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Evidence Before Attribution, Prevention Before Crisis: Fair Accountability and Collaborative Fire Governance in Indonesia's Oil-Palm and Peatland Landscapes

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A B S T R A C T

Indonesia's recurring land and peat fires create acute ecological, economic, public-health and governance challenges. Public controversy frequently presents a false choice between aggressive enforcement against suspected burners and fair treatment of plantation enterprises. This qualitative literature review advances a different proposition: defensible attribution and enforceable prevention duties are complementary rather than competing public objectives. Using a critical, interpretive synthesis of peer-reviewed studies published in 2020–2026, the review examines coupled fire-risk processes, remote-sensing evidence, expert knowledge, regulatory compliance, corporate commitments, peatland restoration and community vulnerability. The synthesis identifies six interconnected findings. Fire hazards emerge from climate–hydrology–land-use interactions; hotspot observations are screening evidence rather than conclusive proof of ignition or culpability; accountability must distinguish acts of ignition from failures of prevention; restoration performance varies by landscape and implementation; private commitments do not substitute for public oversight; and social legitimacy depends on feasible alternatives for exposed communities. An integrated two-track framework is proposed, combining a transparent evidentiary pathway with a risk-reduction pathway governed through shared but differentiated responsibilities

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INTRODUCTION

1. A Recurring Disaster and a Polarizing Public Debate

Forest, vegetation and peat fires in Indonesia are not merely episodic natural disturbances. They occur within landscapes transformed by cultivation, drainage, infrastructure, land-tenure arrangements and institutional incentives. When fires spread through dried peat or degraded vegetation, their consequences extend beyond the point of ignition: terrestrial carbon stocks are mobilized, air quality deteriorates, livelihoods are disrupted and public agencies face large response and recovery demands. A modeling study of major Indonesian fire episodes estimated considerable economic losses and found substantial potential benefits from avoided burning through peatland restoration; these estimates, however, are scenario-dependent rather than directly observed in national accounts (Kiely et al., 2021). Atmospheric measurements and health-oriented research likewise demonstrate that the public cost of fires cannot be understood only through property damage within a single land parcel (Yokelson et al., 2022; Grosvenor et al., 2024). The cross-border consequences of Indonesian peat smoke warrant particular attention because pollutants are transported well beyond the administrative location of a fire. A recent synthesis of Equatorial Asian haze research links peat combustion to altered atmospheric chemistry and public-health exposure, while emphasising that better integration of in-situ monitoring and epidemiological evidence is still needed to improve impact assessment (Kuwata, 2024).

The palm-oil economy is particularly prominent within the debate because oil palm forms part of an internationally connected production system in which land allocation, supply-chain purchasing and sustainability rules operate at different scales. Dependence on Indonesian palm oil generates distant environmental footprints, whereas domestic communities often experience immediate costs of degraded air and weakened ecosystem functions (Shigetomi, Ishimura and Yamamoto, 2020). Yet the spatial overlap of plantations and fire events does not establish that every plantation company initiated a particular ignition. Nor does the difficulty of identifying an individual igniter absolve land managers from applicable duties to prevent, detect and respond to fires. These propositions address different factual and legal questions and therefore require different kinds of evidence (Astuti, 2021; Astuti and Fatimah, 2024). The public expects the government to impose decisive sanctions on proven offenders while cautioning against treating an entire industry as culpable. That public statement motivates the present inquiry, but it is neither an adjudicated account of specific incidents nor an independently validated causal study. Its value for scholarship lies in exposing a persistent governance dilemma: how can authorities avoid both indiscriminate blame and impunity? Research on contested expert testimony in plantation fire litigation shows why a neutral slogan of "following the evidence" is insufficient unless evidence production, selection and interpretation are themselves made transparent and contestable (Astuti and Fatimah, 2024).

2. Why the Distinction Between Attribution and Prevention Matters

An operational fire alert, a mapped burned scar, a concession polygon, witness testimony and documented maintenance failures describe different phenomena. A heat anomaly identifies a potential thermal event; a burned-area layer estimates spatial consequences; an ignition reconstruction concerns where and when combustion started; a land-boundary record concerns possible legal or management relationships. Linking these observations into a finding of responsibility requires reasoning about reliability, alternative explanations, spatial accuracy, chronology, agency and the legal elements of a claim. Studies improving satellite fire monitoring and mapping fire severity reveal the informational strengths of earth observation, but they do not turn satellite pixels into determinations of individual intent (Indradjad et al., 2024; Schmidt et al., 2024). Prevention, by contrast, is forward-looking. Organisations with relevant authority over land, water infrastructure, contractors or emergency systems may be expected to take specified precautions before an igniter can be identified. Compliance with such duties can be assessed through water-level management, preparedness records, patrol logs, contractor controls, incident reporting and timely intervention. The appropriate legal test depends on the applicable statute and adjudicative forum; a literature review cannot decide liability in an unexamined case. Nevertheless, analytical separation helps reconcile procedural fairness with the obligation to reduce predictable hazards (Resosudarmo, Tacconi and Waluyo, 2023; Safitri, 2021).

