wherein catastrophic fire events function as critical junctures that trigger regulatory intensification. Second, the regulatory lag hypothesis (North, 1990; Ostrom, 2009) explains the structural delay between policy enactment and observable implementation outcomes, manifested in this study as the temporal gap between the issuance of high-centrality regulations and subsequent reductions in hotspot frequency. Third, the spatial-institutional fit framework (Bodin & Tengö, 2012) serves as the integrative lens through which degree and betweenness centrality metrics are interpreted against the spatial and temporal distribution of fire hotspots, asserting that governance effectiveness depends on the congruence between institutional structure and biophysical dynamics. Misfit between these two dimensions, operationalized here as the centrality-implementation gap, produces governance outcomes that diverge from formal policy objectives. Together, these frameworks provide the analytical foundation for diagnosing coordination failures and interpreting the relationship between regulatory network structure and fire occurrence patterns across the 22-year study period.

To capture the structural configuration of the policy network in a formal and quantitative manner, the network was visualized using graph-based representations. Several network metrics were employed to assess the structural position and relative influence of each policy within the network, including degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality.

Degree centrality measures the number of direct connections (edges) associated with a given policy node within the network. A higher degree centrality indicates a greater number of direct linkages to other policies, reflecting a stronger influence within the policy network. Consequently, policies that are more extensively connected tend to play a more influential role in shaping the overall structure and dynamics of the forest and land fire governance network.

$$C_D(i) = \frac{Deg(i)}{n-1}$$

$C_D(i)$ = degree centrality of node i

Deg(i) = number of direct connections (degree) of node i

n = total number of nodes in the network

Second, betweenness centrality is used to measure how frequently a node serves as a bridge or lies on the shortest paths between other nodes in the network. Nodes with higher betweenness centrality values are therefore regarded as key connectors or intermediaries linking different groups within the network. In the context of policy networks, betweenness centrality reflects the extent to which a regulation functions as a bridging or linking instrument that connects and mediates relationships among other policies within the governance structure.

$$C_B(i) = \sum_{s \neq i \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}}$$

$C_B(i)$ = betweenness centrality of node i

σ_{st} = total number of shortest paths between node s and node t.

$\sigma_{st}(i)$ = the number of shortest paths between s and t that pass through i

Third, closeness centrality measures the average proximity of a node to all other nodes within a network. In a policy network context, closeness centrality reflects the relative distance among policies, indicating how quickly a given regulation can reach or interact with other regulations in the network. Policies with high closeness centrality values are therefore those that can access and influence other policies more rapidly, highlighting their strategic position in facilitating efficient information flow and coordination within the policy network.

$$C_C(i) = \frac{n-1}{\sum_j d(i,j)}$$

$C_c(i)$ = closeness centrality dari of i

$d(i,j)$ = shortest distance between nodes i and j

n = total number of nodes in the network

Fourth, eigenvector centrality measures a node's influence not only based on the number of its connections, but also on the quality of those connections, specifically whether a regulation is linked to other influential or important regulations within the network. Consequently, policies with high eigenvector centrality values occupy strategically influential positions, as their importance is reinforced by connections to other central and authoritative policies in the governance network.

$$C_E(i) = \frac{1}{\lambda} \sum_{j=1}^{n} A_{ij} C_E(j)$$

$C_E(i)$ = eigenvector centrality of node i

A_{ij} = represents the element of the adjacency matrix (equal to 1 if there is a relationship between nodes i and j, and 0 otherwise).

λ = the largest eigenvalue of matrix A.

To conduct the policy network analysis in this study, the researcher utilized Kumu, a web-based application for network mapping and analysis at www.kumu.io.

RESULT AND DISCUSSION

Land Cover Change Analysis

The first step involved conducting an initial spatial analysis to identify patterns of land cover change in Pelalawan Regency. This analysis was based on land cover data from the Directorate General of Forestry Planning and Environmental Management of the Ministry of Environment and Forestry (KLHK) covering the period from 1996 to 2022. Over this approximately 26 year timeframe, several distinct patterns of land use and land cover change were identified in Pelalawan Regency (Figure 1).

These land cover changes are highly relevant to forest and land fire dynamics, as different land cover types exhibit varying levels of fire susceptibility and management regimes. Degraded lands, shrublands, and plantation areas, particularly those located on peatlands, tend to have higher fire risk due to altered hydrological conditions, fuel accumulation, and the widespread use of fire in land preparation practices (Applegate et al., 2002; Purnomo et al., 2021; Suvanto et al., 2004)A. Consequently, the spatial distribution of land cover change provides critical context for understanding where, how, and under what conditions fires are most likely to occur and recur.

Importantly, the observed spatial heterogeneity of land cover change underscores the need to examine fire governance not merely through individual policies, but through the structure and coherence of the policy network that regulates land use, plantation development, peatland management, and fire prevention (Bodin & Crona, 2009). The increasing dominance of non-forest land cover types implies that fire governance involves multiple sectors and administrative levels, each governed by distinct yet interconnected regulatory frameworks (Kissinger et al., 2012). Without understanding how these policies interact, overlap, or create gaps across governance levels, spatially targeted fire prevention efforts may remain fragmented and reactive. Therefore, the integration of spatial land cover analysis with policy network analysis is essential to assess whether existing regulatory structures are aligned with evolving landscape conditions (Bodin & Tengö, 2012).

