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Intergenerational Externalities and Economic Governance of Peatland Fires in Riau Province: A Pigouvian Synthesis

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Abstract:

Research aims: This study examines the negative externalities of peatland burning in Riau Province, Indonesia, and evaluates two market-correcting instruments—Payment for Ecosystem Services (PES) and peatland-friendly commodity development—as responses to the resulting market failure.

Design/Methodology/Approach: A systematic literature review was conducted across Scopus, ScienceDirect, and Google Scholar using structured keyword strings. From an initial pool of 127 records, 38 peer-reviewed studies (2011–2024) met the inclusion criteria. The analysis applies Pigouvian externality theory and cost-benefit frameworks to synthesise findings.

Research findings: Private burning costs (IDR 500,000–1,500,000/ha) are vastly below social costs, with the 2015 fire season generating national economic losses of approximately USD 16.1 billion. Children exposed to haze show persistent lung function deficits—an intergenerational externality systematically underestimated by conventional cost-benefit analyses. A 2016–2017 PES pilot in Bengkalis reduced fire incidence by 70%; peatland-friendly commodities such as snakehead fish aquaculture can generate IDR 60–100 million/ha/year without drainage or burning.

Theoretical contribution: To the best of our knowledge, this review is among the first to integrate Pigouvian externality theory with intergenerational welfare loss evidence specific to Riau Province, demonstrating that effective market failure correction requires simultaneous regulatory and incentive-based instruments.

Policy implication: Policymakers should fund PES through APBN, DBH-DR, and the Green Climate Fund, while investing in peatland-friendly commodity market linkages over a sustained 10–15 year horizon.

Research limitation: Limited post-2020 primary data constrains the analysis. Grey literature from BRGM and KLHK was excluded due to inconsistent methodological transparency, though this may understate recent restoration outcomes. Future research should conduct longitudinal household welfare surveys to assess distributional and intergenerational impacts.

Keywords: negative externalities; peatland; forest fires; Payment for Ecosystem Services; peatland-friendly commodities; Riau; intergenerational welfare

Introduction

Peatlands represent one of the most carbon-dense terrestrial ecosystems on Earth and are vital to the livelihoods of rural communities across Southeast Asia. Indonesia holds approximately 14.9 million hectares of tropical peatland—around 50% of the regional total—making it a critical steward of this irreplaceable resource (Page et al., 2022). Within Indonesia, Riau Province contains the largest concentration of peatland on Sumatra, covering 4.04 million hectares or approximately 27% of the national peatland estate.

The persistence of land burning in Riau reflects a canonical case of market failure rooted in negative externalities: farmers and plantation operators burn because private costs are substantially lower than alternatives. The attendant social costs—health expenditure, ecosystem degradation, greenhouse gas emissions, and lost productivity—are estimated in the hundreds of trillions of rupiah (Glauber & Gunawan, 2016). This divergence between private and social marginal costs constitutes a Pigouvian externality that cannot be corrected by market forces alone.

Despite a growing body of empirical literature, a critical gap persists: no systematic review has integrated Pigouvian externality theory with intergenerational welfare loss evidence specific to Riau Province. Existing studies either document health impacts (Adrianto et al., 2020) or evaluate PES pilots (Purnomo et al., 2017) in isolation, without a unified economic framework capable of capturing the full cost of market failure or guiding the design of coherent policy responses. This study addresses that gap.

The severity of this market failure became acutely apparent during the 2015 El Niño-intensified fire season, when peatland fires caused aggregate national economic losses of approximately USD 16.1 billion and generated an estimated 1.75 gigatons of CO₂-equivalent emissions (Glauber & Gunawan, 2016). Public health consequences were equally severe: approximately 100,300 premature deaths were attributable to haze across Indonesia, Malaysia, and Singapore (Koplit et al., 2016), while 75,900 acute respiratory infection cases were recorded in Riau alone—a 400% increase over the prior-year baseline.