3. Purpose, Questions and Contribution

This review asks how fair, evidence-based accountability can be integrated with collaborative fire prevention in Indonesia's oil-palm and tropical peatland landscapes. Eight subsidiary questions examine causal risk drivers, evidence standards, enforcement incentives, corporate obligations, restoration outcomes, distributive justice, institutional coordination and measurable policy indicators. The intended contribution is not an additional estimate of hectares burned or a ranking of particular firms. Rather, it is an integrative explanation of how scientific uncertainty, enforceable duties and prevention performance should interact. The review advances a two-track model in which verified attribution and documented preventive compliance are evaluated separately but inform a shared learning system. It also specifies why "collaboration" must preserve responsibility rather than become a euphemism for voluntary action without sanctions (Carmenta et al., 2021; Grabs and Garrett, 2023; Purnomo et al., 2024).

LITERATURE RIVIEW

1. Fire as a Coupled Social–Ecological Process

A useful starting point is the coupled social–ecological interpretation of fire. Weather anomalies and drought can lower fuel moisture, but drainage, vegetation loss, canals, roadside access and land-use decisions determine where that meteorological pressure translates into combustible conditions. In peatlands, lowered water tables expose organic soils that can burn below the surface and remain difficult to extinguish. An assessment of El Niño variability and peat conditions underscores the interaction between climatic anomalies and the environmental substrates on which ignition occurs (Brasika, 2022). Historical reconstruction of West Kalimantan peat dynamics similarly indicates that fire, flooding, climate and anthropogenic disturbances cannot be placed in entirely independent causal categories (Ruwaimana, Gavin and Anshari, 2024).

Empirical analyses increasingly focus on interacting rather than additive drivers. A study of drainage density and land cover reports that their combination helps explain peat-fire occurrence; another investigation across Riau peat hydrological units demonstrates the importance of spatially contextualized fire regimes (Salmayenti et al., 2025; Rossita et al., 2023). Machine-learning investigations can identify predictors and nonlinear thresholds, including landscape conditions and seasonal variation, but predictive contribution is not equivalent to causal or forensic identification of an individual perpetrator (Horton et al., 2021; Karurung, Lee and Lee, 2025). The distinction between predicting a high-risk area and proving the origin of a particular fire is foundational to the framework developed below.

Hydrology connects land management to long-term risk. Studies examining groundwater tables and carbon emissions illustrate why peat water balance is central to both mitigation and ecosystem stability (Novita et al., 2021). Public groundwater and soil-hydrological datasets can support reproducible monitoring, but observations must be interpreted in relation to measurement location, seasonality and the actual infrastructure serving a site (Taufik et al., 2022b). Drought-sensitive fire indicators can help anticipate risk windows; their diagnostic value should be judged against verified events and independently documented field conditions (Taufik et al., 2022a).

2. Institutional Economics, Externalities and Incentives

The economic theory of externalities explains why private decisions about clearing and land management can impose uncompensated costs on neighbors and society. A recent study using Indonesian satellite and landholding information relates fire-setting behavior to the risk that fires spread onto surrounding property, thereby demonstrating why the pattern of neighboring land rights is relevant to prevention incentives (Balboni, Burgess and Olken, 2026). Where prevention benefits cross concession borders, a single landholder may underinvest in collective safeguards; where fire imposes severe external harm, public oversight remains necessary. This argument does not assume that all fires are intentional. It highlights that the configuration of incentives can affect both deliberate burning decisions and investments in avoidance. Institutional analysis also draws attention to coordination failures. Fire protection depends on

the actions of national and regional authorities, plantation firms, independent farmers, village institutions, civil society and emergency responders. Roles may overlap, while the authority to control canals, mobilize equipment and manage access roads is unevenly distributed. Research categorizing numerous Indonesian peat-fire interventions finds a complex portfolio of regulatory, informational, technical and socioeconomic measures (Jefferson et al., 2020). Studies of policy implementation caution that the nominal introduction of a rule cannot be mistaken for uniform compliance, particularly when monitoring capacity and access to practical alternatives differ across communities (Resosudarmo, Tacconi and Waluyo, 2023).

3. Evidence, Expert Knowledge and Environmental Liability

Environmental enforcement must balance two kinds of error: imposing sanctions despite inadequate proof and failing to hold responsible actors accountable despite serious damage. Neither error should be treated as acceptable simply because the desired policy outcome is urgent. Expert knowledge is particularly consequential when judges or investigators must interpret fire spread, peat damage, atmospheric conditions, satellite data and costs of restoration. Research on expert testimony in Indonesian plantation fire cases finds that experts may construct competing interpretations of scientific material, sometimes in ways aligned with litigants' interests (Astuti and Fatimah, 2024). Independent scrutiny of methods, assumptions and disclosed data is consequently a matter of institutional integrity, not just scientific technique. A second distinction concerns the nature of responsibility. Attribution of an initial ignition event, proof of unlawful land clearing, a breach of due diligence, damage causation and liability for restoration may engage different legal standards. This article therefore treats “liability” as an umbrella term to be legally specified before a particular inference is drawn. The socio-political literature shows that state efforts to discipline plantation companies can be shaped by conflicts over jurisdiction and competing framings of what counts as responsible peat management (Astuti, 2020; Astuti, 2021). A legally sound system would connect each allegation to a precisely identified norm and evidentiary burden, rather than infer all elements of a claim from the same hotspot map. The analysis must also avoid treating fault-based ignition attribution as the exclusive legal route to environmental responsibility. Indonesian doctrinal research on forest-fire litigation identifies the significance of strict-liability reasoning in a civil claim for environmental damage and restoration, although the applicable statutory provisions and judicial reasoning require close, case-specific examination rather than automatic extrapolation to all proceedings (Satriawan, Islami and Putra, 2025). Consequently, an independent duty, a legally defined liability regime, and an allegation of intentional burning must be assessed under their respective elements and burdens of proof; “unproven igniter” is not synonymous with “no possible liability” (Astuti and Fatimah, 2024; Satriawan, Islami and Putra, 2025).