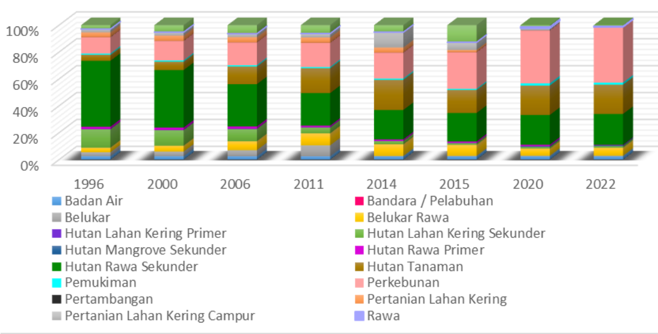

Figure 1. Land Use Change in Pelalawan Regency 1996 – 2022

The quantitative extent of these transitions is presented in Table 1. Over the full study period, total natural forest cover declined from 857,922 hectares in 1996 to 333,443 hectares in 2022, a net reduction of 524,479 hectares or 61.1% of the 1996 baseline. The most severe losses were recorded in secondary dryland forest, which contracted by 91.2% from 181,371 hectares to 16,027 hectares, and in primary swamp forest, which declined by 81.7% from 23,756 hectares to 4,351 hectares. Secondary swamp forest, the single largest land cover class in the regency, underwent a reduction of 53.1% from 650,371 hectares to 305,310 hectares, representing the greatest absolute loss at 345,061 hectares. Concurrently, plantation land expanded by 240.2% from 160,773 hectares to 546,917 hectares, emerging as the dominant land cover type by 2022, while industrial forest plantations grew by 384.5% from 59,814 hectares to 289,768 hectares. Together, these two plantation-based classes occupied approximately 836,685 hectares by 2022 collectively exceeding the remaining natural forest area by a ratio of approximately 2.5:1.

Based on observed trends, land cover dynamics in Pelalawan Regency can be divided into three distinct observation intervals, each reflecting different phases of land use transformation shaped by socio-economic pressures and policy interventions.

Table 1. Land cover change in Pelalawan Regency, 1996 - 2022 (hectare)

Land Cover Category	1996	2006	2015	2022	Change 1996–2022	
					ha	%
Natural Forest	**857.922**	**563.527**	**314.651**	**333.443**	**-524.479**	**-61,1%**
Secondary dryland forest	181.371	120.554	16.708	16.027	*-165.343*	*-91,2%*
Primary swamp forest	23.756	23.242	15.084	4.351	*-19.404*	*-81,7%*
Secondary swamp forest	650.371	417.498	281.101	305.310	*-345.061*	*-53,1%*
Secondary mangrove forest	2.425	2.233	1.758	7.755	*+5.330*	*+219,8%*
Industrial Forest Plantation (HTI)	**59.814**	**175.945**	**227.505**	**289.768**	**+229.954**	**+384,5%**
Plantation	**160.773**	**224.076**	**360.023**	**546.917**	**+386.144**	**+240,2%**
Degraded Land	**114.531**	**224.704**	**273.354**	**87.625**	**-26.907**	**-23,5%**
Shrubland	37.940	59.707	4.017	3.469	*-34.471*	*-90,9%*
Swamp shrubland	45.294	87.997	107.838	79.385	*+34.091*	*+75,3%*
Open land	31.298	77.000	161.499	4.771	*-26.526*	*-84,8%*
Agriculture	**85.212**	**90.915**	**102.922**	**9.372**	**-75.841**	**-89,0%**
Other	**49.794**	**48.880**	**49.593**	**60.922**	**+11.128**	**+22,4%**
Total	**1.328.047**	**1.328.047**	**1.328.047**	**1.328.047**		

Notes: Natural forest = secondary dryland forest + primary/secondary swamp forest + mangrove forest. Degraded land = shrubland (belukar) + swamp shrubland (belukar rawa) + open land. Agriculture = dryland farming + mixed dryland agriculture + paddy fields. Other = water bodies, settlement, mining, swamp, airport, transmigration. Source: Ministry of Environment and Forestry (KLHK), processed.

The first period (1996–2006) was marked by extensive and large-scale conversion of natural forests, representing the most intensive phase of deforestation in the study area. Natural forest declined from 857,922 hectares to 563,527 hectares a loss of 294,395 hectares or 34.3% within a single decade while plantation land expanded from 160,773 hectares to 224,076 hectares and industrial forest plantations from 59,814 hectares to 175,945 hectares. Critically, the disproportion between the rate of forest loss and the rate of plantation establishment indicates that a substantial portion of cleared forest transitioned through intermediate degraded states as recorded in Table 1, degraded land categories collectively expanded from 114,531 hectares to 224,704 hectares, generating extensive fire-prone transitional landscapes outside effective governance control. This period coincided with relatively weak regulatory enforcement, limited spatial planning controls, and the early expansion of extractive and plantation-based land uses. The dominance of forest conversion during this phase suggests that land allocation mechanisms and licensing regimes were not yet sufficiently integrated with environmental protection objectives, allowing rapid transformation of forested landscapes into non-forest land uses.

The second period (2006–2015) continued to exhibit significant conversion of natural forests into plantations, industrial forest plantations. Natural forest contracted from

563,527 hectares to 314,651 hectares a further loss of 248,876 hectares or 44.1% with secondary dryland forest declining most severely from 120,554 hectares to 16,708 hectares, a reduction of 86.1% within nine years that reduced this once-dominant class to a residual fraction of its original extent. Plantation land expanded from 224,076 hectares to 360,023 hectares, an increase of 135,947 hectares or 60.7%, while open land surged from 77,000 hectares to 161,499 hectares an increase of 109.7% (Table 1) closely paralleling the hotspot records showing peak fire occurrence during 2013 and 2015. This spatial coincidence between open land expansion and elevated fire frequency is consistent with fire-based land preparation practices preceding plantation establishment (Applegate et al., 2002). The spatial pattern of change during this phase indicates a gradual shift from primary forest conversion toward more systematic expansion of plantation and planted forest areas, reflecting growing demand for palm oil and timber commodities. This period also corresponds with increasing decentralization of land-use authority, which, in some cases, facilitated accelerated land conversion through overlapping permits and fragmented governance arrangements. Despite the most intensive regulatory expansion in the study period anchored by Law No. 32/2009 the empirical land cover data demonstrate that regulatory intensification was not accompanied by a corresponding reduction in forest conversion, a pattern directly consistent with the centrality-implementation gap examined in the policy network analysis (Ostrom, 2009; Pressman & Wildavsky, 1984).