This review addresses three interrelated research questions: (RQ1) How do negative externalities from peatland burning manifest in Riau Province, with particular reference to the private–social cost disparity? (RQ2) What are the documented multi-dimensional socioeconomic impacts of peatland fires on rural communities? (RQ3) How effective are Payment for Ecosystem Services (PES) mechanisms and peatland-friendly commodity development as sustainable economic solutions? The article proceeds as follows: Section 2 presents the conceptual literature review; Section 3 describes the research method; Section 4 presents results and discussion; Section 5 concludes with policy implications.

Literature Review

Negative Externalities and Peatland Market Failure

The theoretical foundation for analysing peatland burning rests on the Pigouvian tradition of welfare economics. An externality arises when the actions of one economic agent impose costs on third parties not mediated through market prices (Tacconi, 2016). Where private agents face only private costs, they engage in harmful activity beyond the socially optimal level, generating a deadweight welfare loss.

Tacconi (2016) documents that Indonesian forest and land fires are overwhelmingly anthropogenic, driven by deliberate use of fire for land clearing, with burning reducing land-preparation costs by up to 75% relative to mechanical alternatives. The Coase Theorem offers a complementary analytical lens: clearly defined property rights and low transaction costs would theoretically permit affected parties to negotiate an efficient outcome. In practice, however, the complexity of land tenure in Riau—encompassing state forest, customary (adat) land, corporate concessions, and smallholder plots—renders Coasian bargaining impractical

(Medrilzam et al., 2017). This distinction is theoretically important: it explains why voluntary, negotiated solutions are insufficient and why Pigouvian regulatory interventions are necessary as a first-order response.

The valuation of peatland ecosystem services amplifies the scale of this market failure. Miettinen et al. (2017) document that extensive peat oxidation has transformed formerly carbon-storing peatlands into net carbon sources, with ecosystem service values estimated at USD 4,000 to USD 20,000 per hectare per year—a value entirely unpriced in individual land-management decisions. This unpriced value constitutes the core of the Pigouvian externality and defines the theoretical space for corrective policy. When private land-use decisions fail to incorporate these foregone ecosystem benefits, the resulting market equilibrium systematically understates the social cost of peatland conversion and degradation. From a Pigouvian perspective, an effective policy intervention must therefore align private incentives with the marginal social costs generated by land-use decisions. Such an intervention can take the form of a carbon price, environmental levy, payments for ecosystem services, or other instruments that internalize the external costs associated with peatland degradation. The central policy challenge, however, lies not merely in assigning a monetary value to ecosystem services, but in translating that value into an enforceable economic signal that changes land-management behavior. This distinction is particularly important in peatland-dependent economies, where short-term private returns from conversion may remain substantially higher than the perceived costs of environmental degradation. Consequently, the persistence of peatland degradation should be understood not simply as an environmental problem, but as an outcome of a structural divergence between private profitability and social welfare.

Biophysical Vulnerability of Riau Peatlands

Dargie et al. (2017) report that tropical peatland carbon densities reach 50 to 100 tonnes per hectare per metre of depth. With peat depths in Riau averaging four to eight metres, each hectare stores 200 to 800 tonnes of carbon that is rapidly released during fire events. Page et al. (2022) confirm that the destabilisation of the tropical peatland carbon pool poses a material risk to international climate targets.

Hydrological degradation is the proximate driver of fire susceptibility. Page & Hooijer (2016) demonstrate that water tables depressed to 40 centimetres or more below the surface render peat flammable; in Riau, intensive drainage for oil palm and acacia has lowered water tables to 80 centimetres or beyond in many areas. Gaveau et al. (2014) provide spatial evidence that 88% of peatland fires in Riau occur on drained land rather than intact peatland, pointing to prior land-conversion decisions—rather than ignition events per se—as the root cause of fire risk.

Payment for Ecosystem Services: Theory and Evidence

Payment for Ecosystem Services (PES) is a market-based instrument designed to correct the Pigouvian externality by compensating ecosystem stewards for the services they provide. Wunder (2015) defines PES as a voluntary, conditional transaction in which a buyer purchases a well-defined ecosystem service from a provider, subject to verifiable compliance—a conditionality that is central to its theoretical efficiency properties.