4. Private Commitments, Supply Chains and Environmental Justice

Private sustainability governance has gained visibility through no-deforestation policies, traceability expectations and supplier agreements. Nevertheless, the existence of a policy is distinct from operational implementation across subsidiaries, traders, producers and smallholders. Comparative evidence on corporate zero-deforestation commitments highlights variation in company implementation practices, whereas work on Indonesian oil palm identifies tensions and paradoxes in goal-oriented private regulation (Bager and Lambin, 2022; Grabs and Garrett, 2023). The credibility of a commitment depends on what is measured, which actors are included, how noncompliance is corrected and whether consequences are independently verifiable (Grabs, 2023). Corporate commitments coexist with state regulation, sometimes in uneasy ways. Studies of company strategies reveal tensions between zero-deforestation pledges and zero-tolerance state demands, while work on South Sumatra shows that public and private initiatives must be assessed together (Dermawan, Hospes and Termeer, 2022; Purnomo et al., 2023). Economic and ecological effects may also relocate geographically when land-use pressures are displaced rather than reduced. Scenarios of global oil-palm expansion under zero-deforestation commitments show the importance of considering indirect land-use effects and supply-chain boundaries (Leijten et al., 2023). Environmental justice adds a question often lost in debates about formal responsibility: who is exposed to the costs of fire and to the costs of reducing fire? Smallholders may encounter livelihood constraints arising from restrictions, restoration priorities and the absence of affordable no-burn cultivation methods. Research in Indonesian peatlands describes multiple burdens placed on smallholder farmers through climate and land-management transitions (Merten et al., 2021). Studies mapping vulnerability and examining households in South Sumatra show why geographic exposure, economic resources and institutional access should be assessed together rather than assuming that all residents of a fire-prone province face equal risks (Lee et al., 2025; Yazid et al., 2024).

METHODOLOGY

1. Review Design and Epistemic Orientation

This study adopts a critical, interpretive qualitative literature review (QLR), not a systematic literature review or meta-analysis. Its purpose is to build a conceptually coherent synthesis across environmental science, law, political ecology, development studies and business governance. Rather than claiming exhaustive retrieval of every eligible publication, it purposively selects literature for the relevance of its evidence and its potential to confirm, challenge or refine the central proposition. Such a choice is defensible because the underlying research problem is multidisciplinary: a sophisticated fire-detection algorithm cannot alone resolve procedural legitimacy, while a theory of legal accountability cannot describe groundwater dynamics without engagement with hydrological research (Horton, Lehtinen and Kummu, 2022; Astuti and Fatimah, 2024). The primary corpus comprises scholarly journal articles published from 2020 to October 2026, supplemented conceptually by the contemporary newspaper opinion that motivates the question. The opinion is treated as discourse to be

analyzed, not empirical verification. The review privileges journal studies of Indonesian tropical peatlands, oil-palm landscapes, fire-related legal disputes and relevant cross-scale governance mechanisms. A recent socio-ecological synthesis further demonstrates the value of comparing management approaches across disciplines, without replacing the present critical interpretive design (Chika Alexandra, Herdiansyah and Yulianto, 2026). Work from other regions is conceptually informative only when the transfer assumptions are explicit. Priority is given to studies describing methods, uncertainties and observable findings, including field measurements, counterfactual comparisons, remote sensing, interviews, case analysis and mixed-methods evaluation (Carmenta et al., 2021; Purnomo et al., 2024).

2. Literature Identification and Interpretive Selection

Literature identification combined backward and forward thematic exploration around terms such as Indonesian peat fire, plantation concession, fire attribution, expert evidence, peatland rewetting, zero burning, private governance, satellite hotspot, community prevention and environmental justice. Records were screened for substantive proximity to the research questions, publication between 2020 and 2026, methodological transparency and the presence of a traceable journal and DOI or publisher address. The process was deliberately iterative: emerging legal questions prompted searches for expert-knowledge studies, while emerging restoration claims prompted examination of hydrological and counterfactual evaluations. No PRISMA flow, pooled effect size or fabricated "study inclusion count" is reported because the design does not support those claims.

The interpretation proceeds through a structured evidence matrix. For each source, the matrix records the geographic scale, unit of analysis, method, object of inference, principal result, key caveat and theme. For example, a matched-comparison study of restored peatlands may support an average treatment-effect interpretation under its design assumptions, but not a conclusion that a given company caused a fire. A qualitative study of corporate behavior may illuminate incentive structures without producing a nationally representative compliance rate. A satellite study may improve detection accuracy without identifying intent. Keeping these boundaries visible protects the synthesis against inappropriate transfers of evidence (Castro et al., 2026; Indradjad et al., 2024; Grabs and Garrett, 2023).