The third period (2015–2022) represents a transitional phase in which the rate of natural forest conversion declined markedly compared to earlier periods. Natural forest area recorded a modest net recovery from 314,651 hectares in 2015 to 333,443 hectares in 2022 an increase of 18,792 hectares or 6.0% driven primarily by partial recovery of secondary swamp forest from 281,101 hectares to 305,310 hectares (+8.6%) and a substantial expansion of secondary mangrove forest from 1,758 hectares to 7,755 hectares (+341.2%), though the latter may partially reflect reclassification rather than actual ecosystem restoration. The most dramatic land cover transition of this period was the near-complete consolidation of open land, which declined from 161,499 hectares in 2015 to 4,771 hectares in 2022 a reduction of 97.0% (Table 1) reflecting both the cessation of large-scale land-clearing activity and the conversion of previously opened areas into permanent plantation land use. Plantation land continued to expand from 360,023 hectares to 546,917 hectares, a gain of 186,894 hectares or 51.9% the largest absolute plantation expansion of any period indicating that while deforestation from intact forest areas declined significantly, conversion from degraded and agricultural lands into managed plantations persisted. Agriculture contracted sharply from 102,922 hectares to 9,372 hectares, a reduction of 89.0% (Table 1), reflecting large-scale conversion of smallholder agricultural mosaics into monoculture plantation systems with significant implications for rural livelihoods and landscape homogenization (Amalia et al., 2019; Lee et al., 2014). This shift is likely associated with stronger regulatory interventions, including forest and peatland protection policies, moratoriums on new licenses, the establishment of the Badan Retorasi Gambut (BRG) in 2016, and heightened public and international scrutiny of deforestation and forest fires (Bodin, 2017; Purnomo et al., 2018).

Overall, these temporal patterns underscore that land cover change in Pelalawan Regency is not a linear process but rather the outcome of evolving interactions among demographic growth, economic development, market demand, and policy frameworks at both national and subnational levels. The data presented in Table 1 collectively demonstrate that across all three observation intervals, no single regulatory instrument or governance phase was sufficient to arrest the structural drivers of land conversion. Rather, it was the cumulative interaction between institutional capacity, implementation effectiveness, and policy network coherence that shaped observed land cover outcomes. Central government regulations, regional spatial planning policies, and sectoral development strategies have jointly shaped land allocation decisions and land use trajectories (Klijn & Koppenjan, 2016). Consequently, understanding land cover change requires not only spatial analysis but also careful consideration of governance structures, policy coherence, and implementation capacity (Newig & Fritsch, 2009). These findings highlight the importance of integrated land-use planning and stronger cross-sectoral coordination to mitigate unsustainable land conversion and support more balanced and sustainable landscape management.

The trajectory of land cover change documented documented in Table 1 and Figure 1 provides the spatial and ecological foundation for interpreting the hotspot dynamics examined in the following section. The progressive replacement of natural forest ecosystems with plantation, shrubland, and open land particularly pronounced during the 1996–2015 period has not only altered the landscape's structural composition but has fundamentally reshaped the conditions under which fire events occur and recur (Puspitaloka et al., 2021; Tacconi, 2016). As natural forest cover declined and degraded transitional land covers expanded, fire susceptibility across the regency increased substantially, driven by accumulated fuel loads, disrupted peat hydrology, and land preparation practices common to plantation development. Understanding this biophysical transformation is therefore prerequisite to interpreting both the temporal patterns of hotspot occurrence and the governance responses examined through policy network analysis.

Hotspot Analysis

The second spatial analysis involved examining hotspot data classified by year, as well as by their spatial distribution patterns and intensity. The temporal scope used in the hotspot analysis differs slightly from that applied in the land cover change analysis, reflecting data availability and analytical requirements. In addition, hotspot data were overlaid with land cover maps for the period 2000–2022. Based on the hotspot records, the highest number of hotspots in Pelalawan Regency occurred in 2005, with 2,195 hotspots, followed by 2009 with 2,242 hotspots, and 2013 with 2,768 hotspots (Figure 2).

The transformation of Pelalawan Regency's landscape from natural forest to plantation-dominated land use has not only altered the ecological structure of the landscape but has also fundamentally reshaped regional fire regimes by increasing fuel availability, reducing landscape moisture retention, and intensifying land-use activities associated with land preparation (Purnomo et al., 2021; Tacconi, 2016). In this context, hotspot distribution patterns should not be interpreted merely as isolated fire events but as manifestations of longer-term land use trajectories. The observed shift from forest-dominated fires to those concentrated in shrubland, open land, agricultural areas, and plantations reflects a transition from frontier deforestation fires toward recurrent fires in degraded and managed landscapes. This indicates a move from episodic land-clearing fires to more entrenched fire cycles associated with routine land management practices and insufficient post-conversion controls (Suvanto et al., 2004).

In this context, hotspot distribution patterns should not be interpreted merely as isolated fire events but as manifestations of longer-term land use trajectories. The observed shift from forest-dominated fires to those concentrated in shrubland, open land, agricultural areas, and plantations reflects a transition from frontier deforestation fires toward recurrent fires in degraded and managed landscapes. This indicates a move from episodic land-clearing fires to more entrenched fire cycles associated with routine land management practices and insufficient post-conversion controls.

