International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 13; Issue: 11; November 2026
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Renewable Energy Transition and Biodiversity Conservation in Indonesia: A Review of Ecological Impacts, Spatial Planning and Governance, with Implications for Gorontalo

Sudarmanto Hasan[1], Dewi K. Baderan[2], Sukirman Rahim[3], Marini Susanti[4], Asda Rauf[5]

[1]Doctoral Program in Environmental Science, Universitas Negeri Gorontalo, Gorontalo, Indonesia,
[2,3,4,5]Postgraduate Program, Universitas Negeri Gorontalo, Gorontalo, Indonesia.

Corresponding Author: Sudarmanto Hasan

DOI: https://doi.org/10.52403/ijrr.20261111

ABSTRACT

Indonesia is building its energy transition in one of the most biodiverse places on Earth, yet the people who site power plants and the people who plan protected areas rarely read each other's work. We set out to bring these two literatures together, with a close look at Sulawesi and Gorontalo in the Wallacea region. Six Scopus searches (2021–2026, English-language articles and reviews) returned 1,181 records. After removing duplicates we screened 1,072 against explicit criteria and retained 220, of which 106 form the core corpus. We grouped the evidence into five themes: ecological impacts of renewable energy and transition minerals, renewable energy (RE) siting, land competition, conservation planning and governance. Studies of hydropower, geothermal plants and nickel mining document fragmentation, forest loss and contamination, but most are short, site-specific and set in Java. Of 36 RE siting studies, only two mention protected areas or biodiversity in their abstracts; the rest treat land cover as a generic criterion. The mirror image holds in conservation science: Marxan, species distribution models and InVEST are well established, yet they almost never model energy infrastructure as a threat. Bioenergy targets and nickel extraction emerge as the heaviest land-use pressures, and geothermal projects in conservation forests keep generating conflict. In Gorontalo, energy-system models, land-use projections and biodiversity surveys all exist, but in parallel. We propose a biodiversity-inclusive spatial optimisation framework that applies ecological exclusions and sensitivity costs before multi-criteria siting and energy-system modelling, and we set out a research agenda for Wallacea.

Keywords: energy transition; biodiversity conservation; spatial planning; multi-criteria decision analysis; Wallacea; Indonesia

INTRODUCTION

Decarbonisation is usually told as a story about technology. On the ground it is just as much a story about land. Solar farms, reservoirs and geothermal wells need space, and the minerals inside batteries come out of forests and hillsides (OECD, 2024). The minerals are a particular concern. A pantropical analysis attributed 3,264 km² of direct tropical-forest loss between 2000 and 2019 to industrial mining; four countries, including Indonesia, accounted for 80% of

that loss, and indirect effects were detected in many of the countries examined (Giljum et al., 2022). Spatial analysis of transition-mineral projects also shows extensive overlap with Indigenous and peasant territories, with more than half of the resource base located on or near such lands (Owen et al., 2023). In parallel, about half of global metal-ore extraction occurs within 20 km of protected areas (Luckeneder et al., 2021). Indonesia is therefore central to the land-use dimension of the transition. Mining-related biodiversity impacts are concentrated in a small group of countries that includes Indonesia (Cabernard & Pfister, 2022), and a newer spatial assessment attributes 57% of global mining-related biodiversity impacts to five countries, again including Indonesia (Yu et al., 2026). Oil palm creates another major land pressure: satellite mapping shows that plantation area reached 16.24 Mha by 2019, roughly twice the 2001 extent, while 3.09 Mha of forest loss over the period was ultimately converted to oil palm (Gaveau et al., 2022). The way Indonesia builds its transition will therefore matter for biodiversity far beyond its own borders.

The country has committed to a 23% renewable share by 2025, 31% by 2050 and net-zero emissions by 2060 (Adiansyah et al., 2025). Getting there involves almost every technology at once: hydropower and pumped storage, geothermal plants on volcanic slopes, solar arrays on land and on water, wind farms, bioenergy from oil palm and woody biomass, and the nickel that feeds battery supply chains (Hyldmo et al., 2025; Pambudi & Ulfa, 2024; Squire et al., 2026). Each of these competes for the same forests, wetlands, rivers and coasts that shelter endemic species. Indonesia's 554 protected areas already cover some 27 million ha (Nugraha et al., 2024), and much of the country's remaining forest biodiversity may survive only inside them (Dwiyahreni et al., 2021). Deciding where new energy infrastructure goes is, in effect, a conservation decision.

These pressures are especially concentrated in Wallacea, and in Sulawesi in particular. Voigt et al. (2021) estimate that Wallacea lost 10,231 km² of forest from 2000 to 2018 and could lose another 49,570 km² by 2053; their analysis identifies small, coastal and unprotected Key Biodiversity Areas as especially vulnerable. Sulawesi is also one of the world's main nickel-producing regions. Deforestation in nickel-mining villages nearly doubled between 2011 and 2018 (Lo et al., 2024), while rising smelter demand is eroding the roughly 30% renewable share of the southern Sulawesi grid (Utomo et al., 2025). Gorontalo, on the island's northern arm, faces the same interacting pressures at an earlier stage. Its energy planning, land-use change and biodiversity have all been studied (Aldiansyah et al., 2024; Lihawa et al., 2026; Salim et al., 2025). This combination makes the province a useful case for testing how those evidence streams can be integrated before major infrastructure decisions are locked in.

Previous reviews have looked at pieces of this puzzle. A PRISMA review of 24 Southeast Asian studies showed that decarbonisation cuts pollution-related health burdens while shifting environmental and social risks elsewhere, but its scope was regional and its evidence base small (Prabowo et al., 2026). A systematic review of 96 papers on palm-oil bioenergy in Indonesia and Malaysia found that research concentrates on land conversion, deforestation and CO_2, and neglects socio-economic questions (Papilo et al., 2022). Other reviews focus on single technologies or debates: palm biodiesel and food versus fuel (Purnama et al., 2025), agrivoltaics (Aziz et al., 2025) and the national geothermal sector (Pambudi & Ulfa, 2024). What none of them does is ask how RE siting, conservation planning and governance interact across technologies within Indonesia, or what the evidence says about Wallacea.

The gap is practical, not only academic. Spatial multi-criteria decision analysis (MCDA) has become the standard way to find RE sites in Indonesia, from micro-hydropower in South Sumatra (Nur et al.,

2021) to floating PV on 92 water bodies (Wu et al., 2026). Systematic conservation planning offers equally mature tools for deciding what to protect, such as Marxan prioritisation for Sulawesi (Pusparini et al., 2023) and the Citarum watershed (Suprajaka et al., 2026). If these two toolkits never meet, energy sites will be chosen without regard to conservation priorities, and conservation plans will overlook the infrastructure most likely to cut them apart.

In this review we bring together research published between 2021 and 2026 on where RE development and biodiversity conservation meet in Indonesia, paying particular attention to Sulawesi and Gorontalo. We ask four questions:

- **RQ1.** What ecological impacts of RE development and transition-mineral extraction have been documented in Indonesia, and how robust is that evidence?
- **RQ2.** To what extent do RE spatial-planning and site-selection studies use biodiversity and protected-area criteria?
- **RQ3.** How do land competition, governance and social acceptance shape the trade-offs between energy and conservation?
- **RQ4.** What do these findings mean for integrated spatial planning in Gorontalo and the wider Wallacea region?

Our contribution is threefold. We map a cross-disciplinary corpus of 220 studies that are rarely read side by side, from bird counts around geothermal plants to legal analyses of geothermal policy. We put a number on a specific blind spot: siting studies seldom use biodiversity criteria, and conservation plans seldom model energy infrastructure. And we propose a biodiversity-inclusive spatial optimisation framework, with a research agenda for Gorontalo that other Wallacean provinces could adopt. The Materials & Methods section describes how the corpus was built; the Results map the corpus and then work through the evidence theme by theme; the Discussion turns to Sulawesi and Gorontalo; and the Conclusion draws the findings together.

MATERIALS & METHODS

Review design

We followed the reporting logic of PRISMA 2020 (Page et al., 2021) for identifying and screening records, and then synthesised the evidence narratively by theme. A meta-analysis was never realistic. The corpus runs from ecology and engineering to economics, law and political science, and its designs and outcomes are too varied to pool. The protocol was not registered.

Data source and search strategy

We searched Scopus on 21 October 2026. We chose it for its coverage of peer-reviewed journals in environmental science, energy and engineering, and because its exports are well structured. Six queries were written to capture different parts of the problem: four national queries (ID-1 to ID-4) and two for Sulawesi and Gorontalo (GR-5 and GR-2). All searched titles, abstracts and keywords (TITLE-ABS-KEY) and were limited to 2021–2026, to articles and reviews, and to English (Table 1). The full query strings are given in Supplementary Material S1.

Table 1. Search queries and the records that remained after each filter.

Query	Focus	Initial hits	2021–2026	Articles & reviews	English (exported)
ID-1	RE × biodiversity and conservation	480	319	195	193
ID-2	RE spatial planning and site suitability	126	96	52	50
ID-3	RE × land-use conflict and protected areas	347	246	181	179
ID-4	Ecosystem services, conservation planning, governance	810	487	400	398
GR-5	RE and spatial development, Gorontalo/Sulawesi	572	312	177	176
GR-2	Conservation and spatial planning, Gorontalo/Sulawesi	455	265	185	185
Total		2,790	1,725	1,190	1,181

The 2021–2026 window covers the period after Indonesia updated its renewable targets and after the post-2020 global biodiversity framework was negotiated. Records for 2026 run only to the search date.

Data processing and deduplication

We exported every query in CSV and RIS format and merged the files in Python (pandas). Duplicates were matched in three passes: Scopus EID, then DOI, then a normalised title (lower case, letters and digits only). This removed 109 duplicates and left 1,072 unique records. All of them had abstracts; 39 lacked a DOI. Overlap between queries was low, which reassured us that the searches were reaching distinct literatures: 975 records (91%) were returned by only one query.

Eligibility criteria

A record was included only if it met all three criteria:

- **I1. Geography:** the study area lies in Indonesia, or Indonesia is analysed explicitly in a multi-country study.
- **I2. Topic:** the study addresses at least one of (a) RE development or transition-mineral extraction with an ecological, land-use or spatial dimension; (b) spatial planning or site suitability of RE; or (c) conservation planning, protected areas, ecosystem services or land-use governance relevant to siting trade-offs.
- **I3. Type:** a peer-reviewed article or review published in English between 2021 and 2026.

We read "renewable energy" broadly. Nickel is not an energy source, but it is the transition mineral that Indonesia's battery and electric-vehicle strategy depends on, and its extraction is now the country's most visible land-use pressure in Wallacea. Oil palm enters the review as the feedstock of the national biodiesel mandate (B35–B50), not as an agricultural commodity in general; records on palm oil were retained only when they addressed bioenergy, biofuel policy or the land demand those targets create. Leaving either out would have hidden the two largest footprints of the transition.

To make every exclusion traceable, each record that failed screening was assigned one primary exclusion code, E1 to E6, where "E" stands for exclusion and the number identifies the reason (Table 2). Where a record could fit more than one code, we recorded the reason that best described why it fell outside the review. The same codes label the exclusion box in the PRISMA flow diagram (Fig. 1) and are used when the excluded literature is discussed in the Results.

Table 2. Exclusion codes used in screening, with the number of records excluded under each.

Code	Reason for exclusion	Typical examples	Records excluded (n)
E1	Study area outside Indonesia	Studies set in other countries with no Indonesian site	10
E2	Laboratory, biochemical or taxonomic work	Catalyst or biofuel-conversion experiments; species descriptions	31
E3	Energy or economic study with no ecological, land or spatial dimension	Grid stability, dispatch, device design, product life-cycle assessment, macro-econometric panels	402
E4	Off-topic for this review	Agronomy, aquaculture, tourism or geological hazards with no planning link	115
E5	Descriptive ecology with no link to spatial planning or energy	Species inventories and population surveys without planning implications	254
E6	Global or regional analysis without results specific to Indonesia	Multi-country assessments that mention Indonesia only in passing	40
Total			852

Screening procedure

Screening used titles, abstracts and author keywords, in two passes. A rule-based pre-screen first flagged each record for geography, technology, and ecological and spatial terms. We then judged every record individually against the criteria and logged the reason for each exclusion. A large language model assisted with screening, and the authors checked its decisions. Each included record was assigned to one primary theme and classed as either core (directly addressing the review questions) or supporting (contextual evidence). All eligibility decisions were made at the level of titles, abstracts and keywords; full texts were not screened.

Data extraction and synthesis

For every included record we coded the study region, the energy technology and the methodological approach from the title, abstract and keywords, using fixed vocabularies: six regions, seven technologies including transition minerals, and ten families of methods ranging from GIS and MCDA to qualitative policy analysis. A record could carry several codes. For the 106 core records we also built an extraction table, drawn from titles and abstracts, covering objectives, data, main quantitative findings, implications for conservation or planning, limitations and relevance to Gorontalo. The synthesis follows the five themes reported in the Results. Within each theme we looked for findings that agree and findings that conflict, and we weighed the strength of each design, distinguishing site monitoring, counterfactual or quasi-experimental analyses, models and qualitative case studies.

Limitations of the approach

Four limitations should be kept in mind. Relying on Scopus alone leaves out national journals indexed elsewhere (SINTA, Garuda) and grey literature such as environmental impact assessments (AMDAL), which hold much of the site-level ecological data. The English-language filter excludes research published in Indonesian. Our exports did not include citation counts or affiliations, so we do not report indicators of influence. Finally, screening, coding and synthesis rest on titles, abstracts and keywords. Full texts were not screened, so the findings reported here reflect what authors state in their abstracts and may miss detail given only in the full papers.

RESULT

Overview of the literature

What the screening left us with

Of the 2,790 records first identified, 1,181 survived the Scopus filters, 1,072 remained once duplicates were removed, and 220 met our criteria (Fig. 1). The two largest groups we set aside tell their own story. Some 402 records were energy studies with no ecological or spatial angle (E3), and 254 were ecological studies with no link to planning (E5). Much Indonesian energy research, in other words, is technical or macro-economic, and much of its biodiversity research is inventory work. The literature that sits between them is comparatively thin. Of the 220 records we kept, 106 are core and 114 supporting.