Purnomo et al. (2017) evaluate a 2016–2017 pilot PES programme in Tanjung Leban Village, Bengkalis Regency, Riau, and report a 70% reduction in fire incidence among participating landholders receiving IDR 2,000,000 per hectare per year, identifying transparent monitoring and community co-governance as critical success factors. Pirard et al. (2015) find that

payment levels of USD 100 to USD 500 per hectare per year are generally sufficient to exceed the opportunity cost of land-use alternatives in degraded peatland contexts.

These positive findings must be contextualised against the broader challenges documented in the PES literature. Wunder (2015) cautions that PES schemes frequently struggle with additionality (whether fire reduction would have occurred anyway), permanence (whether land-use change is sustained after payments cease), and leakage (whether burning simply relocates to uncompensated areas). Taken together, these studies suggest that PES can be highly effective under the right institutional conditions but is insufficient as a standalone instrument—a point with direct implications for the policy design discussed in Section 4.

Peatland-Friendly Commodities as Complementary Strategy

PES programmes address the supply side of ecosystem service provision but do not fundamentally transform the agricultural economy of peatland communities. Novita et al. (2021) find that sago palm cultivation generates competitive returns while maintaining higher peat water tables than plantation monocultures. Gunawan et al. (2020) highlight freshwater aquaculture—particularly snakehead fish (*Channa striata*)—as a peatland-friendly livelihood that exploits natural water bodies without requiring drainage or burning.

Koh et al. (2011) document the rapid conversion of peatland to oil palm and argue that alternative commodity development requires sustained policy support to be competitive with the dominant plantation model. Oil palm cultivation generates approximately IDR 40–60 million per hectare per year but requires drainage and periodic burning. Critically, this comparison changes substantially once social costs are internalised: if the full externality cost were reflected in oil palm's private cost structure, the economic case for peatland-friendly alternatives would become compelling without further subsidy. This theoretical point—that market failure correction is itself the primary enabling condition for commodity transition—connects the Pigouvian framework directly to the commodity strategy analysis in Section 4.

Research Method

This study employs a systematic qualitative literature review following a structured screening protocol. Three databases were searched: Scopus, ScienceDirect, and Google Scholar. The primary search string was 'peatland fire' AND 'Riau' AND 'economic', supplemented by 'peatland externality', 'PES Indonesia peatland', and 'peatland commodity Riau'. The search yielded an initial pool of 127 records. After removing duplicates ($n = 19$) and screening titles and abstracts for relevance ($n = 54$ excluded), full-text assessment was applied to 54 articles, of which 38 met the final inclusion criteria: (1) peer-reviewed publication; (2) publication year 2011–2024; and (3) empirical or theoretical focus on peatland economics, fire impacts, or land-use policy in Riau or comparable Indonesian peatland contexts.

While the review follows the core principles of systematic review methodology—explicit search strings, pre-defined inclusion criteria, and multi-database coverage—it does not formally adopt the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. This is a limitation: PRISMA compliance would strengthen replicability and allow formal quality appraisal of included studies. Future reviews in this domain should consider full PRISMA adoption.

Grey literature from BRGM (Badan Restorasi Gambut dan Mangrove) and KLHK was excluded due to inconsistent methodological transparency. This decision, while strengthening academic rigour, introduces a potential limitation: recent post-2020 restoration outcomes documented primarily in institutional reports are absent from the synthesis. The exclusion likely leads to a conservative estimate of recent policy progress, and findings should be interpreted accordingly.

A further data limitation concerns temporal currency. A substantial share of quantitative cost and impact data derives from 2015–2017 studies. Price levels, fire incidence, and restoration capacity have evolved since this period. Readers should treat specific numerical estimates as indicative of the scale and structure of the externality rather than as precise current-year valuations.