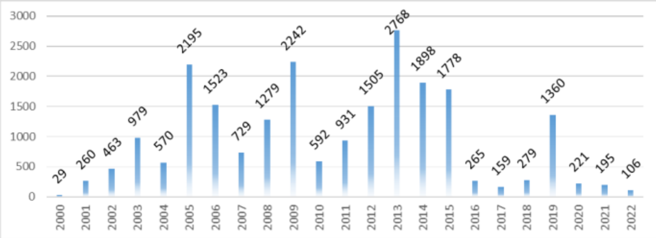

Figure 2. Number of hotspot in Pelalawan Regency at 2000 – 2022

Based on the hotspot analysis overlaid with land cover data from the Ministry of Environment and Forestry (KLHK), years with the highest fire occurrence, namely 2005, 2009, 2013, 2015, and 2019, were selected for further examination (Figure 3). The integration of hotspot and land cover data reveals pronounced temporal shifts in both the spatial distribution and intensity of forest and land fires in Pelalawan Regency. These shifts are reflected not only in fluctuations in hotspot magnitude but also in a clear transformation in the dominant land cover types affected by fire. Over time, fire occurrence has increasingly extended beyond forested areas into degraded lands, agricultural area, bare land, and plantation, indicating broader processes of landscape transformation and a growing exposure of non-forest areas to recurrent burning (Purnomo, Shantiko, et al., 2017; Tacconi, 2016).

Records of high hotspot intensity began to emerge in 2005, when Pelalawan Regency registered a relatively high number of hotspots, totaling 2,195 fire points. More than half of these hotspots 1,181 points, or approximately 53% were identified within secondary swamp forest land cover (Figure 3). The high concentration of hotspots in secondary swamp forest ecosystems indicates that forest and land fires during this period were still predominantly occurring in forested areas. Swamp ecosystems, which are inherently highly sensitive to hydrological alterations, became increasingly vulnerable to fire as a result of drainage activities and land clearing (Applegate et al., 2002). This condition suggests that pressure on forest areas during this period remained extremely intense, driven both by the expansion of new land uses and by weak fire prevention and control systems, particularly in ecologically sensitive areas with important protective functions (Purnomo et al., 2018). These findings underscore that, during the early phase of fire dynamics, secondary swamp forests remained the primary targets of land conversion and the main sources of fire occurrence in Pelalawan Regency.

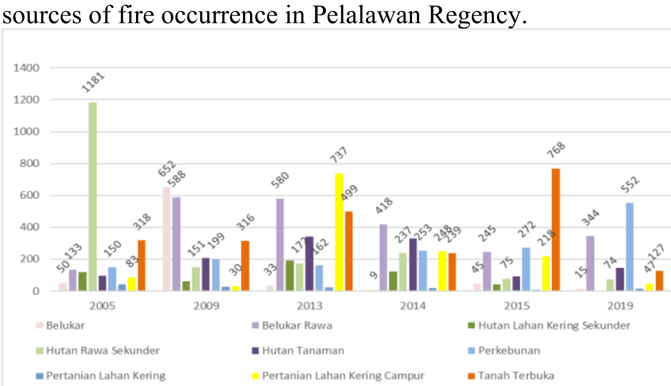

Figure 3. Number of hotspots in Pelalawan Regency by land cover type.

In 2009, the total number of hotspots increased slightly to 2,242 (Figure 2), accompanied by a notable shift in their spatial distribution. Unlike in 2005, hotspots in 2009 were no longer predominantly located in natural forest areas but were instead concentrated in shrubland and swamp shrubland, accounting for 652 and 588 hotspots, respectively. This was followed by open land, which recorded 316 hotspots (Figure 3). This spatial shift indicates that fire occurrence increasingly moved toward degraded or transitional land cover types, often associated with post-deforestation landscapes undergoing conversion to plantation or agricultural uses.

The year 2013 marked the peak of hotspot occurrence during the study period, with a total of 2,768 hotspots recorded within a single year. The majority of these hotspots were located in dryland agriculture areas (737 hotspots), shrubland (580 hotspots), and open land (499 hotspots) (Figure 3). The concentration of fires in agricultural and open land areas suggests an intensification of land management practices involving the use of fire, particularly for land preparation and maintenance (Suvanto et al., 2004). This pattern also reflects persistent weaknesses in monitoring and enforcement related to fire use at the local level (Cisneros et al., 2021; Pramudya et al., 2018), consistent with the structural coordination failures identified in the policy network analysis. The continued elevated hotspot frequency in 2014 with swamp shrubland recording the highest concentration at 418 fire points underscores the continued vulnerability of degraded swamp ecosystems to fire, particularly under disrupted hydrological conditions and reduced soil moisture levels (Applegate et al., 2002).

In 2015, although the total number of hotspots declined to 1,778, fire incidents remained concentrated in specific land cover classes. A total of 768 hotspots were located in open land areas, indicating that fires tended to recur in similar locations. This pattern suggests repeated burning in previously affected areas, particularly those that had experienced extensive fires in 2013. Such recurrence highlights the cyclical nature of fire events and points to shortcomings in post-fire land restoration and management of degraded landscapes.

In 2019, hotspot occurrence increased again, with 1,360 hotspots identified across Pelalawan Regency (Figure 3). This increase reflects a renewed rise in fire intensity, diverging from the post-2016 downward trend. The surge in hotspots in 2019 is strongly associated with the El Niño phenomenon, which resulted in drier climatic conditions and heightened fire susceptibility (Purnomo et al., 2019). In addition to climatic drivers, most hotspots in 2019 were located within plantation areas, accounting for 552 fire points. This finding indicates that, despite strengthened fire control policies, plantation landscapes, particularly those situated on peatlands with altered water management systems, remain highly vulnerable to fire.

Taken together, these spatio-temporal patterns of hotspot distribution indicate that forest and land fire dynamics in Pelalawan Regency are increasingly embedded within human-modified landscapes rather than natural forest systems. The persistence and recurrence of fires in degraded lands, agricultural areas, and plantation landscapes suggest that biophysical vulnerability alone cannot fully explain fire occurrence. Instead, these patterns point to the decisive role of governance arrangements, regulatory effectiveness, and coordination across sectors and administrative levels (Bodin & Crona, 2009; Newig & Fritsch, 2009).