3. Thematic Synthesis and Trustworthiness

First-cycle coding distinguishes six substantive areas: coupled fire-risk production; fire observation and forensic attribution; public enforcement; corporate and supply-chain governance; restoration and prevention; and distributional justice. Second-cycle synthesis asks how mechanisms cross these domains, whether findings converge across methods and whether apparent contradictions are explained by different spatial scales, seasons, institutional contexts or estimands. Counterexamples are treated as informative rather than excluded: restoration may lower observed fire density in one El Niño year while

showing no statistically detectable difference in another, and a corporate rule may succeed in one supply chain yet transfer costs onto poorly resourced producers elsewhere (Salmayenti et al., 2026; Grabs and Garrett, 2023).

Trustworthiness is pursued through explicit separation of observations, inferences and recommendations. Quantified effect estimates are attributed to their particular analyses; causal language is moderated when studies are observational; and legal claims are presented as analytical distinctions rather than case-specific advice. The study does not interview stakeholders, inspect case files, obtain original hotspot pixels or test a new econometric model. Accordingly, the output is a defensible interpretation and a future research agenda, not an independent finding about a particular fire event. The approach also acknowledges that an English-language, peer-reviewed corpus may underrepresent village knowledge and local administrative experience, a limitation that community knowledge-system research makes particularly salient (Robins et al., 2022).

RESULT

4. Fire Exposure is Produced Jointly by Hydrology, Land Cover and Decisions

The first finding is that neither weather nor land-use category is a sufficient stand-alone explanation of Indonesian peat-fire risk. Drought can create a broad period of elevated hazard, but drainage modifies peat moisture and fire persistence; loss of canopy and altered vegetation can change surface microclimates; and settlement or productive activity can increase opportunities for ignition. Studies across Central Kalimantan and Riau consequently point toward targeted, hydrologically informed land management rather than undifferentiated district-level restrictions (Horton et al., 2021; Horton, Lehtinen and Kummu, 2022; Rossita et al., 2023). The significance of interacting drainage density and land cover further cautions against treating a mapped concession boundary as an ecological boundary (Salmayenti et al., 2025). Long-term effects are also evident. Peat combustion changes carbon balance and can reduce the ecological capacity of tropical peat forests to recover after severe disturbance, while repeated burns shape vegetation trajectories and subsequent fuel conditions (Krisnawati et al., 2021; Harrison et al., 2024). Research on fire history and rewetting in South Sumatra shows that restoration outcomes depend on preceding disturbance and the persistence of ecological processes rather than merely on an announced intervention (Giesen et al., 2023). These results suggest that monitoring should track fire susceptibility and ecosystem condition over multiple seasons, not simply count extinguished hotspots immediately after a campaign.

Figure 1 presents the coupled-risk pathway emerging from this literature. The figure distinguishes structural pressures, proximate biophysical conditions, ignition opportunities and societal consequences because each layer responds to different instruments. Its arrows should be read as plausible process connections synthesized from the literature, not as a fitted causal model with estimated coefficients. Consequently, the figure is most useful for locating the responsibilities and evidence that should be examined in any place-specific evaluation (Brasika, 2022; Salmayenti et al., 2025; Taufik et al., 2022a).

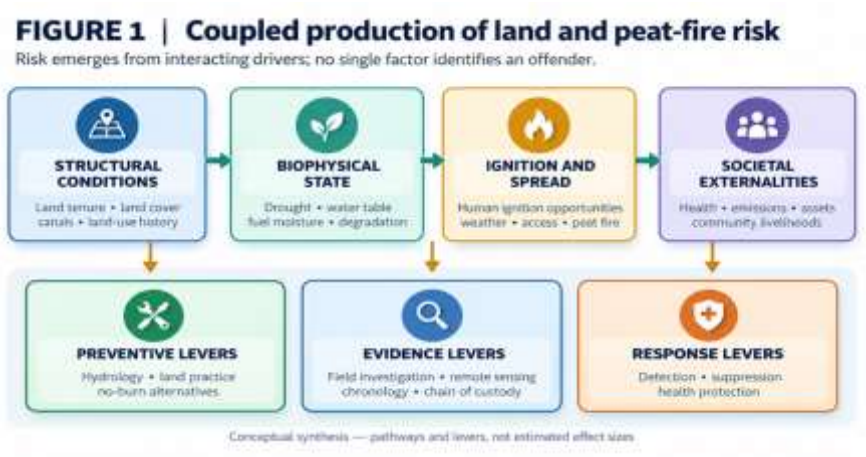


Figure 1. Coupled Biophysical and Institutional Pathways Shaping Peatland Fire Risk
(Authors' Conceptual Synthesis)

A practical implication is that a fire-risk assessment should not stop at rainfall forecasts or a list of concession owners. It should identify hydrological units, canals, drainage maintenance, vegetation conditions, access patterns, livelihood incentives and cross-boundary exposure. This multidimensional assessment provides a defensible basis for prioritizing preventive resources while avoiding the mistaken inference that a high-risk landscape proves that a named actor initiated a particular fire (Ruwaimana, Gavin and Anshari, 2024; Karurung, Lee and Lee, 2025). The three lower-layer levers in Figure 1 are not interchangeable: preventive actions modify susceptibility, evidentiary procedures improve justified inference, and response capacity limits harm after detection. A system can perform well on one lever while remaining deficient on another, which is why separate indicators are needed before judging overall performance.