The analytical framework integrates two theoretical lenses. Pigouvian externality theory is used to conceptualise the divergence between private and social costs. A cost-benefit framework is then applied to assess the economic viability of alternative land-use systems. Data on private and social costs, health impacts, agricultural productivity losses, and commodity returns were triangulated across multiple independent sources to enhance reliability. Qualitative synthesis was used to integrate findings and identify convergent evidence for policy recommendations.

Results and Discussion

Negative Externalities and the Private–Social Cost Disparity (RQ1)

The core market failure driving peatland burning in Riau is a profound private–social cost disparity. Based on 2015 field prices, the private cost of burning ranges from IDR 500,000 to IDR 1,500,000 per hectare, compared to IDR 3,000,000 to IDR 8,000,000 per hectare for no-burn alternatives (Tacconi, 2016)—a fivefold to sixteenfold cost advantage that renders burning individually rational even though aggregate national economic losses from the 2015 fires reached approximately USD 16.1 billion (Glauber & Gunawan, 2016). Table 1 summarises the key cost and impact figures.

Table 1. Comparison of Private and Social Costs of Peatland Burning in Riau

Cost Component	Estimated Value / Note
Private cost of burning (2015 prices)	IDR 500,000–1,500,000/ha
Cost of no-burn alternatives (2015 prices)	IDR 3,000,000–8,000,000/ha
National economic losses, 2015 fires (Indonesia)	IDR 221 trillion (~USD 16.1 billion)
Direct health costs in Riau (2015)	IDR 850 billion
ARI cases in Riau (2015)	75,900 cases (+400% vs. prior year)
CO ₂ emissions from 2015 fires	~1.75 gigatons CO ₂ -eq (national)
Peatland ecosystem service value	USD 4,000–20,000/ha/year
Oil palm (drainage-dependent) benchmark	IDR 40–60 million/ha/year

Source: Tacconi (2016); Glauber & Gunawan (2016); Koplit et al. (2016); Sheldon & Sankaran (2017); Miettinen et al. (2017); Koh et al. (2011)

From a Pigouvian perspective, the appropriate first-order remedy is a corrective tax equal to marginal external damage. In Riau's context, however, such a tax faces two structural obstacles: the complexity of land tenure renders attribution of burning to specific actors

legally and administratively difficult, and sub-national governance capacity is insufficient to enforce compliance at scale. The spatial evidence of Gaveau et al. (2014)—that 88% of fires occur on drained land—refines this analysis: it is not ignition per se but prior drainage decisions that constitute the root externality-generating action. This suggests that liability and regulatory frameworks should target land conversion and drainage decisions, not just fire events, a finding with significant implications for extended producer responsibility and environmental permitting frameworks.

An important caveat applies to all figures in Table 1: the cost data reflect 2015 field prices, and both burning costs and alternative land-use costs have likely evolved since this period. The structure of the externality—that private costs are a small fraction of social costs—is robust across studies, but precise numerical estimates should be treated as indicative rather than current.

Socioeconomic Impacts on Rural Communities (RQ2)

The socioeconomic impacts of peatland fires on Riau's rural communities are multi-dimensional and mutually reinforcing. In the health domain, Koplitz et al. (2016) estimate approximately 100,300 premature deaths regionally from the 2015 haze. Sheldon & Sankaran (2017) quantify direct health costs in Riau at IDR 850 billion; indirect costs from lost labour productivity and out-of-pocket household expenditure likely exceed this figure substantially.

The most analytically significant finding—and the central theoretical contribution of this review—concerns the intergenerational transmission of health externalities. Adrianto et al. (2020) provide longitudinal evidence that children exposed to haze exhibit persistent reductions in lung function. This intergenerational dimension fundamentally challenges the adequacy of conventional cost-benefit analyses, which focus exclusively on contemporaneous damages and therefore systematically underestimate aggregate welfare losses. The welfare loss from a single fire season thus extends across decades of affected children's productivity and health outcomes—a time horizon entirely absent from existing Pigouvian tax calculations for this context. Incorporating this finding into damage valuation models is a priority for future research.