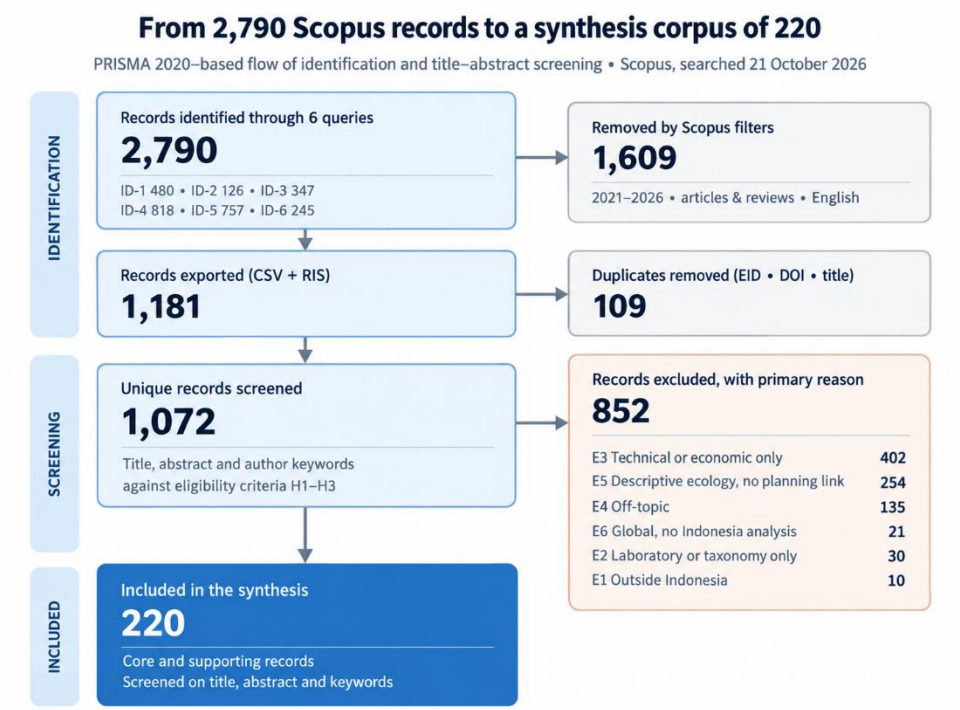


Figure 1. PRISMA 2020-based flow of record identification and title–abstract screening; full texts were not screened (Scopus, searched 21 October 2026). Bars in the exclusion box show the number of records removed under each primary exclusion code (E1–E6, defined in Table 2).

How the literature has grown

The field is growing quickly, but the part that links energy and conservation is not keeping pace (Fig. 2). The number of screened records roughly tripled between 2021 and 2026, from 96 to 300. Included records grew more slowly, from 21 to 58, and their share fell from 22% to about 19%, dipping to 15% in 2025. Most of the recent growth, then, lies in technical energy studies and ecological inventories rather than in work that connects them. Within the included set, conservation planning (Theme 4) and Sulawesi–Gorontalo studies (Theme 6) account for most of the increase after 2024. RE siting studies (Theme 2) show no clear trend, with between 3 and 8 papers a year.

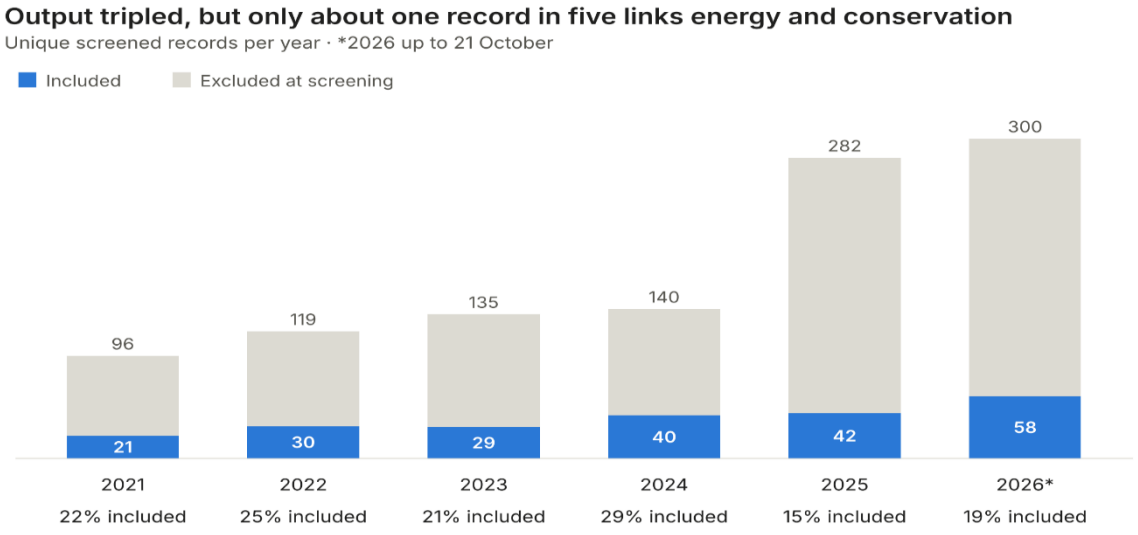


Figure 2. Unique screened records per year, divided into included and excluded records, 2021–2026 (2026 up to 21 October).

Themes

The included records spread fairly evenly across five substantive themes and one regional theme (Fig. 3). Conservation planning, protected areas and ecosystem services form the largest group (49 records). Ecological impacts of RE and transition minerals (40) and land competition from bioenergy, oil palm and deforestation (40) come next, followed by RE spatial planning (36) and the Sulawesi–Gorontalo context (36). Governance, policy and social acceptance is the smallest group (19), although governance questions surface in many papers we assigned elsewhere.

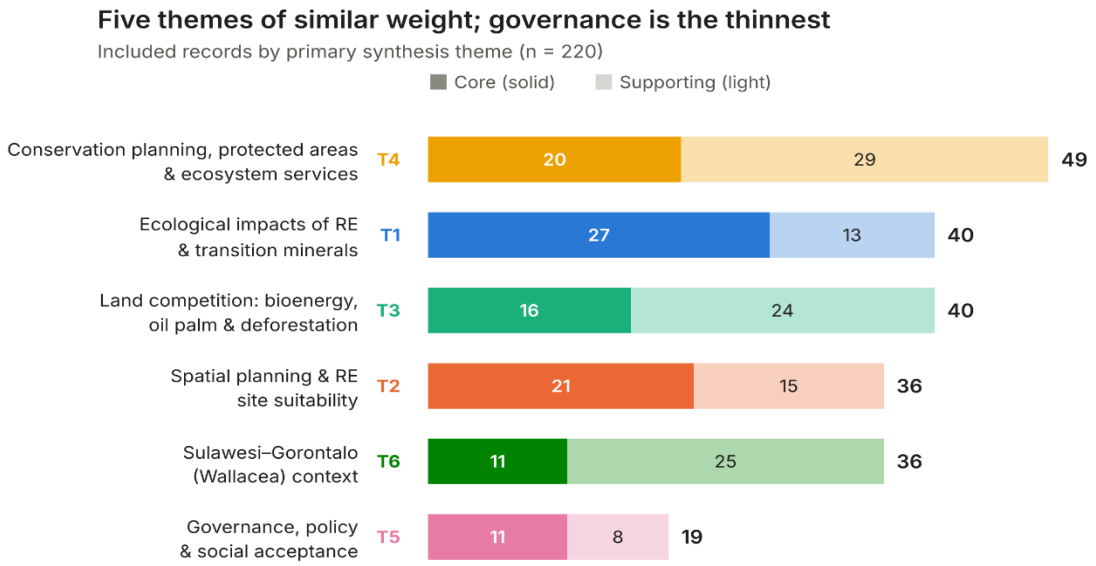


Figure 3. Included records by primary synthesis theme (n = 220). Solid bars show core records and light bars supporting records.

Where, what and how

At first glance Sulawesi looks well covered: it is the most frequently studied region (67 records), ahead of Java–Bali (40), Sumatra (25) and Kalimantan (14), while 80 records are national or multi-regional (Fig. 4a). This partly reflects our two region-specific queries, and the picture changes once we look only at energy. Site-level ecological evidence on power plants comes almost entirely from West Java, above all the Upper Cisokan pumped-storage scheme and the Kamojang, Darajat and Gunung Salak geothermal fields (Husodo et al., 2024b; Irawan et al., 2023; Megantara et al., 2025). Only 11 records mention Gorontalo by name. Bioenergy and oil palm are the most studied technologies (44 records), followed by solar PV (30), hydropower (25), geothermal (18), nickel and other transition minerals (14) and wind (13); ocean energy barely features (3) (Fig. 4b). In all, 127 records deal with at least one energy technology. Only 50 of them also mention biodiversity, habitat, protected areas or species in their title or abstract. That is our first measure of the gap examined in the thematic synthesis below.

The methods split along the same line (Fig. 4c). Qualitative or policy analysis (47 records), scenario and land-use simulation (44), GIS analysis (40), conservation prioritisation (31) and remote sensing (30) dominate. MCDA appears in 18 records, 13 of them RE siting studies. Species distribution models appear in 11, and 10 of those are conservation or Sulawesi biodiversity studies. The two methods an integrated siting framework would need to combine are, in practice, used by different communities.

Because two of our six queries targeted Sulawesi and Gorontalo, we checked whether the regional picture is an artefact of the search. Of the 220 included records, 173

were retrieved by the four national queries and 47 only by the regional ones. In the national set alone, Sulawesi falls to 20 records, behind Java–Bali (38) and Sumatra (21) and only just ahead of Kalimantan (13), while national or multi-regional studies (80) dominate. Gorontalo is named in just two of these records. The theme profile barely moves (conservation planning 43, land competition 40, ecological impacts 35, RE siting 34, governance 14, Sulawesi–Gorontalo synthesis 7), and the central gap holds: 111 records address an energy technology, but only 46 of them also mention biodiversity, and only 2 of the 34 siting studies use ecological criteria. In other words, Sulawesi is well represented only because we went looking for it; left to a national search, Wallacea almost disappears from the evidence base.

Where, What, and How the Corpus Studies

Records per category; a record may fall into several categories. In panel (c), the highlighted methods represent two methodological approaches that an integrated siting framework would combine, although they are currently used largely by separate research communities.

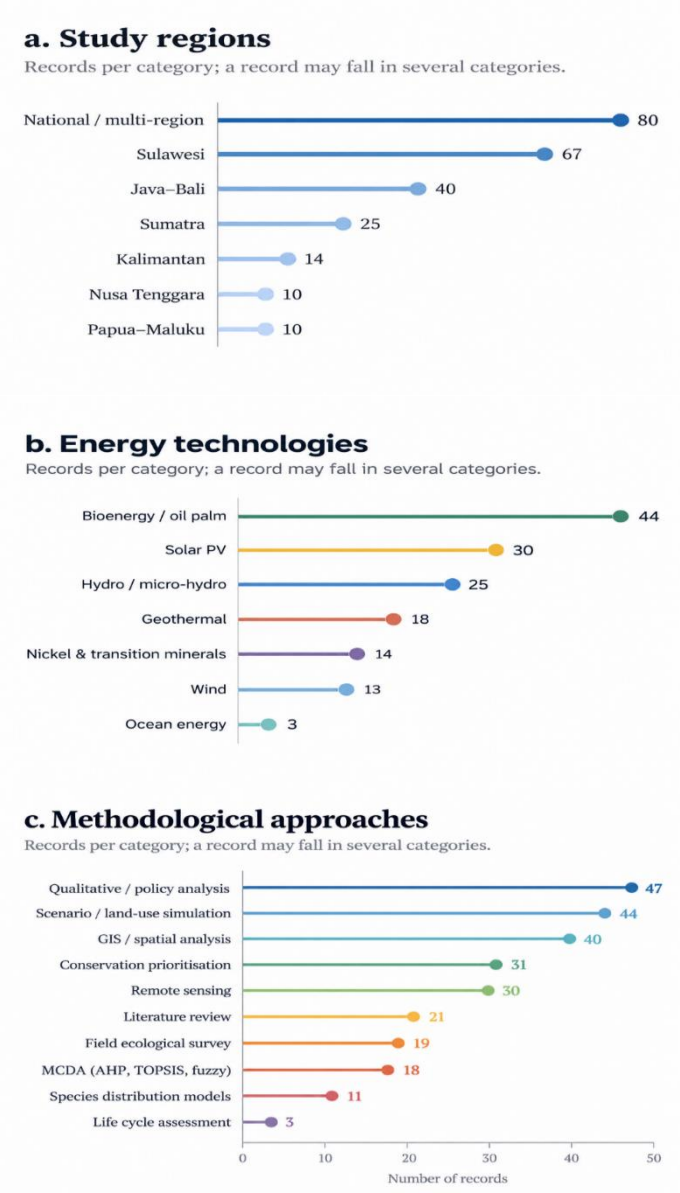


Figure 4. Study regions (a), energy technologies (b) and methodological approaches (c) in the included records. A record may fall into more than one category.

Keywords and journals

Author keywords show the same divide (Fig. 5). After *Indonesia* (37 records), the most common keyword is *renewable energy* (24), followed by *conservation* (13), *biodiversity* (11), *protected areas* (10) and *biodiversity conservation* (10). Yet energy and conservation keywords rarely appear together. Some 82 records carry an energy keyword and 73 a conservation keyword, but only 7 carry both.

Publication venues are just as scattered. The 220 records appear in 148 journals, and 109 of those journals contribute a single paper. The most frequent outlets are *Biodiversitas* (16 records), *Biological Conservation* (7), *International Journal of Sustainable Development and Planning* (5), *Renewable and Sustainable Energy Reviews* (4) and *Sustainability* (4). Ecological studies of power-plant sites tend to appear in regional biodiversity journals, siting studies in energy journals. The two literatures are growing up in separate places. On the positive side, most of the corpus (180 of 220 records, 82%) is open access, which makes it easier to check and build on.