2. Detection Information and Proof of Culpability Occupy Different Evidentiary Levels

The second finding concerns the inferential distance between sensing a fire and attributing culpability. Satellite heat detections, burned-area products and fire-severity maps are invaluable for timely warnings and retrospective description. Different sensors, atmospheric conditions, revisit frequencies and processing thresholds nevertheless affect what is observed; peat combustion may also continue below the surface in ways that complicate a single-time detection. Research on VIIRS-based monitoring improves the ability to identify thermal patterns, while long-term severity analysis reveals the importance of repeated and heterogeneous fire events (Indradjad et al., 2024; Schmidt et al., 2024). Neither type of result automatically identifies the human initiator, timing of first ignition or statutory breach. Operational mapping evidence illustrates this gap with unusual clarity. Vetrita et al. (2025) document the techniques, accuracy limitations, and interagency checking used for monthly burned-area mapping in Indonesia, including constraints from small fires and cloud cover. More recent

nationwide Sentinel-2 mapping by Gaveau, Descals and Salim (2026) offers higher spatial and temporal detail, but its validation concerns burned-area classification rather than identifying an individual who ignited a particular fire. Accuracy in the measurement of burned area is therefore valuable for monitoring and forensic prioritization, not a substitute for investigating human actions, land control, and legally relevant omissions (Vetrita et al., 2025; Gaveau, Descals and Salim, 2026). Proof must therefore be assembled as a chain of claims. An investigator may begin with detection and a provisional location, triangulate the earliest observations with field traces and credible witness accounts, reconstruct possible spread, establish land-control relationships, examine applicable prevention obligations and finally evaluate alternative explanations. Different links may remain uncertain. Remote-sensing error should not be rhetorically erased by overlaying an imprecise point on an apparently precise polygon. Conversely, uncertainty about ignition does not erase documentary evidence of ignored warnings or non-operational equipment when those facts are independently established and legally relevant (Astuti and Fatimah, 2024; Resosudarmo, Tacconi and Waluyo, 2023).

Figure 2 formalizes this "evidence ladder" and sets out two parallel questions after a fire is observed: what conduct, if any, caused unlawful ignition; and whether potentially responsible actors met their legally applicable preventive duties? The two pathways can converge in some cases, but they must not be collapsed by assumption. The figure also locates independent scientific review and opportunities to challenge expert testimony at the interpretation stage, reflecting documented concern about selective scientific narratives in Indonesian plantation litigation (Astuti and Fatimah, 2024).



Figure 2. Evidence Ladder Separating Fire Detection, Direct Ignition Attribution and Assessment of Independent Preventive Duties (Authors' Conceptual Synthesis).

Such an approach supports firmness and fairness at the same time. Its procedural value is strongest when the evidentiary thresholds for an alert, an administrative inspection, an interim safety order and a final sanction are explicitly distinguished. Alerts should prompt rapid action with a precautionary orientation, whereas punitive attribution requires the proof appropriate to the relevant legal claim. Public reporting should use language such as "detected,"

"under investigation," "verified breach" and "adjudicated responsibility" with consistent meanings. The result is not weaker enforcement but a more auditable connection between accusation, evidence and remedy (Safitri, 2021; Astuti, 2021). In Figure 2, Track A addresses event attribution while Track B asks whether an independently applicable preventive duty was fulfilled. Both branches end in legally reasoned decisions and corrective measures, but neither can borrow the other branch's evidence threshold merely for administrative convenience.

3. Regulation Works Through Incentives, Capacity and Credible Follow-Through

The third theme is that enforcement effectiveness depends on how rules interact with incentives and practical constraints. Empirical work on tropical forest fires demonstrates that the prospect of damage to neighboring land can affect private fire-setting incentives, highlighting the relevance of landholding patterns and expected external costs (Balboni, Burgess and Olken, 2026). A separate policy study examines villagers' compliance with no-burning rules, bringing attention to the difficulty of enforcement where alternative clearing techniques, labor, equipment or finance are inaccessible (Resosudarmo, Tacconi and Waluyo, 2023). These findings are complementary: deterrence matters, but rule design must also address capacity to comply.

Enforcement is more credible when investigation and sanctions are consistent across actor types and appropriately tailored to the nature of violations. Selective attention to large firms can obscure wrongdoing elsewhere, while an exclusive focus on smallholder burning can leave powerful land managers insufficiently scrutinized. The legal and political literature indicates that fire governance is embedded in contested institutional relationships; this makes transparent records, review procedures and observable compliance benchmarks essential (Astuti, 2020; Safitri, 2021). Neither uniform suspicion of corporate landholders nor presumptive exoneration of industry follows from the evidence.

The literature on bundled prevention measures further suggests that legal sanctions alone are not a complete solution. A comparative evaluation of interventions found that effective combinations depended on landscape context and that sanctions and concern awareness were important within the settings examined (Carmenta et al., 2021). Mapping many interventions shows the diversity of tools already being employed, but intervention proliferation does not necessarily equal coherent policy implementation (Jefferson et al., 2020). A successful accountability design should therefore combine specific prohibitions with verifiable preventive requirements, escalation rules, corrective action and periodic evaluation.