Accordingly, understanding fire dynamics in Pelalawan Regency requires moving beyond spatial analysis toward an examination of how policy frameworks, institutional interactions, and implementation capacity shape land management practices and fire prevention outcomes (Alamsyah et al., 2019; Yuliani, 2023). This provides a strong rationale for analyzing the structure and performance of the forest and land fire policy network, which is discussed in the following section.

Policy Network Analysis

A policy network analysis in this study was conducted with a specific focus only on regulatory instruments, not on policy actors. In this study, regulations were conceptualized as the primary analytical units (nodes) within the policy network, allowing for a systematic examination of how formal legal instruments are structured, interconnected, and positioned within the forest and land fire governance system of Pelalawan Regency. This instrument-centered approach is particularly relevant for assessing policy coherence, legal integration, and the hierarchical relationships among regulations across governance levels.

However, it is important to acknowledge that this analytical focus also constitutes a limitation of the study. By concentrating exclusively on regulatory frameworks, the analysis does not capture the roles, power dynamics, or interactions of actors involved in policy implementation, enforcement, and coordination. As a result, the findings primarily reflect the structural and normative dimensions of fire governance rather than the behavioral or political processes through which policies are enacted on the ground. Despite this limitation, the regulatory network perspective remains valuable for revealing systemic gaps, fragmentation, and delays in policy integration that shape the effectiveness of forest and land fire management (Bodin & Crona, 2009).

Table 2. Table of centrality value results of Central, Provincial and Regency Government Regulations Relating to Forest and Land Fires in Pelalawan Regency

	Regulation	*Degree Centrality*	*Betweenness Centrality*	*Closeness Centrality*	*Eigenvector Centrality*
1	Law No 32/2009	16	0,161	0,608	0,065
2	Law No 41/1999	13	0,100	0,553	0,049
3	Regulation of the Minister of Agriculture 11/2015	13	0,179	0,561	0,047
4	Regulation of the Minister of Environment and Forestry No 32/2016	12	0,155	0,555	0,049
5	Regional Regulation of Riau Province No 1/2019	11	0,076	0,548	0,053
6	Regulation of the Minister of Agriculture No 5/2018	11	0,166	0,545	0,042
7	Regulation of the Governor of Riau Province No 9/2020	11	0,080	0,537	0,050
8	Government Regulation No 4/2001	11	0,114	0,544	0,047
9	Law No 39/2014	11	0,155	0,550	0,043
10	Regulation of the Regent of Pelalawan Regency No 8/2022	9	0,060	0,509	0,039

This study identified and compiled a total of 53 policy instruments originating from the central government, the Riau Provincial Government, and the Pelalawan Regency Government that are directly or indirectly related to forest and land fire prevention and management, as presented in Table 2. These policies were analyzed using a SNA approach, which is widely applied to examine the structure, strength, and relational patterns among actors or, in this context, among policy instruments (Borgatti et al., 2009; Wasserman & Faust, 1994). The SNA framework was adapted to conceptualize regulations as nodes within a policy network, thereby enabling the identification of policies that function as central nodes, bridging instruments, and structural backbones within the forest and land fire governance system of the study area (Figure 4).

Within SNA theory, the position and influence of a node in a network are determined by several centrality measures, including degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality (Freeman, 1978). These indicators collectively provide a comprehensive understanding of policy connectivity, brokerage capacity, structural proximity, and influence within the network. Consequently, the analysis moves beyond evaluating policies as isolated instruments and instead highlights their structural roles and interdependencies within the broader governance network (Klijn & Koppenjan, 2016).

In the specific context of this study, the policy network analysis reveals that forest and land fire governance in Pelalawan Regency is characterized by a structurally dense yet functionally fragmented configuration. Although numerous policy instruments are formally interconnected, their structural integration does not automatically translate into effective coordination or fire prevention outcomes. This indicates that the presence of a complex regulatory network alone is insufficient to ensure governance effectiveness without strong institutional alignment and implementation capacity (Newig & Fritsch, 2009; Ostrom, 1990).

Within the network, several policies occupy highly central positions, reflecting their formal importance in shaping environmental governance. Law No. 32/2009 emerges as the primary regulatory hub, with the highest degree centrality, indicating extensive direct linkages with other instruments. In addition, its significant betweenness centrality highlights its role as a policy broker connecting multiple sectors and governance levels. Similarly, the ISPO regulation (Minister of Agriculture Regulation No. 11/2015) demonstrates a strong bridging function, as reflected in its high betweenness centrality. This suggests that it plays a strategic role in linking environmental objectives with plantation governance systems, particularly in promoting fire-free land management practices.

Despite the apparent interconnectedness, the policy network exhibits a high degree of fragmentation, characterized by overlapping mandates and weak cross-sectoral coordination (Tosun & Lang, 2017). In such a configuration, policies with high betweenness centrality function as critical bottlenecks, as they serve as the main channels through which coordination and information flow occur.

This structural dependency creates systemic vulnerability. When these intermediary policies are not effectively implemented due to limited resources, weak enforcement, or institutional constraints the overall network performance deteriorates (Pressman & Wildavsky, 1984). As a result, coordination gaps emerge, slowing down response times and weakening fire prevention efforts.

From a multi-level governance perspective, the findings reveal a persistent vertical misalignment between national, provincial, and regency-level policies. National regulations provide strong normative frameworks; however, their translation into subnational instruments is often delayed and uneven.