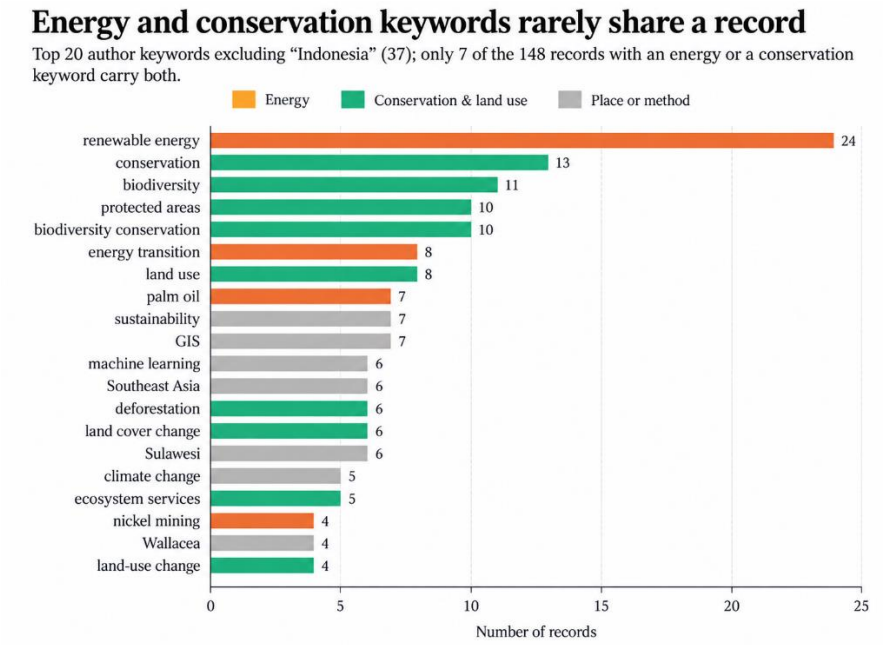


Figure 5. The 20 most frequent author keywords in the included records, excluding "Indonesia", coloured by domain.

Thematic synthesis

The ecological footprint of renewable energy, technology by technology

The evidence on what RE does to Indonesian ecosystems is growing, but it is still local, short-term and heavily concentrated in Java. Read together, it suggests that a project's footprint depends less on the technology itself than on what the project replaces and what it opens up.

Hydropower and pumped storage. The longest run of site-level evidence comes from the Upper Cisokan Pumped Storage (UCPS) scheme in West Java. Over a decade, sign surveys and camera traps kept finding leopard cats (*Prionailurus bengalensis*), Asian small-clawed otters (*Aonyx cinereus*), Java mouse-deer (*Tragulus javanicus*) and ten rare, endemic or protected species in the forest patches and corridors around the construction site (Dirgantara et al., 2021; Husodo et al., 2022, 2024b; Megantara et al., 2024). Leopard cats returned to the same grid cells for five to ten years, favouring shrubland and riparian strips (Husodo et al., 2022; Shanida et al., 2023). The same team warns, though, that fragmentation and overlapping land uses put these populations

at long-term risk, and it identifies nine grid cells as core habitat that needs protecting (Husodo et al., 2024b). Protection so far rests on stakeholder arrangements led by the state utility PLN with Perum Perhutani, contractors and local residents (Husodo et al., 2024a). A study from North Sumatra tells a less reassuring story. In the Batang Toru Key Biodiversity Area, the last refuge of the Tapanuli orangutan (*Pongo tapanuliensis*), the rate of forest loss doubled after a gold mine, a geothermal plant and a hydropower dam were launched in 2012. The area lost 3,472 ha more forest than a synthetic control predicted, although smallholder farming and logging still accounted for about 70% of the total (Sreekar et al., 2026). The two findings need not contradict each other. Infrastructure can leave resident species in place for years while setting off the land-use change that eventually removes their habitat.

Rivers are the second concern. For run-of-river small hydropower, optimisation studies show that environmental flows can be raised a great deal at a modest energy cost: in one plant, e-flow discharge rose by 89.8% while generation fell by 20.5% (Prasetya et al., 2026; see also Prasetya et al., 2025). Below Cirata Dam, habitat modelling found that a discharge of 93.12 m^3/s keeps 94% of suitable habitat. Good water quality, by contrast, would need more than 500 m^3/s, which the river cannot supply (Soekarno et al., 2026). Flow rules alone, in other words, cannot heal a regulated river without pollution control across the catchment. In Sulawesi, the ancient Lake Poso, a hotspot of freshwater endemism, already shows minor to moderate metal pollution from land use in about 32% of its catchment (Damanik et al., 2024). The Poso River holds endemic and IUCN-listed fish both above and below its hydropower facilities, so fish passage has to be designed in from the start (Serdiati et al., 2021; Wibowo et al., 2025).

Geothermal. Studies around Kamojang, Darajat and Gunung Salak describe geothermal fields as mosaics in which remnant natural forest and riparian strips still hold a great deal of life. Kamojang supports 113 bird species from 37 families (Husodo et al., 2025). Kamojang and Darajat together hold 37 species of amphibians and reptiles; the specialists keep to natural habitat, while generalists take over monocultures and replanted ground (Megantara et al., 2025). The conservation forest at Gunung Salak contains 110 plant species, some of them IUCN Endangered, alongside several introduced species that could become invasive (Irawan et al., 2023). Across these sites, species richness falls where forest has been turned into horticulture, not necessarily close to the plant itself. Access roads and the settlement they bring may matter more than the power station. Contamination is a separate pathway. At Wayang Windu, arsenic was the dominant soil pollutant, reaching 151.92 mg/kg, and geothermal emissions were identified as its source (Maria et al., 2025). Because none of these studies uses a before–after–control–impact (BACI) design, we cannot yet say how much of the change is caused by geothermal operations.

Solar PV. Solar has the thinnest ecological evidence of any technology. A mesocosm experiment in Mahoni Lake found that floating PV cover significantly lowered water temperature, dissolved oxygen, conductivity, total dissolved solids and chlorophyll-a, without directly lowering total phosphorus (Andini et al., 2022). This is a result from enclosed tanks; it has not been tested across a whole reservoir. At the 145 MW Cirata floating plant, researchers have focused instead on social and territorial effects, showing how the project fenced off parts of the reservoir that fishers had used (Rudolph et al., 2025). On land, combining PV with crops offers real co-benefits. In a model village, low-density off-grid PV over high-value crops generated nearly three times the residential demand (Choi et al., 2021), yet agrivoltaic research in Indonesia remains scarce (Aziz et al., 2025). For small islands, recycling panels at end of life cuts environmental impacts by 25% compared with landfill, which matters greatly in an archipelago (Adiansyah et al., 2025).

Transition minerals and the grid. The largest documented footprint of Indonesia's energy transition lies not in power generation but in mining. Laterite nickel mining transforms 0.7 ± 0.1 m² of land per tonne of ore, up to 20 times earlier estimates (Heijlen & Duhayon, 2024). Across 7,721 Sulawesi villages, deforestation nearly doubled where nickel was mined between 2011 and 2018, with mixed effects on well-being (Lo et al., 2024). Habitat-quality modelling for Wallacea projects that future mining will remove 10% (513 km²) of the region's excellent-quality habitat, while protected areas are expected to hold their quality (Azizah & Singh, 2026). At Morowali, ethnographic work describes recurrent flooding as a hydrosocial outcome of mining and forest clearance (Yahya & Junaidi, 2026). Rehabilitated mine land at Sorowako supports butterflies, but its communities differ from those in conservation zones (Nuraeni et al., 2025). The ultrabasic forests of East Luwu hold 143 tree species, 17 of them found only in Sulawesi (Nasri et al., 2026). Transmission lines, by contrast, can be benign when their corridors are well managed: the 150 kV Tentena–Kolonedale right-of-way kept more than 99% of its dense vegetation between 2019 and 2024 (Salmon et al., 2026). The regional systematic review by Prabowo et al. (2026) reaches a similar conclusion: decarbonisation reduces pollution-related health burdens but shifts ecological and social risks to the places where resources are extracted.

All of this answers RQ1 only in part. The documented impacts are habitat fragmentation, altered river flows, local contamination and, above all, forest loss driven by mining. Yet only two settings, nickel in Sulawesi (Lo et al., 2024) and Batang Toru (Sreekar et al., 2026), have been studied with robust causal designs. For solar, wind and geothermal energy, impacts are still inferred from one-off surveys and experiments.

Spatial planning of renewable energy: technically mature, ecologically blind

Indonesian RE siting has become methodologically sophisticated, yet it rarely asks what lives on the land it selects. Of the 36 siting and resource-mapping studies in our corpus, only two mention protected areas or biodiversity in their abstracts. Ten use land use or land cover as a criterion, usually to rule out built-up or farmed land rather than to protect habitat.

The standard workflow is GIS-based MCDA with weights from the analytic hierarchy process (AHP). It has been used to find micro-hydropower sites in South Ogan Komering Ulu (Nur et al., 2021) and in the Saddang watershed of Sulawesi (Setiawan et al., 2024), wind farm sites in South Kalimantan and Pandeglang (Abdullah et al., 2021; Suci & Muhamad, 2026) and solar–wind hybrid sites in Lampung (Abdullah et al., 2025). The usual criteria are resource intensity, slope, elevation, and distance to roads, transmission lines and settlements, plus land use. Pandeglang is a partial exception, adding environmental buffers around lakes, rivers, reservoirs and dams (Suci & Muhamad, 2026). Remote sensing increasingly fills in for scarce ground data, from Landsat-based micro-hydropower assessment (Susilowati et al., 2021) to building-level surface models for rooftop PV in Bandung (Sakti et al., 2022) and 5 m machine-learning estimates of crop-residue biomass across Southeast Asia (Sakti et al., 2026).

A second group of studies pairs efficiency screening with fuzzy ranking. Two-stage models that combine data envelopment analysis with fuzzy AHP and a compromise-ranking method have been used to rank Indonesian locations for solar (C. Wang et al., 2023) and wind development, with Lampung, Aceh and Riau coming out on top for wind (C. Wang et al., 2025). These models do include an “environmental” criterion, but it is scored qualitatively at provincial scale, far too coarse to see a habitat or a protected-area boundary.

Where the studies differ most is in what they count as “potential”. Indonesia's technical solar potential has been put at 12,200 TWh a

year. Its socio-economic potential, capped by 2030 demand, is 152.7 TWh, and its bankable potential under current financing conditions only 16.0 TWh (Langer et al., 2023). Nobody has yet estimated an ecological potential, the share of sites that would remain once biodiversity constraints were applied, for any technology. The choice of weights matters too. When 92 water bodies were ranked for floating PV, the ranking changed more with the weighting scheme (entropy, CRITIC or equal weights) than with the ranking algorithm (Wu et al., 2026). In most AHP studies the weights come from expert pairwise comparison, so leaving ecology out is a choice built into the weights, not a neutral default. And it is not a choice that stakeholders themselves would make: national expert panels rank land-use conflict and environmental impact among the most critical concerns for RE (Seran et al., 2026; see also Siregar, 2022).

The exceptions show what a more ecological approach could look like. A run-of-river hydropower assessment for Indonesia's new capital region combined satellite data with SWAT hydrological modelling. It took protected areas and river transport routes into account to avoid conflict sites, and still identified 25 mini- and 16 micro-hydropower sites with a combined 114.4 MW (Kuntoro et al., 2024). A Wallacea bioenergy study argued that using forest biomass must take account of landscape protection, food security and local livelihoods (Darmawan et al., 2024). At larger scales, global and national analyses single out the calm equatorial seas around Indonesia as the world's best sites for offshore floating PV (Silalahi & Blakers, 2023), and map ocean thermal energy sites with a national economic potential of up to 2 GWe (Langer et al., 2021). Neither considers coral reefs, seagrass or marine protected areas, even though, as the conservation-planning evidence shows, these are mapped in detail. Our answer to RQ2 is therefore that biodiversity enters Indonesian RE siting only incidentally, through land-cover exclusions or qualitative environmental scores, never as spatially explicit habitat, connectivity or protected-area layers.

Land competition: bioenergy, oil palm and deforestation

Of all the energy pathways, bioenergy makes the largest direct claim on Indonesian land, and the evidence leaves little doubt that its targets cannot be met without giving up forest somewhere. Reaching the B50 biodiesel blend by 2030 would require converting 4.85–8.55 million ha. Spatial optimisation shows that the food estates and biofuel expansion now planned compete for the same land, and that deforestation can be contained only if expansion is steered onto land that is already degraded (Squire et al., 2026). The past gives reason for concern. Between 2001 and 2015, oil palm expansion into the forests of Indonesia and Malaysia removed 50.2 ± 21.9 TgC of biomass a year, and since 2007 smallholders have increasingly pushed into high-biomass forest (Xu et al., 2022). Annual plantation maps for 2007–2018 point to a very high potential for conflict between oil palm and local biodiversity (Yu et al., 2023). Worldwide, 3.6 Mha of forest became oil palm between 1982 and 2019 (Zhao et al., 2024a).

Whether intensification eases this pressure is still disputed. The land-sparing argument holds that higher yields free land for nature. A spatially explicit land-rent model for Indonesia suggests otherwise: intensification raised agricultural rents and weakened efforts to limit crop expansion under every demand elasticity tested (Lim et al., 2024). Suitability analyses that exclude peat and forest still find land for further expansion in Indonesia and Malaysia (Tapia et al., 2021; Zhao et al., 2024a). Scenario planning for Central Kalimantan shows that smallholders can expand on already cleared land under a zero-deforestation scenario (Zhao et al., 2025). The optimistic and pessimistic findings differ mainly in whether markets are modelled. Static suitability maps show where expansion could go; economic models show where it is likely to go.

Demand from abroad shapes much of this. Non-food biomass demand, bioenergy included, accounted for more than a quarter of global land-use emissions in 2013, much of it embodied in exports from tropical countries such as Indonesia (S. Wang et al., 2023). The European Union's Renewable Energy Directive (RED II) classified palm-oil biofuels as carrying a high risk of indirect land-use change, a move whose compatibility with WTO law legal scholars question (Mayr et al., 2021; Tyson & Meganingtyas, 2022). Modelling suggests that an EU phase-out of palm-oil biodiesel would barely change global palm production or tropical cropland (Heimann et al., 2024). Indonesia's moratorium on new plantation licences was adopted partly in response to this external pressure (Wulandari et al., 2026). At home, biodiesel policy is defended on the grounds of diesel import savings, but it also entails land expansion and export losses that official assessments understate (Halimatussadiah et al., 2021). Reviews of the field agree that land conversion, deforestation and CO_2 dominate environmental assessments of palm bioenergy, while its socio-economic side receives less attention (Papilo et al., 2022; Purnama et al., 2025).