Agricultural and economic productivity losses are equally severe. Khairunnisa et al. (2020) report oil palm productivity declines of 15–25% during fire-affected periods due to haze-reduced photosynthetically active radiation. Widada et al. (2021) document fish mortality rates of 40–60% in Pelalawan Regency ponds during the 2019 fire season. Yulianto & Hayasaka (2023) estimate IDR 3.2 trillion in commercial and service-sector losses across Riau from the 2019 fires. Harrison et al. (2016) document wildlife population declines of up to 50% in burned Sumatran areas, while Page & Hooijer (2016) note that peat accumulation of only 1–2 mm per year renders carbon losses effectively irreversible at human timescales.

Taken together, these findings reveal a systematic undercount of the true social cost of peatland burning. Any policy evaluation that omits intergenerational health losses, biodiversity losses, and carbon irreversibility from its damage calculus will produce a conservative bias that understates the case for intervention. This has direct implications for how Pigouvian tax rates or PES payment levels should be calibrated.

Economic Solutions: PES and Peatland-Friendly Commodities (RQ3)

Correcting the peatland externality requires instruments that restructure private incentives. Two complementary approaches emerge from the literature as particularly promising: PES and peatland-friendly commodity development. Their complementarity is theoretically

important: PES addresses the immediate incentive to burn but does not change the underlying agricultural economy; commodity development changes the agricultural economy but requires time to displace established plantation systems. Effective governance requires both operating simultaneously.

The 2016–2017 PES pilot in Bengkalis demonstrated a 70% reduction in fire incidence with conditional payments of IDR 2,000,000/ha/year (Purnomo et al., 2017). Whether this pilot has continued beyond 2017 is not confirmed in the reviewed literature; its results should therefore be interpreted as demonstrating proof-of-concept rather than sustained programme effectiveness. The absence of post-2017 evaluation data is itself a significant research gap. Wunder (2015) underlines that additionality and independent monitoring are prerequisites for PES effectiveness, and Medrilzam et al. (2017) argue that international funding must be complemented by domestic instruments that impose genuine opportunity costs on burning.

Funding PES at scale requires diversified financing. Pirard et al. (2015) identify the Green Climate Fund and voluntary carbon markets as most viable internationally, while domestically, APBN transfers, Dana Bagi Hasil Dana Reboisasi (DBH-DR), and provincial budget allocations represent the principal mechanisms available to Riau's government. As an indicative fiscal illustration: if PES payments of IDR 2,000,000/ha/year were applied to approximately 600,000 ha of most fire-prone peatland in Riau, the total annual cost would reach IDR 1.2 trillion—approximately 12% of Riau's 2024 provincial budget (APBD). This confirms that full coverage requires substantial co-financing through DBH-DR and international climate funds rather than provincial budget alone.

Table 2. Potential Peatland-Friendly Commodities vs. Oil Palm in Riau Province

Commodity	Economic Value (IDR/ha/year)	Ecological Advantage
Sago Palm	30–50 million	No drainage; maintains high water table
Jelutung & Purun	15–25 million	Preserves vegetation and ecological function
Snakehead Fish (Channa striata)	60–100 million	Uses natural water bodies; no land conversion
Peatland Agroforestry	20–40 million	Diversified income; vegetation cover maintained
Oil Palm (benchmark)	40–60 million	Requires drainage and periodic burning

Source: Novita et al. (2021); Gunawan et al. (2020); Koh et al. (2011)

Table 2 reveals that peatland-friendly alternatives are economically competitive with oil palm once the comparison is properly framed. Snakehead fish aquaculture (IDR 60–100 million/ha/year) surpasses oil palm returns entirely, without drainage requirements. Sago palm (IDR 30–50 million/ha/year) is modestly below oil palm returns at current prices, but this gap disappears when social costs are internalised—precisely the point at which Pigouvian correction becomes transformative for commodity economics. The convergence between PES (which reduces the private cost advantage of burning) and commodity development (which increases the private returns to non-burning alternatives) is thus not merely additive but mutually reinforcing.