4. Peatland Restoration Can Reduce Risk, But Effectiveness is Conditional

The fourth theme identifies promising, but heterogeneous, preventive effects of peat restoration. Raising water tables and restoring hydrological functioning aim to make peat less combustible, with additional potential benefits for subsidence, ecosystem recovery and greenhouse-gas mitigation. Field and modeling evidence on rewetting reports favorable outcomes in particular contexts, including lower estimated net emissions and improved restoration performance (Lestari, Murdiyarso and Taufik, 2022; Hooijer et al., 2024). Work on integrated water management in tropical peat agriculture also illustrates that productive land management and lower subsidence or emissions can be jointly considered, while requiring careful attention to the setting and counterfactual comparison (Fawzi et al., 2024). Recent quasi-experimental evidence supports a cautious, measurable approach. Salmayenti et al. (2026) compared restored sites with matched controls and estimated that restoration lowered 2019 hotspot occurrence in their study landscape, while the effect was not statistically evident in the lower-fire year of 2023. Their analysis attributes a material share of the observed 2015–2019 change to restoration but also highlights the role of climate variability. An independent Kalimantan counterfactual evaluation found heterogeneous performance among canal blocks and suggested that strategically effective installations could avoid part of the burned area under a prospective improvement scenario (Castro et al., 2026). These are not universal effects applicable to every concession; they are evidence that design, location, climatic year and infrastructure functioning matter.

Economic evaluation strengthens the case for preventive investment but does not guarantee that any project is cost-effective. Kiely et al. (2021) estimated large historic fire losses and modeled meaningful avoided damages under a peat-restoration scenario. Tan et al. (2022) likewise examined restoration as a nature-based mitigation strategy with conservation and fire-reduction co-benefits. Such studies justify scrutiny of benefits beyond company property boundaries, including health and climate externalities; nevertheless, costs, avoided losses and discounting assumptions must remain explicit. Restoration should be judged through monitored water levels, ecological indicators, independently compared fire outcomes, community feasibility and the durability of funding.

Operationally, risk reduction is more than canal blocking. Rewetting may need to be paired with early warnings, effective patrols, vegetation management consistent with peat conservation, firefighting readiness and community alternatives to burning. Evidence on restoration actors emphasizes multiple implementation barriers, from local engagement to risk management and institutional continuity (Lestari et al., 2024). The reported potential of weather-modification approaches should be evaluated as a supplemental, context-dependent response rather than as a substitute for keeping peat wet and preventing ignition at its source (Sandhyavitri et al., 2023).

5. Corporate Commitments Are Credible Only When They Change Operations

The fifth finding is that voluntary pledges can help extend environmental rules through supply chains but can also obscure material differences between a statement and a result. Studies of implementation reveal variations in monitoring, supplier engagement and verification mechanisms among companies making zero-deforestation commitments (Bager and Lambin, 2022). In Indonesian oil palm, goal-based governance may create contradictions when aspirational targets meet uneven monitoring capacity, contested land status and complex supplier relationships (Grabs and Garrett, 2023). Cross-temporal credibility therefore depends on measurable interim targets, consistent disclosures and consequences when declared goals are missed (Grabs, 2023).

The potential value of corporate governance lies in capabilities that exceed the reach of any one inspection: mapping supply chains, financing safer land preparation, requiring preparedness from contractors, managing hydrological infrastructure and providing standardized incident records. However, companies should not be permitted to rely on certification statements as conclusive evidence of compliance, nor should regulators ignore verified investments because an unrelated operator is accused. Research on competing state and private governance expectations suggests that organizations must navigate simultaneous regulatory and market pressures, sometimes producing inconsistent incentives (Dermawan, Hospes and Termeer, 2022; Purnomo et al., 2023). This tension warrants attention to leakage and exclusions. A purchasing rule that disengages from high-risk suppliers without supporting improved practices can move damaging land-use activities outside auditable chains. Modeled indirect effects of zero-deforestation commitments show why system boundaries matter; supplier relationships and external land markets must be considered alongside an individual firm's declared footprint (Leijten et al., 2023). A credible corporate program would therefore report not only its own certified hectares or absence of documented fire, but also contractor oversight, supplier engagement, remediated incidents, local grievance resolution and evidence of avoided rather than displaced risk.

6. Community Participation and Distributive Justice Are Necessary For Durable Prevention

The sixth theme concerns social legitimacy. Fire governance fails when it reduces community members to possible ignition sources while overlooking their exposure to smoke, land insecurity, restoration restrictions and transition costs. Analysis of farmers in tropical peatlands identifies multiple burdens arising when mitigation is pursued without adequate livelihood consideration (Merten et al., 2021). Household vulnerability studies in South Sumatra and spatial vulnerability mapping indicate that income, adaptive capacity, infrastructure access and fire exposure vary across settlements; a uniform village-level restriction can therefore produce unequal consequences (Yazid et al., 2024; Lee et al., 2025).

There is growing evidence that prevention can improve through participatory learning and economic alternatives. Community-based action research in Riau identifies local demand, political support, institutional leadership and sustainable livelihood business models as conditions supporting collective action (Purnomo et al., 2024). Research on knowledge systems argues that environmental programs benefit from integrating local and scientific forms of evidence, while studies of community education emphasize the role of credible awareness and engagement (Robins et al., 2022; Syahza et al., 2024). These conclusions should not be idealized: participation without resources, rights recognition or influence over decisions risks becoming ceremonial rather than transformative.