Alternatives on degraded land look promising but remain small. Indonesia has about 14 million ha of degraded and marginal land, and the leguminous tree *Pongamia pinnata* could produce biofuel while helping to restore it (Leksono et al., 2021). Eucalyptus plantations on dryland in Timor improve land cover and supply an energy feedstock (Sadono et al., 2023). Solar PV on former coal-mining land can pay its way: a 300 MWp plant would generate an estimated 464 GWh a year, with a discounted payback of 13 years (Ronyastra et al., 2024). Even inside plantation landscapes, protected forest remnants matter. Camera traps in East Kalimantan recorded at least 33 mammal species there, including the Critically Endangered Bornean orangutan (Kasper et al., 2024).

In practice, these trade-offs are settled when land is acquired. A comparison of two large wind projects in Indonesia and the Philippines found that multilateral safeguards shaped outcomes only when funding arrived early and when developers could not easily acquire land through non-compliant routes (Kennedy & Qayyum, 2024). Project-level safeguards, it seems, are not enough on their own. Land-use policy and spatial planning are the stronger levers for keeping RE away from high-value habitat.

Conservation planning as the evidence base for no-go and go zones

Indonesian conservation science already produces the spatial layers that RE siting lacks. What it rarely does is treat energy infrastructure as something to plan around. The conservation studies in our corpus draw on four families of tools, each of which could feed directly into siting.

Systematic prioritisation. Marxan and similar decision-support tools are now used from the watershed to the ocean basin. In the Citarum watershed, InVEST estimates of water yield, sediment retention and carbon storage were fed into Marxan to identify priority areas, with and without the existing protected areas (Suprajaka et al., 2026). For the West Pacific, representing every species would require protecting more than half of the world's most species-rich ocean region, far beyond the 30% target (Zhao et al., 2024b). In the Coral Triangle and Southeast Sulawesi, the way larval connectivity is built into the analysis changes the reserve design (Muenzel et al., 2023). Planning forests and reefs together, ridge to reef, avoids future deforestation and sediment exposure more efficiently than planning land and sea separately (Muenzel et al., 2026). Across Sumatra, Kalimantan and Papua, 45.5% of peatland should be conserved, yet only 15.6% of that is protected (Terzano et al., 2023).

Species and connectivity models. Maxent models for 51 primate species predict range losses for 30 of them by 2050 and point to the protected areas that matter most under

climate change (Condro et al., 2021). In the Leuser Ecosystem, occupancy models link forest regained through restoration and connectivity to the recovery of Sumatran elephants and tigers (Lubis et al., 2023). Camera traps at 671 locations in Kerinci Seblat show how habitat gradients and patrol effort shape mammal communities (Haidir et al., 2024). Graph-theory corridor analysis has been used to reduce human–tiger conflict in West Sumatra (Rahman et al., 2023), and in community-managed forests of Sumatra habitat connectivity shapes mammal biodiversity outcomes (Hughes et al., 2026). The clearest link to infrastructure comes from Borneo and Sumatra. Movement models for the clouded leopard show that the Trans-Sumatran Toll Road, the Pan Borneo Highway and the new capital, Nusantara, will sharply reduce functional connectivity; core habitat already covers only about 13% of Sumatra (Kaszta et al., 2024).

Protected-area effectiveness. Across 170 protected areas assessed repeatedly between 2015 and 2019, Indonesia's management effectiveness scores rose by 44.1% on average, with national parks scoring highest (Nugraha et al., 2024). In the Leuser Ecosystem, protected land slowed deforestation twice as effectively as unprotected land (Condro et al., 2022). The 43 terrestrial national parks lost 1.62% of their forest cover between 2012 and 2017 (Dwiyahreni et al., 2021). Across Southeast Asia, adequate funding and staffing, together with government transparency and species body size, explain 29% of the variation in mammal and bird population trends inside protected areas (Graham et al., 2021). Beyond formal reserves, more than 390 potential marine OECMs have been identified in Indonesia; if recognised, they would form a denser network with many climate-refugia reefs (Estradivari et al., 2022, 2024). Marine protected areas already cover 235,622 km² (White et al., 2021).

Ecosystem-service and habitat-risk modelling. InVEST habitat-quality and habitat-risk models are increasingly used to test spatial plans. In Bengkulu City, the habitat quality of coastal forests and mangroves was modelled for 1993–2023 and tested against the 2021–2041 regional spatial plan (RTRW) (Lestari et al., 2026). In Indramayu, aquaculture, agriculture and settlements were mapped as stressors on mangroves under three marine spatial planning scenarios (Pramudita et al., 2026). National maps of coral reefs, mangroves and seagrass from Sentinel-2 and SPOT imagery now provide ecosystem extents for ocean accounting and marine spatial planning (Gunawan et al., 2025). LUMENS, a land-use planning tool for multiple environmental services, has been used to weigh instrumental against relational values of nature in Indonesian planning (Dewi et al., 2023).

Yet energy is almost absent from these tools. Their threat layers are typically roads, settlements, farming, aquaculture or mining. Hydropower dams, geothermal concessions, solar farms and transmission corridors almost never appear as threats or costs. The only island-wide prioritisation in our corpus to include an extractive layer is for Sulawesi, where valuable metal-rich areas were weighed alongside biodiversity, forest cover, carbon and karst (Pusparini et al., 2023). The gap we found in RE siting therefore has a mirror image in conservation planning. The layers exist on both sides; the two communities are simply not exchanging them.

Governance, policy and social acceptance

When energy and conservation collide, institutions usually decide the outcome: who holds authority over land and water, how science reaches policy, and whether the people affected have any say. Geothermal development in conservation forests is the best-documented example.

Opening Indonesia's conservation forests to geothermal energy took more than a decade of policy change. Two advocacy coalitions, one for development and one for conservation, fought over whether geothermal use was legitimate, and the weak use of science in policy left projects inside conservation forests deadlocked (Pratiwi &

Juerges, 2022a). At Kamojang Nature Reserve, a ministerial decree reclassified land from restricted to accessible use. The decision sparked grassroots conflict, and digital advocacy became the way local people contested it (Pratiwi & Juerges, 2022b). A normative legal analysis concludes that Indonesia's geothermal regulation is no more protective of ecology than that of the United States and does not guarantee environmental justice where projects enter conservation areas (Hanum et al., 2023).

Community responses are polarised, and they often fail to change outcomes. In West Sumatra, social acceptance explains why one district's geothermal project moved forward while another stalled (Anggreta et al., 2022). At Dieng, resistance to the Dieng 2 expansion faltered because economic dependence on the operator weakened solidarity and decision-making was not democratic (Ahimsa, 2025). Participatory research in 14 geothermal locations found that elites and local communities hold contrasting stories about what "green energy" means, and contrasting ideas about how to manage the resulting polarisation (Smith et al., 2026). Read through a decolonial lens, the same material shows opponents describing geothermal development as a continuation of extractive relations with nature (Susilowati et al., 2026).

Nickel shows a similar pattern on a much larger scale. Centralising authority made possible a 14-fold increase in extraction over ten years, while local accountability for social and environmental harm in Sulawesi weakened (Hyldmo et al., 2025). An analysis of the Mandiodo block identified both design failure, in hierarchical arrangements poorly matched to local socio-ecological conditions, and capacity failure, in weak monitoring, fragmented coordination and limited enforcement; formal rules coexist with informal practices that allow illegal mining (Kadir et al., 2026). Inside Indonesia's largest multinational nickel concession, in protected forest landscapes of Sulawesi, extraction, conservation and smallholder farming overlap as a "triple frontier" of competing claims to land (Mangiwa et al., 2026).

Hydropower raises comparable questions. When the level of Lake Poso was raised to increase output at the Sulewana hydropower plant, lakeshore communities were flooded. The district government, the operator, affected villages and Indigenous groups then entered a collaborative-governance process (Alamsyah et al., 2025). At Saguling, corporate social responsibility has been reframed as an "ecosystem of shared value" that links reservoir restoration with community development (Herfiantara & Famiola, 2023).

At national level, energy transition, energy-related measures, mining governance and resource transition compete for attention. An AHP analysis ranks energy transition first, with national energy policy and electricity-sector reform as the leading instruments (Ali & Kim, 2024). Justice-based analyses caution that bioeconomy transitions in Brazil, India and Indonesia have often concentrated the benefits while shifting distributive, procedural and restorative burdens onto rural communities (Bastos Lima, 2022). Our reading of the evidence for RQ3 is that land competition and weak governance, more than technology, are the proximate drivers of biodiversity loss in Indonesia's energy transition. Good spatial plans will not resolve these conflicts if authority, monitoring and participation remain weak.

DISCUSSION

Sulawesi and Gorontalo: converging pressures, parallel evidence

The gaps described in the Results are at their sharpest in Sulawesi, where endemic biodiversity, nickel extraction and rising electricity demand all meet. Deforestation in Wallacea is expected to speed up (Voigt et al., 2021), and nickel mining has nearly doubled forest loss in the villages where it operates (Lo et al., 2024). Smelter demand threatens the renewable share of the southern Sulawesi grid (Utomo et al., 2025).

Generation-expansion modelling favours linking Sulawesi's two separate grids so that its scattered renewable resources can be used (Sarjiya et al., 2023). At the same time, land-use change is already reducing the water available to some of the island's hydropower plants (Novitasari et al., 2023). Between 1990 and 2022, the share of Sulawesi with high water-regulation capacity fell from 59.5% to 44.9% (Nursaputra, 2026). An island-wide prioritisation shows that reaching 30% protection would mean expanding a terrestrial network that today covers only about 10% of the island (Pusparini et al., 2023).

Gorontalo has relevant work in every one of these domains, but none that ties them together. On the energy side, LEAP modelling for the Tomini Bay region projects demand to 2050 and points to river energy as part of a more diverse supply (Salim et al., 2025). Rooftop PV potential has been assessed for houses and apartment blocks (Djafar et al., 2023, 2025). Lamtoro (*Leucaena leucocephala*), co-fired at the Anggrek coal plant, grows on 69,074 ha across 14 districts of Bone Bolango (Mohamad et al., 2023), a bioenergy land claim whose ecological effects nobody has yet assessed. On the land side, agent-based and RUSLE modelling of the Bolango watershed projects a 14.25% loss of forest cover and a 42.37% expansion of dryland farming between 2013 and 2033 (Lihawa et al., 2026). In the upper Limboto watershed, degradation has been traced to weak enforcement and limited community participation (Bakari et al., 2025), and land-cover change in North Gorontalo has been checked against the regional spatial plan (RTRW) (Djafar et al., 2026).

On the biodiversity side, plasma oil palm plantations in Pohuwato support 56 plant species, compared with 79 in neighbouring forest, and the area holds eight Sulawesi endemics, among them the Vulnerable *Diospyros celebica* (Hamidun et al., 2025). Distribution models for the maleo (*Macrocephalon maleo*) and the knobbed hornbill (*Rhyticeros cassidix*) identify distance to hot springs, rivers and roads as key predictors (Aldiansyah et al., 2024). At the Hungayono sanctuary, maleo nest close to geothermal sources, and seven hatcheries use geothermal heat for semi-natural incubation (Karim et al., 2022). This points to a specific risk that no study has yet examined. The very features maleo depend on, warm ground near hot springs, are the surface signs that geothermal exploration looks for. The overlap is already visible on the ground. The Hungayono sanctuary lies inside Bogani Nani Wartabone National Park (Karim et al., 2023), and the Hungayono hot springs are themselves a geothermal prospect: surface manifestations reach 54–60 °C and geothermometers indicate a reservoir of about 232–234 °C (Tolodo et al., 2022). Elsewhere in the province, Suwawa has been designated an official geothermal working area (Gustama et al., 2026). We found no study that maps working-area boundaries against the national park or against maleo nesting grounds. Offshore, the Sulawesi Sea is being assessed for pelagic marine protected areas (Hakim et al., 2025, 2026), and coastal zoning in North Sulawesi already shows fishing grounds overlapping with other uses (Ibnusina et al., 2023). Both are constraints that any future marine or floating renewables will have to respect.

For RQ4, then, the problem in Gorontalo is not a lack of data. Energy-system models, land-use projections, species distribution models and marine spatial plans all exist, but in separate disciplines and separate agencies. What is missing is a way to bring them into a single spatial decision.

Indonesia in the global picture

Is biodiversity-blind siting an Indonesian peculiarity? The international literature suggests it is not, but it also shows where Indonesia differs. At global scale, the overlap between projected wind and solar expansion and conservation priorities can be modest once differences in area are taken into account, although it stays high in some biodiverse countries and depends on policy and regulatory controls (Dunnett et al.,

2022). Footprint overlap, however, understates impact. Once zones of influence of 1–5 km around facilities are included, renewable-energy areas become over-represented in priority conservation areas in most regions (Niebuhr et al., 2022). Where national siting has ignored ecology, the outcome looks much like what we found. Greece's proposed wind investment zone overlaps about 93% of the country's Important Bird Areas and 82–91% of the exclusion zones proposed in three bird-sensitivity maps (Kati et al., 2021), and most of the world's utility-scale PV has been built on cropland (Kruitwagen et al., 2021). The Indonesian siting studies in our corpus, which at best exclude land-cover classes at the footprint level, fit squarely within this pattern.

Where Indonesia does stand out is in what drives the footprint. Globally, the biodiversity risk of the transition increasingly lies upstream, in the mines that supply it (Giljum et al., 2022; Owen et al., 2023). Metal-ore extraction roughly doubled between 2000 and 2019; 79% of it now comes from five of the six most species-rich terrestrial biomes, and mining in tropical moist forests doubled over the same period (Luckeneder et al., 2021). Oil palm, the feedstock of Indonesia's biodiesel mandate, follows the market in a similar way: in Indonesia, a 1% fall in palm-oil prices was associated with a 0.68% fall in forest loss, and deforestation dropped below pre-2004 levels in 2017–2019 as expansion slowed (Gaveau et al., 2022). Mandates that lift domestic demand work against that slowdown unless land conversion is regulated. Indonesia thus carries the two largest land footprints of the transition at once, in landscapes of exceptional endemism. This is why our finding that nickel and bioenergy, rather than power plants, are the best-documented drivers of land loss matters beyond Indonesia's borders.

The same literature shows that the tools to close the gap already exist. Governments are already being advised on how to build biodiversity into power-sector planning and policy (OECD, 2024). In the western United States, a capacity-expansion analysis of net-zero pathways that screened land and ocean for habitat value found that stronger protections raised total system cost by only 3%, reduced the need for new interstate transmission by 20% and did not significantly change the generation mix (Wu et al., 2023). At project level, guidance on applying the mitigation hierarchy to solar and wind development is available (Bennun et al., 2021). We found no Indonesian study in our corpus that uses zones of influence or links ecological screening to capacity-expansion modelling. What this review adds, then, is not the observation that siting and conservation are disconnected, but evidence of how and where that disconnection plays out across technologies in one of the world's most biodiverse countries, together with a framework (Figure 6) that adapts these international methods to Wallacea's data and institutions.