At the provincial level, instruments such as Riau Provincial Regulation No. 1/2019 and Riau Governor Regulation No. 9/2020 demonstrate relatively high degree centrality values (11 each), along with notable eigenvector centrality values of 0.549 and 0.538, respectively. However, despite this structural prominence, regulatory development at this tier tends to be highly reactive, emerging primarily after major fire events. This delay weakens vertical policy integration and limits the ability of provincial institutions to coordinate cross-district responses effectively. Consequently, when transitioning to the regency level where policies play a more operational role in translating higher-level regulations into concrete actions local execution frequently faces significant hurdles. The on-the-ground effectiveness of regency policies remains heavily constrained not only by limited institutional capacity but also by their inherent dependency on these delayed, higher-level regulatory frameworks.

Nevertheless, the timing of the regulation's enactment reflects a predominantly reactive governance pattern. The provincial regulation was issued only after recurrent large-scale fire episodes during 2013–2015 and another severe escalation in 2019. This delay indicates a crisis-driven policy response, in which regulatory action emerged primarily after fires had generated widespread environmental, economic, and political consequences, including heightened national and international scrutiny. The absence of a robust provincial instrument constrained cross-district coordination, fragmented sectoral policy alignment, and limited the consolidation of resources for proactive fire prevention (Tosun & Lang, 2017). As a result, fire governance during this period was largely oriented toward emergency response rather than long-term structural prevention.

At the regency level, Pelalawan Regent Regulation No. 8/2022 emerges as the most central policy in terms of on-the-ground implementation. This is reflected in its degree centrality value of 9 and a relatively high closeness centrality value of 0.509. A high closeness centrality indicates that this regulation is structurally proximate to other policies in the network, enabling it to access and coordinate national and provincial policy frameworks more efficiently in operational contexts (Freeman, 1978). From an SNA perspective, this position underscores the strategic role of regency-level regulations as critical connectors that translate macro-level policy frameworks into actionable measures at the local scale.

A key finding of this study is that structural centrality does not necessarily lead to policy effectiveness. Although certain policies occupy dominant positions within the network, their ability to reduce fire hotspots is highly dependent on local implementation capacity.

This reveals a policy implementation gap within decentralized governance systems, where strong central regulations are not always matched by effective local execution (Pressman & Wildavsky, 1984). Therefore, the influence of a policy within a network must be understood not only in terms of its structural position but also in terms of its operational impact.

The development of the policy network has been predominantly reactive, as evidenced by the delayed issuance of provincial regulations in Riau following major fire episodes in 2013–2015 and 2019. This temporal lag significantly weakened vertical policy integration and constrained cross-level coordination during critical periods of fire escalation. Within this fragmented landscape, the ISPO regulation emerges as a crucial operational bridge linking environmental objectives with plantation management, particularly through the institutionalization of zero-burning policy. However, despite its high centrality and potential to harmonize economic and ecological goals, ISPO's effectiveness remains strictly contingent upon its alignment with subnational regulatory frameworks. Without consistent local enforcement, its structural role risks being reduced to a mere formal compliance mechanism rather than a transformative policy tool (Pressman & Wildavsky, 1984).

Ultimately, the overall effectiveness of this complex policy network is determined by the capacity of local institutions to translate these centralized regulations into actionable measures (Brinkerhoff, 2000). Severe constraints in financial resources, technical expertise, and organizational capacity at the grassroots level significantly bottleneck implementation. Consequently, these findings imply that policy centrality within a governance network should not be interpreted merely as a marker of legal authority, but rather as an indicator of potential influence that must be activated by robust implementation mechanisms. Strengthening fire governance therefore requires a multi-faceted approach: improving vertical coordination, accelerating the formulation of derivative regulations, and fundamentally enhancing local institutional capacity (Bodin, 2017). More broadly, this study contributes to the literature on decentralized environmental governance by demonstrating that network structure alone is insufficient to explain policy effectiveness; rather, it is the dynamic interaction between a policy's structural position, institutional capacity, and temporal responsiveness that ultimately determines governance outcomes (Bodin, 2017; Newig & Fritsch, 2009; Ostrom, 1990).

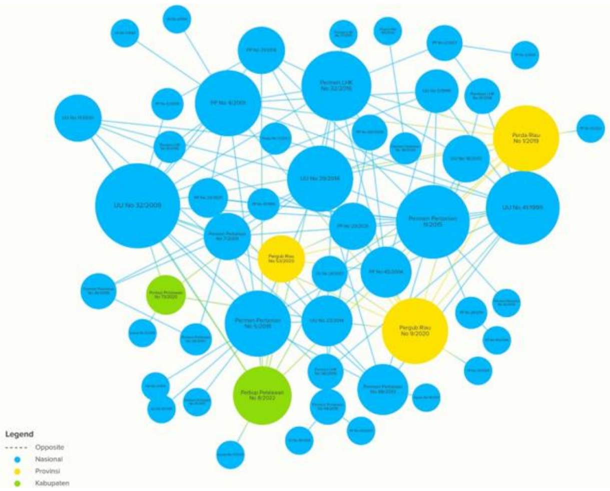

Figure 4. Policy network of forest and land fire prevention and management in Pelalawan Regency

Periodization Analysis

The temporal overlay analysis of 53 regulatory instruments and 22-year hotspot data (2000–2022) reveals a complex and non-linear relationship between the structural evolution of the forest and land fire policy network and the observed dynamics of fire occurrence in Pelalawan Regency. Rather than demonstrating a straightforward inverse relationship wherein increasing regulatory density produces declining fire intensity the integrated analysis exposes four distinct governance phases, each characterized by a unique configuration of policy network structure, institutional capacity, and fire outcome. Across these phases, the data collectively substantiate the existence of a centrality-implementation gap: a structural disconnect in which the normative dominance of key regulations within the policy network does not automatically translate into effective fire suppression at the landscape level. This gap is not uniform across time; rather, it narrows during periods of genuine institutional reform and widens during periods of regulatory proliferation without corresponding enforcement capacity. The following periodization analysis systematically traces these dynamics by aligning the enactment years and centrality values of the 53 identified regulations with annual hotspot trends, thereby exposing the governance mechanisms and failures that have shaped forest and land fire patterns in Pelalawan Regency over the past two and a half decades.