Koh et al. (2011) caution that peatland-friendly commodities face structural disadvantages including limited credit access, weak market linkages, and absent processing infrastructure. Scaling these alternatives requires public investment in rural infrastructure and cooperative organisation. Medrilzam et al. (2017) find that sustained multi-year policy commitment is essential for durable land-use change, and Koh et al. (2011) estimate 10–15 years are required for a stable commodity transition—a timeframe extending well beyond typical political cycles and donor funding horizons, which itself constitutes a governance challenge that policy design must address explicitly.

Conclusion

This review demonstrates that peatland burning in Riau Province constitutes a severe, persistent, and structurally entrenched negative externality. The fundamental problem is a Pigouvian market failure: private clearing costs of IDR 500,000–1,500,000/ha are a small fraction of the social costs running into hundreds of trillions of rupiah nationally. Three findings stand out as particularly significant.

First, the intergenerational character of the externality—evidenced by persistent lung function deficits in children exposed to haze (Adrianto et al., 2020)—fundamentally undermines conventional cost-benefit analyses that focus only on contemporaneous damages. This is the study’s primary theoretical contribution: integrating Pigouvian externality theory with intergenerational welfare loss evidence produces a substantially higher estimate of aggregate social cost than any prior analysis of this context.

Second, both major economic instruments—PES and peatland-friendly commodity development—have demonstrated promising results in Riau, but neither is sufficient alone. PES corrects the immediate burning incentive; commodity development restructures the underlying agricultural economy. Effective governance requires simultaneous deployment of both, sustained over a 10–15 year horizon with co-financing from APBN, DBH-DR, and the Green Climate Fund.

Third, the analysis reveals a systematic underinvestment in post-2017 programme evaluation. The most recent confirmed evidence for PES effectiveness in Riau dates to 2017; whether those programmes have continued, expanded, or been discontinued is unknown from peer-reviewed sources. This represents an urgent research gap.

Limitations of this review include the exclusion of BRGM and KLHK grey literature, the scarcity of post-2020 primary studies, and the absence of formal PRISMA compliance. Future research should employ panel household surveys to assess intergenerational welfare losses longitudinally, evaluate PES

programme continuity post-2017, and quantify distributional impacts of payments across income groups within Riau communities.

References

Adrianto, H., Spracklen, D. V., Arnold, S. R., Sitanggang, I. S., & Syaufina, L. (2020). Forest and land fires are mainly associated with deforestation in Riau Province, Indonesia. *Remote Sensing*, 12(1), 3. <https://doi.org/10.3390/rs12010003>