Towards biodiversity-inclusive spatial optimisation

Drawing on the tools reviewed above for RE siting and conservation planning, we propose a framework in four layers (Fig. 6). The first applies hard exclusions: protected areas, Key Biodiversity Areas, mapped critical habitat such as maleo nesting grounds, mangroves, seagrass, coral reefs and peat. The second assigns ecological sensitivity costs drawn from habitat-quality and ecosystem-service models (InVEST), connectivity corridors and habitat suitability for endemic species. These costs enter the siting objective itself rather than acting as simple yes-or-no masks. The third layer is conventional multi-criteria siting, covering resource intensity, terrain, grid and road access, and the risk of land acquisition. The fourth links candidate sites to an energy-system model such as LEAP, so that the ecological cost of meeting projected demand can be compared across scenarios. Governance and participation run through all four layers. Communities and agencies agree the exclusion rules and the weights, and monitoring results feed into the next planning

cycle, in line with the lesson from the governance evidence that spatial plans fail where authority and participation are weak.

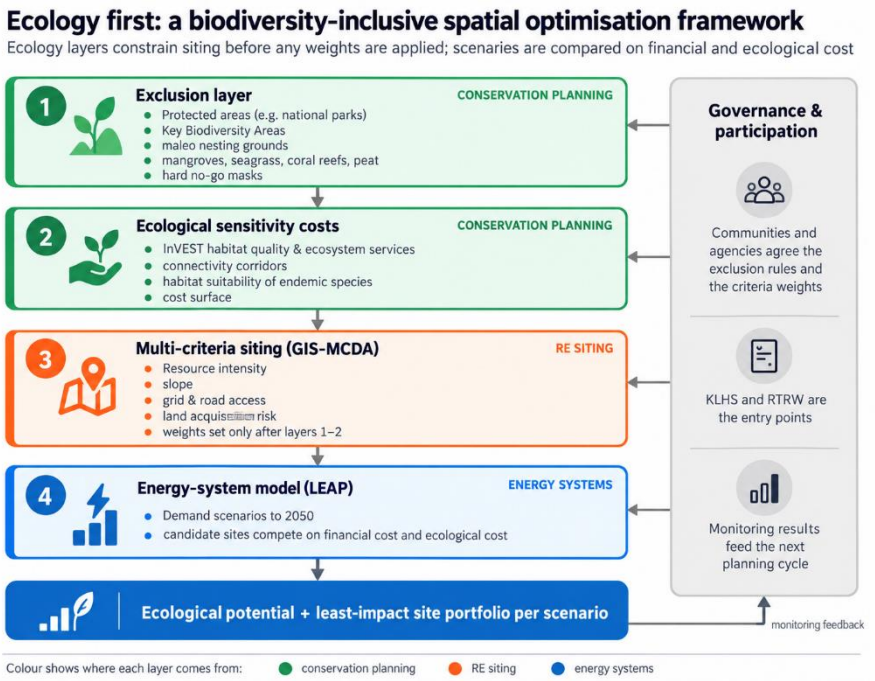


Figure 6. A biodiversity-inclusive spatial optimisation framework. Ecological layers (green) constrain the siting step (orange) before any weights are applied, and the energy-system model (blue) compares scenarios on both financial and ecological cost.

Two design choices set this framework apart from current practice. Ecological constraints are applied before weighting, which removes the sensitivity to expert weights reported by Wu et al. (2026). And the framework reports an *ecological potential* alongside the technical, socio-economic and bankable potentials of Langer et al. (2023). Ecological potential is the energy that can be generated from sites that pass ecological screening, and it shows planners, in their own units, what conservation constraints cost.

Research agenda

1. Causal designs for impact. BACI or synthetic-control studies are needed for geothermal, solar and wind projects, following the approaches already used for nickel and Batang Toru (Lo et al., 2024; Sreekar et al., 2026).
2. Floating PV ecology at reservoir scale. The mesocosm results of Andini et al. (2022) should be tested on operating plants, including their effects on fisheries, which Rudolph et al. (2025) show are socially contested.
3. Energy in conservation planning. Hydropower, geothermal concessions, solar farms and transmission corridors should be added as threat or cost layers in Marxan and InVEST applications.
4. An ecological potential metric. Siting studies should report how much of their technical potential survives biodiversity screening.
5. Evidence from Wallacea. Field and modelling studies are needed in Sulawesi, Maluku and Nusa Tenggara, which remain underrepresented compared with Java.
6. National literature. AMDAL documents and SINTA-indexed journals probably hold site-level ecological baselines that Scopus does not.

Policy implications

Three implications follow for policy. First, strategic environmental assessments (KLHS)

and regional spatial plans (RTRW) are the most effective points of entry. The evidence on land acquisition (Kennedy & Qayyum, 2024) and on nickel governance (Kadir et al., 2026) suggests that project-level safeguards arrive too late to change where projects go. Second, provincial governments could publish biodiversity screening maps, showing no-go and go-with-care zones, as part of RE planning, building on existing national ecosystem maps (Gunawan et al., 2025) and protected-area assessments (Nugraha et al., 2024). Third, giving priority to degraded and post-mining land for solar and bioenergy (Leksono et al., 2021; Ronyastra et al., 2024) would ease the conflict with forest conservation.

CONCLUSION

Indonesia's energy transition and its biodiversity agenda depend on the same land and water, yet the research behind them has grown up in separate communities. Having read 220 studies published between 2021 and 2026, we can now answer our four questions. On ecological impacts (RQ1), the documented footprint includes fragmentation around hydropower and geothermal sites, altered river flows, local soil contamination and, most clearly, forest loss linked to nickel mining. Only nickel and Batang Toru have been studied with robust causal designs. For solar, wind and geothermal energy, what we know rests on one-off surveys and experiments, most of them in Java.

On spatial planning (RQ2), Indonesian RE siting uses sophisticated GIS, MCDA and remote-sensing methods, but biodiversity enters only by the back door. Two of 36 siting studies refer to protected areas or biodiversity, and none estimates how much RE potential would remain once ecological constraints were applied.

On land competition and governance (RQ3), bioenergy targets and transition minerals exert the heaviest pressure on land. How that pressure plays out depends on how land is acquired, how well science informs policy and how far communities can influence decisions. Geothermal development in conservation forests and centralised nickel governance show how weak institutions can turn a technical trade-off into a lasting conflict.

For Gorontalo and Wallacea (RQ4), most of the data needed for integrated planning already exist: energy-system models, land-use projections, species distribution models and marine spatial plans. They have simply not been connected. The framework we propose connects them by applying ecological exclusions and sensitivity costs before multi-criteria siting, and then comparing energy scenarios on both financial and ecological cost. The overlap between maleo nesting habitat and the surface features that geothermal exploration targets is a concrete example of a conflict such a framework would reveal before drilling begins.

Our review has limits. It relies on a single database and on English-language studies; its screening and synthesis rest on titles and abstracts rather than full texts, and our exports did not support citation analysis. The next steps are clear enough: extend the corpus to national journals and environmental impact assessments, apply causal designs to RE projects, and test the proposed framework in a Wallacean province, starting with Gorontalo.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

Creative Commons Attribution License 4.0

This is an open-access article published under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0).

https://creativecommons.org/licenses/by/4.0

REFERENCES

1. Abdullah, A. G., Aziz, M., & Chairulloh, A. (2025). Smart decision-making with GIS: Advanced multi-criteria analysis for solar–wind hybrid renewable energy systems. *Arabian Journal for Science and Engineering*, *50*(21), 17989–18014. https://doi.org/10.1007/s13369-025-10259-x

2. Abdullah, A. G., Setiorini, A. H., Dwitasari, N. A., Hakim, D. L., & Aziz, M. (2021). Location suitability analysis for wind farm exploitation using fuzzy analytic hierarchy process. *Indonesian Journal of Science and Technology*, *6*(3), 523–534. https://doi.org/10.17509/ijost.v6i3.38957
3. Adiansyah, J. S., Agusdinata, D. B., & Putra, A. P. (2025). Environmental impacts of solar PV energy systems for small-island communities in Indonesia: A life cycle assessment approach. *Energy for Sustainable Development*, *85*, Article 101651. https://doi.org/10.1016/j.esd.2025.101651
4. Ahimsa, A. (2025). Chasing the shadow of green energy transition: Ineffective policy advocacy towards Dieng 2 geothermal mining. *Jurnal Ilmu Sosial dan Ilmu Politik*, *29*(2), 211–227. https://doi.org/10.22146/jsp.102134
5. Alamsyah, M. N., Chandra, A., & Arief, M. (2025). Governing the infrastructure in Indonesia: An empirical evidence from the Sulewana hydropower plants of Lake Poso, Central Sulawesi. *Acta Scientiarum Polonorum, Administratio Locorum*, *24*(4), 533–549. https://doi.org/10.31648/aspal.11366
6. Aldiansyah, S., Risna, & Saputra, R. A. (2024). Assessing potential distributions of bird endemic species: Case studies of Macrocephalon maleo and Rhyticeros cassidix and their threats. *Geomatics and Environmental Engineering*, *18*(3), 45–61. https://doi.org/10.7494/geom.2024.18.3.45
7. Ali, P. O., & Kim, K. N. (2024). Analysis of Indonesia's priority selection: Energy transition, energy-related measures, mining governance, and resource transition using the analytic hierarchy process (AHP). *Energy for Sustainable Development*, *83*, Article 101559. https://doi.org/10.1016/j.esd.2024.101559
8. Andini, S., Suwartha, N., Setiawan, E. A., & Ma'arif, S. (2022). Analysis of biological, chemical, and physical parameters to evaluate the effect of floating solar PV in Mahoni Lake, Depok, Indonesia: Mesocosm experiment study. *Journal of Ecological Engineering*, *23*(4), 201–207. https://doi.org/10.12911/22998993/146385
9. Anggreta, D. K., Somantri, G. R., & Purwanto, S. A. (2022). Social acceptance: Mapping the perspectives of stakeholder in the development of geothermal power plants in West Sumatra, Indonesia. *International Journal of Sustainable Development and Planning*, *17*(4), 1053–1065. https://doi.org/10.18280/ijsdp.170402
10. Aziz, A., Majid, N. C., Fikriyadi, Z. A., Dwijatmiko, A., & Lee, S. (2025). Agrivoltaics systems in Indonesia: Opportunities, challenges, and lessons from other countries. *AIMS Energy*, *13*(5), 1076–1103. https://doi.org/10.3934/energy.2025040
11. Azizah, L., & Singh, M. (2026). Sourcing critical metal from critical habitat: Is the trade-off worth making? *Land*, *15*(2), Article 273. https://doi.org/10.3390/land15020273
12. Bakari, O., Arsyad, U., Demmalino, E. B., Naping, H., Latief, M. I., & Soma, A. S. (2025). Ecological justice in land use management: The case study of the upstream Limboto watershed in Indonesia. *Engineering, Technology and Applied Science Research*, *15*(6), 29523–29528. https://doi.org/10.48084/etasr.13727
13. Bastos Lima, M. G. (2022). Just transition towards a bioeconomy: Four dimensions in Brazil, India and Indonesia. *Forest Policy and Economics*, *136*, Article 102684. https://doi.org/10.1016/j.forpol.2021.102684
14. Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., & Carbone, G. (2021). *Mitigating biodiversity impacts associated with solar and wind energy development: Guidelines for project developers*. IUCN; The Biodiversity Consultancy. https://doi.org/10.2305/IUCN.CH.2021.04.en
15. Cabernard, L., & Pfister, S. (2022). Hotspots of mining-related biodiversity loss in global supply chains and the potential for reduction through renewable electricity. *Environmental Science and Technology*, *56*(22), 16357–16368. https://doi.org/10.1021/acs.est.2c04003
16. Choi, C. S., Ravi, S., Siregar, I. Z., Dwiyanti, F. G., Macknick, J., Elchinger, M., & Davatzes, N. C. (2021). Combined land use of solar infrastructure and agriculture for socioeconomic and environmental co-benefits in the tropics. *Renewable and Sustainable Energy Reviews*, *151*, Article 111610. https://doi.org/10.1016/j.rser.2021.111610