The first governance phase spans from 2000 to 2008, a period characterized by a sparse regulatory network and rapidly escalating fire hotspot frequency. During this phase, only a limited number of regulations were in force, anchored primarily by Law No. 41/1999 on Forestry (degree centrality: 13) and Government Regulation No. 4/2001 on the Control of Environmental Damage and Pollution Related to Forest and Land Fires (degree centrality: 11). The policy network during this period was structurally thin, with low overall network density and limited inter-regulatory connectivity, reflecting an institutional architecture that was reactive rather than preventive in orientation. The empirical consequences of this regulatory vacuum are clearly visible in the hotspot data: annual hotspot counts escalated from a baseline of 29 in 2000 to a peak of 2,195 in 2005, followed by sustained high levels of 1,523 in 2006 and 1,279 in 2008. This trajectory is consistent with the punctuated equilibrium model, wherein the absence of an integrated governance framework allowed fire-driving land-use pressures particularly the accelerating expansion of oil palm plantations to operate largely unconstrained. The dominance of PP No. 4/2001 as a structurally central node during this phase indicates that fire governance was primarily framed within a general environmental damage control paradigm, without sector-specific preventive instruments targeting peatland fire dynamics (Cisneros et al., 2021; Purnomo et al., 2019).

The second governance phase, spanning 2009 to 2015, represents the most paradoxical period in Pelalawan's fire governance trajectory. This phase witnessed the most intensive regulatory expansion in the study period with seven regulations enacted in 2009 alone, anchored by the landmark Law No. 32/2009 on Environmental Protection and Management, which achieved the highest degree centrality in the entire network (16) and a betweenness centrality of 0.161. The enactment of Law No. 32/2009 fundamentally restructured the policy network by introducing stringent environmental liability provisions, strengthening the legal basis for zero-burning requirements, and establishing it as the primary normative hub from which most subsequent sectoral and subnational regulations derive their legal authority. The network further expanded with the enactment of PP No. 71/2014 on Peat Ecosystem Protection and Management (degree: 6), Law No. 39/2014 on Plantations (degree: 11; betweenness: 0.155), and Minister of Agriculture Regulation No. 11/2015 on ISPO Certification (degree: 13; betweenness: 0.179 the highest in the entire network), which emerged as the most critical bridging node linking environmental governance with plantation sector regulation. However, paradoxically, this period of maximum regulatory densification coincided with the highest recorded hotspot intensities in the entire 22-year study period: 2,242 hotspots in 2009, 2,768 in 2013 the absolute peak and sustained high levels of 1,898 in 2014 and 1,778 in 2015. This empirical pattern constitutes the clearest manifestation of the centrality-implementation gap: despite Law No. 32/2009 occupying the most structurally dominant position in the policy network, its normative centrality failed to translate into effective fire suppression at the landscape level. This gap reflects the structural limitations identified by Ostrom (2009) regarding the incongruence between formal institutional rules and the social-ecological dynamics they seek to govern, compounded by fragmented enforcement authority, overlapping land concessions, and weak inter-agency coordination at the district level (Pramudya et al., 2018; Wibowo et al., 2019).

The third governance phase, from 2016 to 2018, represents the most significant governance transition in the study period, characterized by a dramatic and sustained reduction in hotspot frequency that constitutes the strongest empirical evidence of policy effectiveness in the entire dataset. Hotspot counts declined precipitously from 1,778 in 2015 to 265 in 2016, 159 in 2017 the lowest recorded value since 2000 and 279 in 2018, representing a reduction of approximately 94% from the 2013 peak. This dramatic decline coincided with a cluster of transformative post-crisis governance reforms enacted in direct response to the catastrophic 2015 fire season, including Minister of Environment and Forestry Regulation No. 32/2016 on Ecosystem Restoration Concessions (degree: 12; betweenness: 0.155), Government Regulation No. 57/2016 amending PP No. 71/2014 on Peat Ecosystem Management (degree: 2), and the establishment of the Peatland Restoration Agency (BRG) through Presidential Regulation No. 1/2016. These instruments collectively represent a qualitative shift in governance orientation from reactive fire suppression toward proactive landscape-level peatland restoration and hydrological management. Critically, the structural position of Permen LHK No. 32/2016 in the policy network with the third-highest degree centrality and a notable betweenness value indicates that this regulation functioned as an effective bridging node that channeled environmental restoration principles into operational concession management frameworks. The alignment between the enactment of these high-centrality post-crisis regulations and the dramatic hotspot reduction during 2016–2018 suggests that when regulatory instruments are accompanied by dedicated institutional mechanisms (BRG), sufficient resource allocation, and enhanced enforcement as mandated by the post-2015 peat moratorium the policy network can produce measurable governance outcomes (Epstein et al., 2015; Sabatier & Weible, 2014).