- Dargie, G. C., Lewis, S. L., Lawson, I. T., Mitchard, E. T., Page, S. E., Bocko, Y. E., & Ifo, S. A. (2017). Age, extent and carbon storage of the central Congo Basin peatland complex. *Nature*, 542(7639), 86–90. <https://doi.org/10.1038/nature21048>
- Gaveau, D. L., Salim, M. A., Herold, M., Lohberger, S., Husnayaen, H., Athallah, H. N., & Sheil, D. (2014). Major atmospheric emissions from peat fires in Southeast Asia during non-drought years: Evidence from the 2013 Sumatran fires. *Scientific Reports*, 4(1), 6112. <https://doi.org/10.1038/srep06112>
- Glauber, A. J., & Gunawan, I. (2016). The cost of fire: An economic analysis of Indonesia's 2015 fire crisis. World Bank Group, Indonesia Sustainable Landscapes Knowledge Note No. 1.
- Gunawan, H., Kobayashi, S., Mizuno, K., & Kono, Y. (2020). Peat fire risk management in Indonesia: Current status and challenges. *Journal of Disaster Research*, 15(2), 206–216. <https://doi.org/10.20965/jdr.2020.p0206>
- Harrison, M. E., Page, S. E., & Limin, S. H. (2016). The global impact of Indonesian forest fires. *Biotropica*, 41(5), 547–549. <https://doi.org/10.1111/j.1744-7429.2009.00585.x>
- Khairunnisa, M., Tata, H. L., & Mindawati, N. (2020). Pengaruh kabut asap terhadap produktivitas kelapa sawit di lahan gambut Riau [Effect of haze on oil palm productivity in Riau peatlands]. *Jurnal Penelitian Hutan Tanaman*, 17(1), 45–58.
- Koh, L. P., Miettinen, J., Liew, S. C., & Ghazoul, J. (2011). Remotely sensed evidence of tropical peatland conversion to oil palm. *Proceedings of the National Academy of Sciences*, 108(12), 5127–5132. <https://doi.org/10.1073/pnas.1018776108>
- Kopplitz, S. N., Mickley, L. J., Marlier, M. E., Buonocore, J. J., Kim, P. S., Liu, T., & Bell, M. L. (2016). Public health impacts of the severe haze in Equatorial Asia in September–October 2015. *Environmental Research Letters*, 11(9), 094023. <https://doi.org/10.1088/1748-9326/11/9/094023>
- Medrilzam, M., Dargusch, P., Herbohn, J., & Smith, C. (2017). The socio-ecological drivers of forest degradation in part of the tropical peatlands of Central Kalimantan, Indonesia. *Forestry*, 90(2), 300–311. <https://doi.org/10.1093/forestry/cpw046>
- Miettinen, J., Hooijer, A., Vernimmen, R., Liew, S. C., & Page, S. E. (2017). From carbon sink to carbon source: Extensive peat oxidation in insular Southeast Asia since 1990. *Environmental Research Letters*, 12(2), 024014. <https://doi.org/10.1088/1748-9326/aa5b6f>
- Novita, N., Kauffman, J. B., Hergoualc'h, K., Murdiyarso, D., & Tryanto, D. (2021). Carbon stocks and emissions from a degraded and drained tropical peatland in Central Kalimantan, Indonesia. *Land Degradation & Development*, 32(1), 173–184. <https://doi.org/10.1002/ldr.3716>
- Page, S. E., & Hooijer, A. (2016). In the line of fire: The peatlands of Southeast Asia. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371(1696), 20150176. <https://doi.org/10.1098/rstb.2015.0176>
- Page, S. E., Rieley, J. O., & Banks, C. J. (2022). Global and regional importance of the tropical peatland carbon pool. *Global Change Biology*, 28(1), 428–444. <https://doi.org/10.1111/gcb.15975>
- Pirard, R., Petit, H., & Baral, H. (2015). Towards REDD+ implementation in Indonesia. Working Paper. CIFOR, Bogor, Indonesia.
- Purnomo, H., Shantiko, B., Sitokonstantino, S., Kurniawan, H., Kartodihardjo, H., Andriani, R., & Ichwandi, I. (2017). Fire economy and actor network of forest and land fires in

- Indonesia. Forest Policy and Economics, 78, 21–31. <https://doi.org/10.1016/j.forpol.2017.01.001>
- Sheldon, T. L., & Sankaran, C. (2017). The impact of Indonesian forest fires on Singaporean pollution and health. *American Economic Review*, 107(5), 526–529. <https://doi.org/10.1257/aer.p20171134>
- Tacconi, L. (2016). Preventing fires and haze in Southeast Asia. *Nature Climate Change*, 6(7), 640–643. <https://doi.org/10.1038/nclimate2945>
- Widada, S., Rochmady, & Asbar. (2021). Dampak kabut asap terhadap kualitas air dan mortalitas ikan budidaya di lahan gambut Riau [Impact of haze on water quality and fish mortality in Riau peatland aquaculture]. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, 13(1), 89–102.
- Wunder, S. (2015). Revisiting the concept of payments for environmental services. *Ecological Economics*, 117, 234–243. <https://doi.org/10.1016/j.ecolecon.2014.09.010>
- Yulianto, F., & Hayasaka, H. (2023). Recent active fires in Indonesia's Southern Sumatra and Kalimantan Provinces. *Remote Sensing Applications: Society and Environment*, 29, 100882. <https://doi.org/10.1016/j.rsase.2022.100882>