17. Condro, A. A., Prasetyo, L. B., Rushayati, S. B., Santikayasa, I. P., & Iskandar, E. (2021). Predicting hotspots and prioritizing protected areas for endangered primate species in Indonesia under changing climate. *Biology*, *10*(2), 1–23. https://doi.org/10.3390/biology10020154
18. Condro, A. A., Prasetyo, L. B., Rushayati, S. B., Santikayasa, I. P., & Iskandar, E. (2022). Protected areas slow down tropical rainforest disturbance in the Leuser Ecosystem, Indonesia. *Journal of Land Use Science*, *17*(1), 454–470. https://doi.org/10.1080/1747423X.2022.2115571
19. Damanik, A., Janssen, D. J., Tournier, N., Stelbrink, B., von Rintelen, T., Haffner, G., Cohen, A., Yudawati Cahyarini, S., & Vogel, H. (2024). Perspectives from modern hydrology and hydrochemistry on a lacustrine biodiversity hotspot: Ancient Lake Poso, Central Sulawesi, Indonesia. *Journal of Great Lakes Research*, *50*(3), Article 102254. https://doi.org/10.1016/j.jglr.2023.102254
20. Darmawan, A., Asyhari, T., Dunggio, I., Salmahaminati, & Aziz, M. (2024). Energy harvesting from tropical biomasses in Wallacea region: Scenarios, technologies, and perspectives. *Biomass Conversion and Biorefinery*, *14*(17), 20017–20035. https://doi.org/10.1007/s13399-023-04223-8
21. Dewi, S., Mulia, R., Johana, F., Ekadinata, A., & van Noordwijk, M. (2023). Integrating relational and instrumental values of nature in planning land use for multiple ecosystem services (LUMENS): Tools and process. *Current Opinion in Environmental Sustainability*, *64*, Article 101333. https://doi.org/10.1016/j.cosust.2023.101333
22. Dirgantara, A. P., Megantara, E. N., Husodo, T., Febrianto, P., Wulandari, I., & Shanida, S. S. (2021). The existence of Asian small-clawed otter (Aonyx cinereus Illiger, 1815) in the UCPS hydropower, Cianjur, West Java, Indonesia. *Biodiversitas*, *22*(10), 4391–4401. https://doi.org/10.13057/biodiv/d221032
23. Djafar, A. G., Pratiwi, N., Mohamad, Y., & Zhai, Z. J. (2025). The application potential of net zero energy building using rooftop photovoltaics case study of apartments in Gorontalo Province. *International Journal of Applied Power Engineering*, *14*(3), 743–751. https://doi.org/10.11591/ijape.v14.i3.pp743-751
24. Djafar, A. G., Pratiwi, N., Rahmayanti, & Mutmainnah, N. (2023). Analysis of suitable roof designs for a photovoltaic panel: A case study of housing roof in Gorontalo. *Engineering Proceedings*, *53*(1), Article 17. https://doi.org/10.3390/IOCBD2023-15212
25. Djafar, N. W. R. E. M. I., Soma, A. S., Achmad, M., & Hakiki, L. K. (2026). Land cover change and urban growth in North Gorontalo Regency using Sentinel-2 imagery. *Ecological Engineering and Environmental Technology*, *27*(3), 341–367. https://doi.org/10.12912/27197050/218187
26. Dunnett, S., Holland, R., Taylor, G., & Eigenbrod, F. (2022). Predicted wind and solar energy expansion has minimal overlap with multiple conservation priorities across global regions. *Proceedings of the National Academy of Sciences*, *119*(6), Article e2104764119. https://doi.org/10.1073/pnas.2104764119
27. Dwiyahreni, A. A., Fuad, H. A., Sunaryo, Soesilo, T. E. B., Margules, C., & Supriatna, J. (2021). Forest cover changes in Indonesia's terrestrial national parks between 2012 and 2017. *Biodiversitas*, *22*(3), 1235–1242. https://doi.org/10.13057/biodiv/d220320
28. Estradivari, Agung, M. F., Adhuri, D. S., Ferse, S. C., Sualia, I., Andradi-Brown, D. A., Campbell, S. J., Iqbal, M., Jonas, H. D., Lazuardi, M. E., Nanlohy, H., Pakiding, F., Pusparini, N. K. S., Ramadhana, H. C., Ruchimat, T., Santiadji, I. W. V., Timisela, N. R., Veverka, L., & Ahmadia, G. N. (2022). Marine conservation beyond MPAs: Towards the recognition of other effective area-based conservation measures (OECMs) in Indonesia. *Marine Policy*, *137*, Article 104939. https://doi.org/10.1016/j.marpol.2021.104939
29. Estradivari, Kartika, I., Adhuri, D. S., Adrianto, L., Agung, F., Ahmadia, G. N., Bejarano, S., Campbell, S. J., Fachri, F. R., Kushardanto, H., Marlessy, C., Pane, B., Puebla, O., Purnama, R. C., Santiadji, I. W. V., Suherfian, W., Tillah, M., Widodo, H., Wild, C., & Ferse, S. C. (2024). Prospective ecological contributions of potential marine OECMs and MPAs to enhance marine conservation in Indonesia. *Ocean and Coastal Management*, *258*, Article 107411.

https://doi.org/10.1016/j.ocecoaman.2024.107411

30. Gaveau, D. L. A., Locatelli, B., Salim, M. A., Husnayaen, Manurung, T., Descals, A., Angelsen, A., Meijaard, E., & Sheil, D. (2022). Slowing deforestation in Indonesia follows declining oil palm expansion and lower oil prices. *PLoS ONE*, *17*(3), Article e0266178. https://doi.org/10.1371/journal.pone.0266178
31. Giljum, S., Maus, V., Kuschnig, N., Luckeneder, S., Tost, M., Sonter, L. J., & Bebbington, A. J. (2022). A pantropical assessment of deforestation caused by industrial mining. *Proceedings of the National Academy of Sciences*, *119*(38), Article e2118273119. https://doi.org/10.1073/pnas.2118273119
32. Graham, V., Geldmann, J., Adams, V. M., Grech, A., Deinet, S., & Chang, H. (2021). Management resourcing and government transparency are key drivers of biodiversity outcomes in Southeast Asian protected areas. *Biological Conservation*, *253*, Article 108875. https://doi.org/10.1016/j.biocon.2020.108875
33. Gunawan, T. S., Hamidah, M., Rahayu, A. K., Septiani, N. N., Pingkan, J., Hermansyah, A., Farhan, M., Sholihah, R., Arundina, A. B., Minarni, D. R., Susanti, R., Gustiar, G. G., Kusumastuti, D. N., Maharani, G. R., Nurhakim, M. D., Khalishah, P. V., Rahman, I. F., Nugianto, N., Hakim, A., . . . Yulianto, I. (2025). National-scale mapping of ecosystems to improve ocean accounting for marine and coastal management in Indonesia. *One Ecosystem*, *10*, Article e155166. https://doi.org/10.3897/oneeco.10.e155166
34. Gustama, M. A., Ar Rouf, F. B., & Adianto, M. O. (2026). Interpretasi sistem panas bumi Suwawa berdasarkan sudut pandang tektonik dan anomali gravitasi [Interpretation of the Suwawa geothermal system from tectonic and gravity-anomaly perspectives]. *Jurnal Pendidikan, Sains, Geologi, dan Geofisika (GeoScienceEd Journal)*, *7*(1), 595–601. https://doi.org/10.29303/goescienceed.v7i1.1719
35. Haidir, I. A., Wearn, O. R., Deere, N. J., Struebig, M. J., Dohong, A., Macdonald, D. W., & Linkie, M. (2024). Prioritizing wildlife conservation along habitat gradients in Sumatra. *Biological Conservation*, *299*, Article 110795. https://doi.org/10.1016/j.biocon.2024.110795
36. Hakim, A., Taurusman, A. A., Wiryawan, B., Purbayanto, A., Darmawan, R., & Yulianto, I. (2026). Systematic conservation planning for pelagic fish habitats in the Sulawesi Sea, Indonesia. *Biodiversitas*, *27*(5). https://doi.org/10.13057/biodiv/d270513
37. Hakim, A., Wiryawan, B., Purbayanto, A., Taurusman, A. A., Agung, F., Simanjuntak, C. P. H., Ningtias, P., Prasetia, R., Kartawijaya, T., Andayani, N., Natsir, M., Agustina, S., Retnoningtyas, H., Nabil, Darmawan, R., Herdiana, Y., & Yulianto, I. (2025). Spawning and nursery areas of Decapterus macarellus: Siting pelagic fisheries marine protected area (MPA) in the Sulawesi Sea, Indonesia. *Frontiers in Marine Science*, *12*, Article 1606963. https://doi.org/10.3389/fmars.2025.1606963
38. Halimatussadiah, A., Nainggolan, D., Yui, S., Moeis, F., & Siregar, A. (2021). Progressive biodiesel policy in Indonesia: Does the government's economic proposition hold? *Renewable and Sustainable Energy Reviews*, *150*, Article 111431. https://doi.org/10.1016/j.rser.2021.111431
39. Hamidun, M. S., Baderan, D. W. K., Dunggio, I., & Lamangantjo, C. J. (2025). Plant diversity with high conservation value in oil palm plantation in Pohuwato Regency, Gorontalo, Indonesia. *Environment and Ecology Research*, *13*(6), 821–837. https://doi.org/10.13189/eer.2025.130606
40. Hanum, W. N., Handayani, I. G. A. K. R., & Tegnan, H. (2023). The geothermal development policy on environmental in Indonesia and the USA. *Journal of Human Rights, Culture and Legal System*, *3*(2), 160–184. https://doi.org/10.53955/jhcls.v3i2.85
41. Heijlen, W., & Duhayon, C. (2024). An empirical estimate of the land footprint of nickel from laterite mining in Indonesia. *Extractive Industries and Society*, *17*, Article 101421. https://doi.org/10.1016/j.exis.2024.101421
42. Heimann, T., Argueyrolles, R., Reinhardt, M., Schuenemann, F., Söder, M., & Delzeit, R. (2024). Phasing out palm and soy oil biodiesel in the EU: What is the benefit? *GCB Bioenergy*, *16*(1), Article e13115. https://doi.org/10.1111/gcbb.13115

43. Herfiantara, B., & Famiola, M. (2023). The ecosystem of shared value model for the community development program in Saguling hydroelectric power station area (West Java). *International Journal of Professional Business Review*, *8*(4), Article e01476. https://doi.org/10.26668/businessreview/2023.v8i4.1476
44. Hughes, L. J., Deere, N. J., Radinal, Primadona, E., Roddini, M., Massie, M., Seaman, D. J. I., Hutabarat, J., Budiharta, S., Avriandy, R., Kiswayadi, D., Olsen, K., Smith, R. J., Winarni, N., Banin, L. F., & Struebig, M. J. (2026). Habitat connectivity shapes biodiversity outcomes in Indonesia's community-managed forests. *Journal of Applied Ecology*, *63*(8), Article e70518. https://doi.org/10.1111/1365-2664.70518
45. Husodo, T., Megantara, E. N., Mutaqin, A. Z., Kendarto, D. R., Withaningsih, S., Wulandari, I., Shanida, S. S., & Febrianto, P. (2024b). Rare, endangered, endemic, and protected species (REEPS) conservation in the Cisokan, West Java, Indonesia. *Biodiversitas*, *25*(12), 5094–5102. https://doi.org/10.13057/biodiv/d251247
46. Husodo, T., Megantara, E. N., Mutaqin, A. Z., Kendarto, D. R., Wulandari, I., & Shanida, S. S. (2022). Short communication: Leopard cat (Prionailurus bengalensis) distribution in the Cisokan hydropower plant, West Java, Indonesia. *Biodiversitas*, *23*(12), 6247–6253. https://doi.org/10.13057/biodiv/d231220
47. Husodo, T., Megantara, E. N., Mutaqin, A. Z., Kendarto, D. R., Wulandari, I., & Shanida, S. S. (2024a). The protection effort of leopard cats (Prionailurus bengalensis Kerr, 1792) in the Upper Cisokan Pumped Storage, West Java, Indonesia. Biodiversitas, 25(1), 169–176. https://doi.org/10.13057/biodiv/d250119
48. Husodo, T., Megantara, E. N., Rosandi, Y., Wulandari, I., Atsaury, Z. I. A., Aminuddin, S. F., Suroso, Shanida, S. S., & Tohir, Y. (2025). Bird diversity in a human-modified geothermal landscape of Kamojang, West Java, Indonesia. *Biodiversitas*, *26*(11), 5679–5693. https://doi.org/10.13057/biodiv/d261127
49. Hyldmo, H. d. S., Wardhani, I. S., Kurniawan, N. I., Cahayati, D. D., Rye, S. A., & Vela-Almeida, D. (2025). Urgent transition, urgent extraction? Global decarbonization, national governance, and local impacts in the Indonesian nickel industry. *Environmental Research Letters*, *20*(5), Article 054003. https://doi.org/10.1088/1748-9326/adc31c
50. Ibnusina, F., Purbayanto, A., Wiryawan, B., Novita, Y., & Yulianto, I. (2023). The zoning plan for coastal and small islands: An evaluation of its implementation on small-scaled fisheries in North Sulawesi waters of Indonesia. AACL Bioflux, 16(5), 2434–2453. https://www.bioflux.com.ro/docs/2023.2434-2453.pdf
51. Irawan, A., Peniwidiyanti, Ainurrofiah, Destrianto, H., Kusumah, M., & Apriandana, V. (2023). Floristic composition and structure of vegetation in Gunung Salak geothermal power plant, West Java, Indonesia. *Reinwardtia*, *22*(1), 37–53. https://doi.org/10.55981/reinwardtia.2023.4565
52. Kadir, A., Amir, M., Hos, J., Dewa, M. J., & Suaib, E. (2026). Misaligned governance in Indonesia's nickel boom: Design and capacity failures in the Mandiodo block. *Resources Policy*, *120*, Article 106018. https://doi.org/10.1016/j.resourpol.2026.106018
53. Karim, F. R., Masy'ud, B., & Hernowo, J. B. (2022). Nesting site characteristics and egg hatching success of maleo (Macrocephalon maleo) in Hungayono Sanctuary, Gorontalo. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan*, *12*(4), 570–578. https://doi.org/10.29244/jpsl.12.4.570-578
54. Karim, F. R., Masy'ud, B., & Hernowo, J. B. (2023). Welfare assessment of maleo chicks in Hungayono Sanctuary, Bogani Nani Wartabone National Park, Gorontalo. *Tropical Animal Science Journal*, *46*(1), 20–26. https://doi.org/10.5398/tasj.2023.46.1.20
55. Kasper, K., Devriance, N., Aran, K., & Martin, B. (2024). Conservation among oil palm plantations? Mammalian diversity in protected forest areas of a mixed-use landscape in Indonesian Borneo. *Animal Biodiversity and Conservation*, *47*(2), 123–134. https://doi.org/10.32800/abc.2024.47.0123
56. Kaszta, Ż., Cushman, S. A., Hearn, A., Sloan, S., Laurance, W. F., Haidir, I. A., & Macdonald, D. W. (2024). Projected development in Borneo and Sumatra will greatly reduce connectivity for an apex

carnivore. *Science of the Total Environment*, *918*, Article 170256. https://doi.org/10.1016/j.scitotenv.2024.170256