Restoration goals are themselves negotiated. Research into definitions of ecological restoration finds that stakeholders emphasize different desired outcomes, while national-level perspectives reveal potentially divergent interpretations of success and acceptable land uses (Puspitaloka et al., 2020; Ward et al., 2020). Analysis of alternative governance and cost arrangements, together with recent multistakeholder work on multifunctional peat landscapes, suggests that fair negotiation must include livelihood and ecological functions within a shared planning space (Puspitaloka et al., 2021; Widayati et al., 2026). Justice is thus not an optional social safeguard attached after technical planning. It is a condition for achieving lasting behavioral and ecological changes.

DISCUSSION

1. Resolving the Accountability Paradox

The synthesized literature points to an apparent paradox: vigorous enforcement is demanded because fires cause serious harm, but haste and weak attribution can damage the fairness and credibility on which enforcement ultimately depends. The paradox dissolves when two objects of accountability are distinguished. The first is event-specific culpability: whether identifiable conduct initiated unlawful burning or otherwise satisfies an established legal claim. The second is governance performance: whether an actor with legally relevant duties managed foreseeable risk and responded appropriately. The questions can overlap but need not have the same answer. A landholder may not be the proven igniter yet may possess independently assessable preventive obligations; another actor may ignite an unlawful fire on land over which it has no management rights. The relevant findings depend on evidence and law rather than rhetorical allocation of blame (Astuti and Fatimah, 2024; Resosudarmo, Tacconi and Waluyo, 2023).

This formulation avoids two symmetrical mistakes. One mistake treats location alone as liability, thereby substituting cartography for proof of acts, omissions and their legally relevant connections. The other treats the absence of a named arsonist as a complete defence against every possible governance failure. Neither inference follows from the social–ecological evidence, which makes clear that risk production is distributed across drainage, climate, land management and incentives (Salmayenti et al., 2025; Horton et al., 2021). Nor should the distinction be interpreted as a claim that all legal forums have identical burdens of proof. The governing legal provisions, administrative

standards, causation rules and available remedies must be specified for each case before penalties or restoration obligations are determined.

A third risk is performative neutrality. Calls for fairness can be used sincerely to resist unsupported allegations, but they can also become a tactic to delay scrutiny or cast unwarranted doubt on well-grounded expert evidence. The study of scientific testimony in plantation litigation illustrates why the credibility of each expert's methods should be assessed symmetrically, irrespective of who retained the expert (Astuti and Fatimah, 2024). A credible institution should publish detection metadata, preserve site evidence, disclose uncertainty and allow reasoned challenge. Transparency does not require public disclosure of protected witness details or premature judgments; it requires a reviewable record connecting facts to decisions.

2.. A two-track evidence-to-action governance architecture

Figure 3 brings the six thematic findings together into a proposed architecture. Track A comprises the event investigation and legally specific determination of responsibility. Track B comprises preventive capacity and ecological risk reduction. Shared information systems support both tracks, but the sanctions for proven violations are not replaced by informal dialogue, and remedial investments do not establish innocence for a separate unlawful act. A coordinating layer sets transparent standards, independent auditing, public reporting and dispute-resolution mechanisms. This separation of functions is designed to reduce politically convenient shortcuts and to improve the quality of decisions over time (Astuti, 2020; Grabs and Garrett, 2023; Robins et al., 2022).



Figure 3. Proposed Two-Track Governance Architecture Linking Due Process With Preventive Performance and Collaborative Learning (Authors' Conceptual Synthesis)

Public reporting should preserve distinctions between observed data and legal findings. For instance, a regulator can publish that an inspection occurred, that a water-management plan was inadequate or that an investigation remains unresolved, without claiming an adjudicated finding of intentional ignition. An enterprise can disclose investment, non-compliance correction and independently measured ecological improvements without portraying self-reported "fire-free" years as categorical proof of innocence. Community participants should have access to understandable information, appeals and grievance channels. These practices operationalize the procedural dimension of fairness while retaining firm expectations of conduct (Astuti and Fatimah, 2024; Grabs and Garrett, 2023; Widayati et al., 2026). Figure 4 explicitly treats the caution column as part of the evaluation design: stronger detection does not prove culpability; greater spending does not itself establish reduced risk; ecological change must be interpreted against climate and land-cover baselines; and participation never displaces statutory duties. The bottom verification principle identifies four minimum safeguards that should accompany any comparative performance statement.

6. A Differentiated Policy Agenda for Major Stakeholder Groups

For regulators, the immediate priority is an evidence protocol distinguishing alert, investigation, temporary protection measures, administrative findings and final legal determinations. Training should integrate geospatial uncertainty, field verification, hydrological expertise, documentation standards and transparent expert selection. A second priority is consistent oversight of preventive duties across firms and relevant non-corporate actors, with inspections targeted at risk yet protected against selective enforcement. Comparative work on no-burning compliance and the political dimensions of plantation governance supports this two-pronged approach (Resosudarmo, Tacconi and Waluyo, 2023; Astuti, 2021). For plantation companies, the priority is an auditable chain from board-level commitment to operational evidence. This would include mapped management responsibility, transparent water-management procedures, verified contractor instructions, documented emergency response, supplier monitoring, maintenance budgets and independent remediation review. Disclosure needs to recognize uncertainty and adverse findings rather than select only favorable metrics. A strong program should demonstrate that prevention survives personnel turnover, commodity-price pressures and shifts in supply-chain demand (Dermawan, Hospes and Termeer, 2022; Bager and Lambin, 2022; Grabs, 2023). For local governments and communities, priorities include negotiated hydrological management, culturally and economically workable no-burn alternatives, access to alert information and locally managed but adequately resourced response capacity. Community education should be linked to practicable land-preparation technology and credit rather than delivered as a substitute for material assistance. Research on local education, participatory restoration and multifunctional planning indicates that local institutions are stronger when they have real influence over implementation

and recognizable benefits from avoided fire (Syahza et al., 2024; Purnomo et al., 2024; Widayati et al., 2026).