The fourth and final governance phase, from 2019 to 2024, is characterized by institutional consolidation through subnational regulatory development, the occurrence of a climate-driven fire rebound in 2019, and a subsequent trajectory of sustained hotspot reduction. The hotspot count rebounded to 1,360 in 2019, driven primarily by extreme El Niño-related drought conditions rather than governance failure, before declining progressively to 221 in 2020, 195 in 2021, 106 in 2022, 132 in 2023, and 125 in 2024. This phase witnessed the most intensive subnational regulatory activity in the study period, with seven regulations enacted in 2020, including Riau Governor Regulation No. 9/2020 (degree: 11; betweenness: 0.080), Riau Governor Regulation No. 53/2020, and Pelalawan Regency Regulation No. 73/2020 all of which represent the downward vertical integration of national and provincial fire governance frameworks into district-level operational instruments. The subsequent enactment of Pelalawan Regent Regulation No. 8/2022 (degree: 9; closeness centrality: 0.509 the highest among all subnational regulations) as the most structurally proximate district-level node further reinforced the vertical coherence of the policy network. The progressive hotspot reduction observed between 2020 and 2024, despite the 2019 rebound, suggests that the combination of institutionally dense post-crisis regulations, dedicated restoration agencies, and district-level operational instruments has produced a more resilient governance architecture capable of maintaining reduced fire intensity even under conditions of climatic stress. However, the 2019 rebound also underscores the continued vulnerability of Pelalawan's fire governance to exogenous climatic shocks, indicating that while the regulatory network has achieved greater structural coherence, its implementation capacity remains contingent on non-climatic conditions and consistent enforcement (Ostrom, 2009).

CONCLUSION

This study demonstrates that the dynamics of forest and land fires in Pelalawan Regency cannot be adequately explained solely by the presence or strength of individual regulatory instruments. Instead, these dynamics are strongly shaped by the structure, connectivity, and performance of the environmental policy network as a whole. The integration of spatial analysis, encompassing land cover change and hotspot analysis, with policy network analysis reveals that recurrent fire events persist despite the substantial development of the national legal framework. This condition points to structural constraints in environmental governance, particularly weak inter-policy coordination, cross-sectoral institutional fragmentation, and limited implementation capacity at the local level.

The policy network analysis identified 53 regulations related to forest and land fire control in Pelalawan Regency. Law No. 32/2009 on Environmental Protection and Management exhibits the highest degree centrality (16), positioning it as the most normatively central node within the fire governance network. This high level of centrality reflects its role as an overarching legal framework and a primary reference for a wide range of derivative regulations at both national and subnational levels. However, the findings indicate that strong structural centrality does not automatically translate into improved environmental outcomes. Periods of high hotspot intensity suggest that this normative centrality has not been consistently operationalized through effective implementation, law enforcement, and cross-sectoral coordination.

Following the enactment of several fire control policies, most notably Minister of Environment and Forestry Regulation No. 32/2016, Riau Provincial Regulation No. 1/2019, and Pelalawan Regent Regulation No. 8/2022, a decline in forest and land fire occurrences has been observed in Pelalawan Regency. The reduction in hotspots after 2016 indicates that effective policy implementation can have a direct impact on fire incidence. Nevertheless, the persistence of fire events in 2019 underscores the influence of external factors, such as extreme climatic conditions associated with the El Niño phenomenon, which can undermine policy performance even when regulatory frameworks are in place.

The periodization analysis further reveals that the relationship between regulatory development and fire outcomes is neither linear nor automatic. The second governance phase (2009–2015) demonstrated the clearest manifestation of the centrality-implementation gap: despite the most intensive regulatory expansion in the study period anchored by Law No. 32/2009 as the most structurally dominant node hotspot counts reached their absolute peak of 2,768 in 2013. Conversely, the dramatic hotspot reduction of approximately 94% between 2015 and 2017 was achieved not through regulatory proliferation alone, but through the combination of high-centrality post-crisis instruments, dedicated institutional mechanisms such as the Badan Restorasi Gambut (BRG), and enhanced cross-sectoral enforcement. This contrast underscores a critical governance lesson: it is the dynamic interaction between a policy's structural position, institutional capacity, and temporal responsiveness rather than regulatory density alone that determines governance outcomes.

From an environmental policy perspective, these findings highlight the critical importance of policy coherence and multi-level governance in addressing complex environmental risks such as forest and land fires. Fragmented authority across environmental, forestry, and land-based economic sectors remains a major barrier to the integrative functioning of the policy network. Enhancing the effectiveness of fire governance therefore requires strengthening policy network integration through clearer vertical coordination across levels of government, the development of more functional cross-sectoral bridging regulations, and the consistent enforcement of laws at the subnational level.

While this study offers meaningful contributions to the literature on forest fire governance and introduces the concept of the centrality-implementation gap as a theoretical lens for decentralized environmental governance, several limitations should be acknowledged in interpreting the results. First, by focusing exclusively on regulatory instruments as network nodes, the analysis does not capture the informal interactions, power asymmetries, and behavioral dynamics among implementing actors that ultimately shape on-the-ground outcomes. Second, the construction of inter-regulatory connections retains an element of interpretive judgment, which may introduce analytical subjectivity. Third, MODIS-derived hotspot data are subject to spatial resolution constraints that may underrepresent fire occurrences in densely vegetated or cloud-covered areas. As a result, the findings should be interpreted as an assessment of structural policy potential rather than a comprehensive evaluation of governance performance.

The omission of actor-based analysis also creates certain analytical gaps in understanding how policy structures translate into practice on the ground. While regulatory network analysis can reveal the formal architecture and hierarchical relationships between policy instruments, this approach does not explain how government institution, private sector actors, or local communities interpret, prioritize, negotiate, or selectively implement these regulations. Variations in implementation outcomes across sectors and levels of government strongly mediated by institutional capacity, inter-agency coordination, political incentives, and compliance behavior cannot therefore be fully explained within this study's analytical framework.

Future research should integrate policy network analysis with actor-based network analysis to simultaneously examine formal regulatory structures and actor-level coordination dynamics. Incorporating qualitative methods such as elite interviews and participatory mapping would further strengthen the interpretive validity of findings and deepen contextual understanding of implementation failures at the local level. The analytical framework introduced in this study integrating long-term hotspot data with Social Network Analysis of regulatory instruments offers a transferable model that may be applied to fire governance research in other peatland-dominated landscapes across Indonesia and comparable developing country contexts where decentralized governance structures and multi-level regulatory fragmentation remain persistent challenges.

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