57. Kati, V., Kassara, C., Vrontisi, Z., & Moustakas, A. (2021). The biodiversity-wind energy-land use nexus in a global biodiversity hotspot. *Science of the Total Environment*, *768*, Article 144471. https://doi.org/10.1016/j.scitotenv.2020.144471
58. Kennedy, S. F., & Qayyum, F. (2024). Land acquisition governance and its implications for renewable energy development in Indonesia and the Philippines. *Journal of Planning Education and Research*, *44*(4), 2056–2067. https://doi.org/10.1177/0739456X221147859
59. Kruitwagen, L., Story, K. T., Friedrich, J., Byers, L., Skillman, S., & Hepburn, C. (2021). A global inventory of photovoltaic solar energy generating units. *Nature*, *598*(7882), 604–610. https://doi.org/10.1038/s41586-021-03957-7
60. Kuntoro, A. A., Roesbianto, A. S. B., Farid, M., Kardhana, H., Rohmat, F. I. W., Rizaldi, A., Kusuma, M. S. B., Adityawan, M. B., & Wahid, A. N. (2024). Utilization of satellite data in determining hydropower potential to support energy security in new capital city region of Indonesia. *Frontiers in Earth Science*, *12*, Article 1371356. https://doi.org/10.3389/feart.2024.1371356
61. Langer, J., Cahyaningwidi, A. A., Chalkiadakis, C., Quist, J., Hoes, O., & Blok, K. (2021). Plant siting and economic potential of ocean thermal energy conversion in Indonesia a novel GIS-based methodology. *Energy*, *224*, Article 120121. https://doi.org/10.1016/j.energy.2021.120121
62. Langer, J., Kwee, Z., Zhou, Y., Isabella, O., Ashqar, Z., Quist, J., Praktiknjo, A., & Blok, K. (2023). Geospatial analysis of Indonesia's bankable utility-scale solar PV potential using elements of project finance. *Energy*, *283*, Article 128555. https://doi.org/10.1016/j.energy.2023.128555
63. Leksono, B., Rahman, S. A., Larjavaara, M., Purbaya, D. A., Arpiwi, N. L., Samsudin, Y. B., Artati, Y., Windyarini, E., Sudrajat, D. J., Aminah, A., Maulana, A. M., Bhatta, K. P., Kwon, J., & Baral, H. (2021). Pongamia: A possible option for degraded land restoration and bioenergy production in Indonesia. *Forests*, *12*(11), Article 1468. https://doi.org/10.3390/f12111468
64. Lestari, D. A., Yonvitner, Damar, A., Kurniawan, F., & Nurjaya, I. W. (2026). How effective is regional spatial plan for coastal habitat quality? An exercise in Bengkulu City, Indonesia. *Journal of Coastal Conservation*, *30*(4), Article 82. https://doi.org/10.1007/s11852-026-01265-8
65. Lihawa, F., Lahay, R. J., Dunggio, I., Machmud, A. N. F., & Djuraini, M. F. (2026). Coupled socio-ecological modelling of land-use dynamics and erosion risks in Bolango Watershed, Indonesia. *Journal of Water and Land Development*, *2026*(70), 232–245. https://doi.org/10.24425/jwld.2026.3631
66. Lim, F. K. S., Carrasco, L. R., Edwards, D. P., & McHardy, J. (2024). Land-use change from market responses to oil palm intensification in Indonesia. *Conservation Biology*, *38*(1), Article e14149. https://doi.org/10.1111/cobi.14149
67. Lo, M. G., Morgans, C. L., Santika, T., Mumbunan, S., Winarni, N., Supriatna, J., Voigt, M., Davies, Z. G., & Struebig, M. J. (2024). Nickel mining reduced forest cover in Indonesia but had mixed outcomes for well-being. *One Earth*, *7*(11), 2019–2033. https://doi.org/10.1016/j.oneear.2024.10.010
68. Lubis, M. I., Lee, J. S. H., Rahmat, U., Tarmizi, Ramadiyanta, E., Melvern, D., Suryometaram, S., Trihangga, A., Isa, M., Yansyah, D., Abdullah, R., Ardiantiono, Marthy, W., Jones, K. R., Andayani, N., & Linkie, M. (2023). Planning for megafauna recovery in the tropical rainforests of Sumatra. *Frontiers in Ecology and Evolution*, *11*, Article 1174708. https://doi.org/10.3389/fevo.2023.1174708
69. Luckeneder, S., Giljum, S., Schaffartzik, A., Maus, V., & Tost, M. (2021). Surge in global metal mining threatens vulnerable ecosystems. *Global Environmental Change*, *69*, Article 102303. https://doi.org/10.1016/j.gloenvcha.2021.102303
70. Mangiwa, L., Saputra, I., Sirimorok, N., Malamassam, D., Santika, T., & Sahide, M. A. K. (2026). The making of triple frontier in mineral extraction, conservation, and agrarian livelihoods. *Geoforum*, *177*, Article 104852.

https://doi.org/10.1016/j.geoforum.2026.104852

71. Maria, R., Nurohman, H., Lestiana, H., Ernowo, E., Jakah, J., Shoedarto, R. M., Dida, E. N., Rahayudin, Y., Fahimah, N., & Nugraha, W. C. (2025). Source apportionment, ecological and health risk assessment of heavy metals in soils of the Wayang Windu geothermal field, Indonesia. *International Journal of Design and Nature and Ecodynamics*, *20*(10), 2233–2246. https://doi.org/10.18280/ijdne.201003
72. Mayr, S., Hollaus, B., & Madner, V. (2021). Palm oil, the RED II and WTO law: EU sustainable biofuel policy tangled up in green? *Review of European, Comparative and International Environmental Law*, *30*(2), 233–248. https://doi.org/10.1111/reel.12386
73. Megantara, E. N., Husodo, T., Kendarto, D. R., Mutaqin, A. Z., Withaningsih, S., Wulandari, I., Shanida, S. S., Febrianto, P., & Hendrawan, R. (2024). Records of Java mouse-deer (Tragulus javanicus Gmelin, 1788) in the Cisokan forest patches, West Java, Indonesia. *Biodiversitas*, *25*(8), 2713–2719. https://doi.org/10.13057/biodiv/d250844
74. Megantara, E. N., Husodo, T., Mutaqin, A. Z., Kendarto, D. R., Wulandari, I., Pujianto, M. P., Shanida, S. S., & Afriyanti, F. (2025). Exploring habitat characteristics and herpetofauna diversity in the Kamojang and Darajat geothermal power plants, West Java, Indonesia. *Biodiversitas*, *26*(1), 212–230. https://doi.org/10.13057/biodiv/d260122
75. Mohamad, Y., Salim, S., Amali, L. M. K., & Djafar, A. G. (2023). Mapping of lamtoro field in supporting the co-firing of steam power plants program. *International Journal of Applied Power Engineering*, *12*(1), 37–48. https://doi.org/10.11591/ijape.v12.i1.pp37-48
76. Muenzel, D., Critchell, K., Cox, C., Campbell, S. J., Jakub, R., Chollett, I., Krueck, N., Holstein, D., Treml, E. A., & Beger, M. (2023). Comparing spatial conservation prioritization methods with site- versus spatial dependency-based connectivity. *Conservation Biology*, *37*(2), Article e14008. https://doi.org/10.1111/cobi.14008
77. Muenzel, D., Stewart, E., Andayani, N., Dumbrell, A. J., Jompa, J., Limmon, G., Supriatna, J., Tasirin, J. S., Winarni, N. L., Zakaria, Z., Davies, Z. G., Struebig, M. J., Beger, M., & Smith, R. J. (2026). Ridge-to-reef conservation avoids future deforestation and sediment exposure of coral reefs. *Biological Conservation*, *322*, Article 112058. https://doi.org/10.1016/j.biocon.2026.112058
78. Nasri, Nursaputra, M., Hamzah, A. S., Larekeng, S. H., Arif, A. R., & Ardiansyah, A. (2026). Understanding tree diversity in ultrabasic forests of Sulawesi, Indonesia for restoration and conservation planning. *Asian Journal of Forestry*, *10*(1), Article r100102. https://doi.org/10.13057/asianjfor/r100102
79. Niebuhr, B. B., Sant'Ana, D., Panzacchi, M., van Moorter, B., Sandström, P., Morato, R. G., & Skarin, A. (2022). Renewable energy infrastructure impacts biodiversity beyond the area it occupies. *Proceedings of the National Academy of Sciences*, *119*(48), Article e2208815119. https://doi.org/10.1073/pnas.2208815119
80. Novitasari, D., Sarjiya, Hadi, S. P., Budiarto, R., & Deendarlianto. (2023). The climate and land-use changes impact on water availability for hydropower plants in Indonesia. *Energy Strategy Reviews*, *46*, Article 101043. https://doi.org/10.1016/j.esr.2022.101043
81. Nugraha, R. T., Komara, W. Y., Krisna, P. A. N., Puspita, O. R., Muslich, M., Mardhiah, U., & Marthy, W. (2024). Evaluating the effectiveness of protected area management in Indonesia. *Oryx*, *58*(4), 474–484. https://doi.org/10.1017/S003060532300145X
82. Nur, W. H., Yuliana, Susilowati, Y., Kumoro, Y., & Yunarto. (2021). Overview about GIS multi-criteria spatial analysis for micro hydropower plant site suitability in South Ogan Komering Ulu District, South Sumatera, Indonesia. *Bulletin of Electrical Engineering and Informatics*, *10*(2), 1024–1034. https://doi.org/10.11591/eei.v10i2.2770
83. Nuraeni, S., Prastiyo, A., Larekeng, S. H., Ardiansyah, A., Aldi, & Jufri, S. W. (2025). Butterfly community structure in a rehabilitated post-mining tropical rainforest landscape, Sorowako, South Sulawesi, Indonesia. *Biodiversitas*, *26*(9), 4761–4774. https://doi.org/10.13057/biodiv/d260945
84. Nursaputra, M. (2026). Spatial heterogeneity of landscapes and land cover in Sulawesi Island in relation to water regulation

ecosystem services. *Environmental Monitoring and Assessment*, *198*(10), Article 1086. https://doi.org/10.1007/s10661-026-15892-z

85. OECD. (2024). *Mainstreaming biodiversity into renewable power infrastructure*. OECD Publishing. https://doi.org/10.1787/357ac474-en
86. Owen, J. R., Kemp, D., Lechner, A. M., Harris, J., Zhang, R., & Lèbre, É. (2023). Energy transition minerals and their intersection with land-connected peoples. *Nature Sustainability*, *6*(2), 203–211. https://doi.org/10.1038/s41893-022-00994-6
87. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., . . . Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, *372*, Article n71. https://doi.org/10.1136/bmj.n71
88. Pambudi, N. A., & Ulfa, D. K. (2024). The geothermal energy landscape in Indonesia: A comprehensive 2023 update on power generation, policies, risks, phase and the role of education. *Renewable and Sustainable Energy Reviews*, *189*, Article 114008. https://doi.org/10.1016/j.rser.2023.114008
89. Papilo, P., Marimin, M., Hambali, E., Machfud, M., Yani, M., Asrol, M., Evanila, E., Prasetya, H., & Mahmud, J. (2022). Palm oil-based bioenergy sustainability and policy in Indonesia and Malaysia: A systematic review and future agendas. *Heliyon*, *8*(10), Article e10919. https://doi.org/10.1016/j.heliyon.2022.e10919
90. Prabowo, B., Simatupang, N. A., Pertiwi, S. R., Elo, Y. L., Pratama, A. B., Madra, Q. N., Firnanda, M. R., & Prihantoro, R. (2026). Energy transition and conservation trade-offs: A systematic review of biodiversity, ecosystem, and health outcomes in Southeast Asia. *Environmental and Sustainability Indicators*, *31*, Article 101442. https://doi.org/10.1016/j.indic.2026.101442
91. Pramudita, D., Fauzi, A., & Nguyen, T. K. A. (2026). Assessing habitat risk to support marine spatial planning in Indramayu's coastal zone, Indonesia. *Anthropocene Coasts*, *9*(1), Article 18. https://doi.org/10.1007/s44218-026-00131-2
92. Prasetya, A., Riadi, A., Fakhri Muzhoffar, D. A., & Muhammad, A. W. (2025). Optimizing run-of-river small hydropower plants through environmental flow regulation using ANN, RSM, and MCDM: A case study in Indonesia. Sustainable Energy Technologies and Assessments, 83, Article 104636. https://doi.org/10.1016/j.seta.2025.104636
93. Prasetya, A., Riadi, A., & Muhammad, A. W. (2026). Optimisation strategy for run-of-river small hydropower plants using an e-flow approach to balance generated power and river ecological sustainability: A case study in Indonesia. International Journal of Hydrology Science and Technology, 21(1), 29–55. https://doi.org/10.1504/IJHST.2026.150575
94. Pratiwi, S., & Juerges, N. (2022a). Advocacy coalitions and knowledge transfer within geothermal policy change in Indonesian conservation forests. *Journal of Environment and Development*, *31*(2), 168–195. https://doi.org/10.1177/10704965211070244
95. Pratiwi, S., & Juerges, N. (2022b). Digital advocacy at the science-policy interface: Resolving land-use conflicts in conservation forests. *Land Use Policy*, *121*, Article 106310. https://doi.org/10.1016/j.landusepol.2022.106310
96. Purnama, I., Mutamima, A., Aziz, M., Wijaya, K., Maulida, I. D., Junaidi, J., Sari, K., Effendi, I., & Dini, I. R. (2025). Environmental impacts and the food vs. fuel debate: A critical review of palm oil as biodiesel. *GCB Bioenergy*, *17*(6), Article e70043. https://doi.org/10.1111/gcbb.70043
97. Pusparini, W., Cahyana, A., Grantham, H. S., Maxwell, S., Soto-Navarro, C., & Macdonald, D. W. (2023). A bolder conservation future for Indonesia by prioritising biodiversity, carbon and unique ecosystems in Sulawesi. *Scientific Reports*, *13*(1), Article 842. https://doi.org/10.1038/s41598-022-21536-2
98. Rahman, H., Hidayat, R. A., Nofrizal, A. Y., Wilastra, I., & Nasution, A. F. R. (2023). Priority corridor zone for human-tiger conflict mitigation: A landscape connectivity approach in West Sumatra region, Indonesia. *Journal for Nature Conservation*, *76*, Article