For scientific organizations and courts, the priority is epistemic accountability. Independent or court-appointed expertise, reproducible methods, disclosed model assumptions and adversarial scrutiny of interpretations are indispensable where evidence is contested. Scientific institutions should state the resolution and uncertainty of satellite products, the limits of retrospective ignition reconstruction and the conditions under which an estimated restoration effect applies. The relevant lesson of the Indonesian expert-witness literature is not that experts should be excluded, but that their epistemic work requires institutional safeguards against motivated interpretation (Astuti and Fatimah, 2024).

7. Research gaps, limitations and future directions

Several unanswered questions deserve comparative investigation. First, how much additional inferential value results from integrating high-resolution imagery, time-stamped community observations, canal maintenance records and field-based burn-pattern evidence? Such research should test whether multimodal data improve factual accuracy without raising risks of surveillance or erroneous accusation. Second, how do different legal enforcement strategies influence both deliberate ignition and investment in preventive capacity? Econometric studies of externalities offer useful starting points, but a complete evaluation must also observe administrative burden and distributive effects (Balboni, Burgess and Olken, 2026; Indradjad et al., 2024).

Third, prevention studies should measure not only average intervention effects but their heterogeneity by peat condition, land ownership, climatic year and community livelihood system. The latest restoration findings show the importance of counterfactual design and caution against mechanically extrapolating a successful site to all Indonesian peatlands (Castro et al., 2026; Salmayenti et al., 2026). Fourth, research on corporate promises should track whether improvements persist through supplier turnover and whether exclusion policies displace risk. Fifth, comparative justice studies should quantify who pays for no-burn transitions and who receives the benefits of cleaner air, fewer fires and improved livelihoods (Merten et al., 2021; Lee et al., 2025).

The present synthesis has important limits. It cannot establish case-specific guilt, provide binding interpretations of Indonesian legal doctrine, estimate a new national trend or claim causal effects beyond those demonstrated by individual studies. Its purposive QLR design is interpretive rather than exhaustive; publication selection and thematic judgments may influence emphasis. Research concentration in particular provinces, peat types and intervention settings constrains generalizability. These limitations suggest a future program combining doctrinal legal analysis, matched comparisons of preventive investments, ethnographic attention to local institutions and cross-sector administrative-data linkage, subject to appropriate privacy and procedural safeguards.

CONCLUSIONS AND RECOMMENDATIONS

The principal conclusion is that firm sanctions against proven wrongdoing and fair treatment of the oil-palm sector are not competing principles. They become incompatible only when responsibility is assigned through unsupported generalization or when procedural safeguards are invoked to evade demonstrable duties. Indonesian landscape fires are produced by interacting climatic, hydrological, ecological and socioeconomic processes, so the relevant object of governance cannot be reduced either to a hotspot inside a polygon or to the identity of a single landholder. A defensible institutional model must establish who did what, what duties applied, which evidence supports each inference and what preventive conditions need correction.

The proposed two-track framework separates event-specific attribution from forward-looking preventive performance while creating common standards for evidence management, transparency and learning. It also emphasizes shared but differentiated responsibilities: public agencies must investigate and enforce, companies must manage the risks within their control, communities must be supported rather than merely instructed, and scientific institutions must make uncertainty and potential conflicts of interest visible. Hydrologically informed peat management, timely response and credible no-burn alternatives should operate as an integrated portfolio, with outcomes verified against climatic variation and appropriate comparison settings.

A practical reform sequence has five components. Authorities should first establish explicit evidentiary thresholds for alerts, investigations and sanctions. They should then implement auditable preventive-duty standards appropriate to land and infrastructure control; prioritize landscape-scale hydrological and operational risk reduction; finance inclusive livelihood transitions and credible local participation; and publish independent, outcome-oriented performance reports. These reforms should be adjusted over time through transparent evaluation rather than judged only by announcements, expenditure or short periods without detected fire.

Ultimately, responsible fire governance is neither an exercise in defending a sector nor one of condemning it collectively. It is a system for establishing demonstrable responsibility, reducing foreseeable harm and ensuring that ecological protection and procedural fairness reinforce one another. Such a system makes prevention a permanent institutional duty rather than an emergency reaction and treats evidence as the basis for accountability rather than as an instrument of predetermined blame.

FURTHER STUDY

This research still has limitations, so further studies are needed on the topic of Evidence Before Attribution, Prevention Before Crisis: Fair Accountability and Collaborative Fire Governance in Indonesia's Oil-Palm and Peatland Landscapes to improve this research and broaden insights for the author and readers

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