126501. https://doi.org/10.1016/j.jnc.2023.126501

99. Ronyastra, I. M., Saw, L. H., & Low, F. S. (2024). Techno-economic analysis with financial risk identification for solar power plant as post-mining land use in Indonesia. *Energy for Sustainable Development*, *80*, Article 101462. https://doi.org/10.1016/j.esd.2024.101462
100. Rudolph, D., Maulidia, M., & Busyrah, H. (2025). Solar–water nexus: On local implications of the procurement and deployment of the first floating solar photovoltaics project in Indonesia. *Sustainability Science*, *20*(4), 1393–1406. https://doi.org/10.1007/s11625-025-01637-3
101. Sadono, R., Wardana, W., Idris, F., & Wirabuana, P. Y. A. P. (2023). Developing energy production from Eucalyptus urophylla plantation in dryland ecosystem at East Nusa Tenggara, Indonesia. *Journal of Degraded and Mining Lands Management*, *10*(4), 4673–4681. https://doi.org/10.15243/jdmlm.2023.104.4673
102. Sakti, A. D., Ihsan, K. T. N., Anggraini, T. S., Shabrina, Z., Sasongko, N. A., Fachrizal, R., Aziz, M., Aryal, J., Yuliarto, B., Hadi, P. O., & Wikantika, K. (2022). Multi-criteria assessment for city-wide rooftop solar PV deployment: A case study of Bandung, Indonesia. *Remote Sensing*, *14*(12), Article 2796. https://doi.org/10.3390/rs14122796
103. Sakti, A. D., Prakoso, T., Santoso, C., Milliandza, J. A., Putra Garniwa, P. M., Susantoro, T. M., Wikantika, K., & Harto, A. B. (2026). Machine learning-based high resolution spatial economic modeling of biomass energy potential in Southeast Asia. *International Journal of Applied Earth Observation and Geoinformation*, *146*, Article 105081. https://doi.org/10.1016/j.jag.2025.105081
104. Salim, S., Wolok, E., & Tanipu, F. (2025). Sustainable energy planning case study of Tomini Bay region of Gorontalo Province. *Journal of Sustainable Development of Energy, Water and Environment Systems*, *13*(3), Article 1130588. https://doi.org/10.13044/j.sdewes.d13.0588
105. Salmon, R. M., Arif, S., & Darhamsyah. (2026). Ecological dynamics and carbon sequestration in the 150 kV Tentena–Kolonedale transmission corridor. *Ecological Engineering and Environmental Technology*, *27*(9), 459–469. https://doi.org/10.12912/27197050/226627
106. Sarjiya, Putranto, L. M., Tumiran, Budi, R. F. S., Novitasari, D., & Deendarlianto. (2023). Generation expansion planning with a renewable energy target and interconnection option: A case study of the Sulawesi region, Indonesia. *Renewable and Sustainable Energy Reviews*, *183*, Article 113489. https://doi.org/10.1016/j.rser.2023.113489
107. Seran, K., Rotimi, J. O. B., & Le, A. (2026). Prioritizing renewable energy development criteria in Indonesia using analytic hierarchy process (AHP) for sustainable development goals (SDGs). *International Journal of Sustainable Energy*, *45*(1), Article 2719359. https://doi.org/10.1080/14786451.2026.2719359
108. Serdiati, N., Arfiati, D., Widodo, M. S., Lelono, T. D., Ndobe, S., Mansyur, K., & Moore, A. M. (2021). Perspectives on sustainable management of the Poso Lake (Indonesia) endemic ricefish, Oryzias nigrimas (Actinopterygii: Adrianichthyidae). *Revista de Biologia Tropical*, *69*(1), 139–152. https://doi.org/10.15517/RBT.V69I1.42404
109. Setiawan, O., Nugroho, H., Wahyuningrum, N., Auliyani, D., & Hardjo, K. (2024). A suitability modeling based on geographic information system for potential micro hydropower dam site. *Global Journal of Environmental Science and Management*, *10*(2), 713–732. https://doi.org/10.22035/gjesm.2024.02.18
110. Shanida, S. S., Megantara, E. N., Husodo, T., Mutaqin, A. Z., Kendarto, D. R., & Wulandari, I. (2023). Habitat preference of leopard cat (Prionailurus bengalensis Kerr. 1792) in the Cisokan hydropower development area, West Java, Indonesia. *Biodiversitas*, *24*(4), 2284–2293. https://doi.org/10.13057/biodiv/d240442
111. Silalahi, D. F., & Blakers, A. (2023). Global atlas of marine floating solar PV potential. *Solar*, *3*(3), 416–433. https://doi.org/10.3390/solar3030023
112. Siregar, Y. I. (2022). Ranking of energy sources for sustainable electricity generation in Indonesia: A participatory multi-criteria analysis. *International Journal of*

Sustainable Energy Planning and Management, *35*, 45–64. https://doi.org/10.54337/ijsepm.7241

113. Smith, J. D., Susilowati, M. H., Maarif, S., & Cahyono, E. (2026). When energy transitions drive polarization: Narratives of green energy and mitigation strategies by proponents and opponents of geothermal energy developments in Indonesia. *Energy Policy*, *210*, Article 115080. https://doi.org/10.1016/j.enpol.2026.115080
114. Soekarno, I., Sebayang, I. S. D., Nugroho, E. O., Widyaningtias, Wahyudi, D. P., Huseiny, M. I., Oriandra, R. D., Putri, E. S., & Arisiwe, I. E. (2026). An extended environmental flow assessment in regulated rivers: Integrating hydraulic modelling, habitat suitability, and water quality. *Journal of Sustainable Development of Energy, Water and Environment Systems*, *14*(3), Article 1140710. https://doi.org/10.13044/j.sdewes.d14.0710
115. Squire, C. V., Lou, J., Parker, K. J., Schreier, M. A., Hilde, T. C., Sari, A., Lohff, L. C., Shah, K., & Hultman, N. (2026). Land-use optimization for food security, bioenergy and forest conservation in Indonesia. *Nature Sustainability*. https://doi.org/10.1038/s41893-026-01923-7
116. Sreekar, R., Ardiantiono, Ni'am, L., Meyers, K., Lim, J. Y., Zeng, Y., Lamba, A., Teo, H. C., Siregar, E. A., Muharyanda, F., Mammides, C., Violetta, I., Tambunan, R. W., Tambunan, K. J., Ng, S. J., & Watson, J. E. (2026). Disentangling the impacts of agriculture, logging, and extractive industries on Tapanuli orangutan habitat: A geo-ethnographic assessment. *Biological Conservation*, *321*, Article 111960. https://doi.org/10.1016/j.biocon.2026.111960
117. Suci, F. R. Z., & Muhamad, I. B. (2026). Land suitability for wind farm development in Pandeglang Regency, Banten Province, Indonesia. *Kompleksnoe Ispolzovanie Mineralnogo Syra*, *337*(2), 55–65. https://doi.org/10.31643/2026/6445.17
118. Suprajaka, S., Cahya, D. L., Puspateja, A., Kurniawan, S., Nurhaidar, W. O., Gaffara, G. R., Windiastuti, R., Rahadiati, A., Pranoto, B., & Nahib, I. (2026). Spatially explicit systematic conservation planning based on multi-ecosystem services in an urban tropical watershed: A case study of the Citarum watershed, Indonesia. *International Journal of Sustainable Development and Planning*, *21*(8), 3529–3549. https://doi.org/10.18280/ijsdp.210810
119. Susilowati, M. H., Smith, J. D., Maarif, S., & Cahyono, E. (2026). Geothermal narratives and grassroots resistance in Indonesia: Decolonial frameworks for energy transitions and environmental justice. *Capitalism, Nature, Socialism*, *37*(3), 170–186. https://doi.org/10.1080/10455752.2025.2607977
120. Susilowati, Y., Irasari, P., Kumoro, Y., Nur, W. H., & Yunarto. (2021). Micro hydropower plant potential study based on Landsat 8 operational land imager satellite data. *Bulletin of Electrical Engineering and Informatics*, *10*(6), 3167–3177. https://doi.org/10.11591/EEI.V10I6.3208
121. Tapia, J. F. D., Doliente, S. S., & Samsatli, S. (2021). How much land is available for sustainable palm oil? *Land Use Policy*, *102*, Article 105187. https://doi.org/10.1016/j.landusepol.2020.105187
122. Terzano, D., Trezza, F. R., Rezende, M., Malatesta, L., Lew Siew Yan, S., Parish, F., Moss, P., Bresciani, F., Cooke, R., Dargusch, P., & Attorre, F. (2023). Prioritization of peatland restoration and conservation interventions in Sumatra, Kalimantan and Papua. *Journal for Nature Conservation*, *73*, Article 126388. https://doi.org/10.1016/j.jnc.2023.126388
123. Tolodo, D. D., Manyoe, I. N., & Arifin, Y. I. (2022). Geochemistry characteristics of the Hungayono geothermal area for the development of clean energy in Gorontalo Province. *IOP Conference Series: Earth and Environmental Science*, *1089*, Article 012020. https://doi.org/10.1088/1755-1315/1089/1/012020
124. Tyson, A., & Meganingtyas, E. (2022). The status of palm oil under the European Union's Renewable Energy Directive: Sustainability or protectionism? *Bulletin of Indonesian Economic Studies*, *58*(1), 31–54. https://doi.org/10.1080/00074918.2020.1862411
125. Utomo, D. P., Subrata, M. E., & Dhelika, R. (2025). Decarbonization roadmap and energy system scenarios for Southern Sulawesi system: Response to demand growth from smelters sector. *Journal of*

Asian Energy Studies, *9*, 149–171. https://doi.org/10.24112/jaes.090009

126. Voigt, M., Supriatna, J., Deere, N. J., Kastanya, A., Mitchell, S. L., Rosa, I. M. D., Santika, T., Siregar, R., Tasirin, J. S., Widyanto, A., Winarni, N. L., Zakaria, Z., Mumbunan, S., Davies, Z. G., & Struebig, M. J. (2021). Emerging threats from deforestation and forest fragmentation in the Wallacea centre of endemism. *Environmental Research Letters*, *16*(9), Article 094048. https://doi.org/10.1088/1748-9326/ac15cd
127. Wang, C., Chung, Y., Wibowo, F. D., Dang, T., & Nguyen, N. (2023). Site selection of solar power plants using hybrid MCDM models: A case study in Indonesia. *Energies*, *16*(10), Article 4042. https://doi.org/10.3390/en16104042
128. Wang, C., Chung, Y., Wibowo, F. D., Dang, T., & Nguyen, N. (2025). The planning of best site selection for wind energy in Indonesia: A synergistic approach using data envelopment analysis and fuzzy multi-criteria decision-making. *Energies*, *18*(15), Article 4176. https://doi.org/10.3390/en18154176
129. Wang, S., Chen, B., Sun, Z., Long, X., Xue, M., Yu, H., Sun, M., & Wang, Y. (2023). The booming non-food bioeconomy drives large share of global land-use emissions. *Global Environmental Change*, *83*, Article 102760. https://doi.org/10.1016/j.gloenvcha.2023.102760
130. White, A., Rudyanto, Agung, M. F., Minarputri, N., Lestari, A. P., Wen, W., Fajariyanto, Y., Green, A., & Tighe, S. (2021). Marine protected area networks in Indonesia: Progress, lessons and a network design case study covering six eastern provinces. *Coastal Management*, *49*(6), 575–597. https://doi.org/10.1080/08920753.2021.1967560
131. Wibowo, A., Kurniawan, K., Prakoso, V. A., Ginanjar, R., Rochman, F., Zamroni, M., Atminarso, D., Sumarto, B. K. A., Chadijah, A., Irawan, D., Deniansen, T., Suriani, I., Syamsi, A. N., Achmadi, A., Surbani, I. L., Akbar, S. A., Hubert, N., Robinson, W., Stuart, I. G., & Baumgartner, L. J. (2025). Characterizing spatial patterns among freshwater fishes and shrimps of the Poso River (Sulawesi, Indonesia) using DNA barcoding. *Aquatic Sciences*, *87*(1), Article 2. https://doi.org/10.1007/s00027-024-01128-0
132. Wu, G. C., Jones, R. A., Leslie, E., Williams, J. H., Pascale, A., Brand, E., Parker, S. S., Cohen, B. S., Fargione, J. E., Souder, J., Batres, M., Gleason, M. G., Schindel, M. H., & Stanley, C. K. (2023). Minimizing habitat conflicts in meeting net-zero energy targets in the western United States. *Proceedings of the National Academy of Sciences*, *120*(4), Article e2204098120. https://doi.org/10.1073/pnas.2204098120
133. Wu, H., Budi, I., West, S., & Almashor, M. (2026). Floating utility-scale photovoltaic site selection in Indonesia: A multi-criteria decision analysis approach. *International Journal of Sustainable Energy*, *45*(1), Article 2607911. https://doi.org/10.1080/14786451.2025.2607911
134. Wulandari, W., Testriono, & Karim, M. F. (2026). Adopting the palm oil moratorium under external pressure: Indonesia's response to the EU's RED II. *Forest Policy and Economics*, *182*, Article 103692. https://doi.org/10.1016/j.forpol.2025.103692
135. Xu, Y., Yu, L., Ciais, P., Li, W., Santoro, M., Yang, H., & Gong, P. (2022). Recent expansion of oil palm plantations into carbon-rich forests. *Nature Sustainability*, *5*(7), 574–577. https://doi.org/10.1038/s41893-022-00872-1
136. Yahya, & Junaidi, M. (2026). When ecology encounters industry: Dynamics of local community and floodings in the Bahodopi Morowali mining area of Central Sulawesi, Indonesia. *Forest and Society*, *10*(2), 624–647. https://doi.org/10.65844/2549-4333.1271
137. Yu, L., Cao, Y., Cheng, Y., Zhao, Q., Xu, Y., Kanniah, K., Lu, H., Yang, R., & Gong, P. (2023). A study of the serious conflicts between oil palm expansion and biodiversity conservation using high-resolution remote sensing. *Remote Sensing Letters*, *14*(6), 654–668. https://doi.org/10.1080/2150704X.2022.2063701
138. Yu, Y., Wang, S., Cabernard, L., & Pfister, S. (2026). Revealing hidden biodiversity footprints embedded in global mining supply chains. *Environmental Science and Technology*, *60*(24), 17234–

17246. https://doi.org/10.1021/acs.est.6c01834

139. Zhao, J., Cochrane, M., Lee, J., Zhang, X., & Elmore, A. (2025). Managing sustainable expansion of smallholder oil palms with strategic spatial planning of land use. *Journal of Land Use Science*, *20*(1), 276–288. https://doi.org/10.1080/1747423X.2025.2583927

140. Zhao, Q., Huang, H., & Costello, M. J. (2024b). Systematic planning shows more than half of the most species-rich ocean region is needed to include all species in representative protected areas. *Global Ecology and Conservation*, *53*, Article e03036. https://doi.org/10.1016/j.gecco.2024.e03036

141. Zhao, Q., Yu, L., Li, X., Xu, Y., Du, Z., Kanniah, K., Li, C., Cai, W., Lin, H., Peng, D., Zhang, Y., & Gong, P. (2024a). The expansion and remaining suitable areas of global oil palm plantations. *Global Sustainability*, *7*, Article e9. https://doi.org/10.1017/sus.2024.8

How to cite this article: Sudarmanto Hasan, Dewi K. Baderan, Sukirman Rahim, Marini Susanti, Asda Rauf. Renewable energy transition and biodiversity conservation in Indonesia: a review of ecological impacts, spatial planning and governance, with implications for Gorontalo. *International Journal of Research and Review*. 2026; 13(11): 113-142.
DOI: *https://doi.org/10.52403/ijrr.20261111*

******