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Integrating Geospatial Siting and Energy System Modelling for Solar Energy Transition Planning: A Review with Implications for Gorontalo, Indonesia

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ABSTRACT

Planning a solar transition means answering several questions at once: where panels can go, how much the grid can absorb, when investment should happen, and who gets a say in the decision. Too often, photovoltaic suitability is treated as a stand-alone mapping exercise. In this structured review we ask how geospatial site screening, long-term energy planning, LEAP-based scenarios, grid flexibility and governance criteria connect with one another, and we use the answer to sketch a cautious research agenda for Gorontalo, Indonesia.

We documented two Scopus TITLE-ABS-KEY searches run on 8 October 2026 and covering 2021 to 2026. The exports held 435 spatial solar records and 33 LEAP-query records. After the LEAP export was screened down to 25 candidates and four cross-query matches were merged, a working list of 456 records was screened and 168 studies were kept (105 core, 63 partially relevant). All counts and multi-label codes come straight from the final screening workbook. Most included studies appeared in 2025 (48) and 2026 (76). GIS or spatial indicators turned up in 107 studies, energy planning or modelling in 124, grid or flexibility topics in 70, governance or social dimensions in 75, and LEAP in 25. These labels overlap, and they describe which topics are covered, not how well anything performed.

The literature holds many partial attempts at integration, yet metadata alone cannot show that a fully coupled model has never been built. We therefore propose a testable GIS-to-LEAP data-exchange architecture with explicit network and governance feedback. It is a conceptual synthesis, not an implemented or validated optimization system. And because none of the 168 titles or abstracts mentions Gorontalo, our regional recommendations look forward and still need local data and empirical checking.

Keywords: spatial energy planning; solar photovoltaics; geographic information systems; LEAP; energy transition; evidence synthesis; Gorontalo

INTRODUCTION

Putting solar panels on the ground is never only an engineering question. It is a question about space. Sunshine alone cannot tell us where a project can realistically be built, because land cover, biodiversity, slope, distance to demand, grid hosting capacity and local rules change from one site to the

next. Recent geospatial studies make the point clearly: a suitability score depends on the environmental exclusion rules that remove land from consideration, and on the multi-criteria method used to rank whatever is left (Fakharizadehshirazi & Rösch, 2024; Antonuccio & Xydis, 2026).

A second body of work takes the long view. It asks when to invest, how demand shifts across sectors, how carbon limits bite and which generation mixes make sense. That work is essential for transition planning, but its regional or national scale can hide the project-level differences that matter most for siting. The real challenge, then, is not to mark a large amount of solar capacity on a map. It is to carry credible, site-specific constraints into dynamic energy planning, without passing off a coarse energy balance as proof that the power system will actually work (El Hafdaoui et al., 2026; Lemba et al., 2021).

We look at this problem as an interface between four domains: (i) spatial potential and competition for land; (ii) scenario and energy-system modelling, including the Low Emissions Analysis Platform (LEAP); (iii) grid flexibility and operability; and (iv) regional implementation and governance. Four research questions guide the review:

RQ1: Which methods dominate the updated corpus on spatial solar planning and LEAP?

RQ2: Which data exchanges and decision variables are needed to link GIS with scenario analysis?

RQ3: Where do uncertainty, grid constraints and governance remain poorly connected?

RQ4: What can reasonably be transferred to a prospective application in Gorontalo?

The paper makes three contributions. It offers an auditable re-analysis of the October 2026 corpus. It compares what each method is *for*, instead of ranking models on performance that the evidence cannot support. And it sets out a falsifiable protocol for feeding candidate-site supply blocks into scenarios. We also want to be upfront about the limits: our empirical claims concern the bibliographic sample only. We did not run ArcGIS or LEAP simulations, and we do not estimate a new solar capacity for Gorontalo.

LITERATURE REVIEW

Geospatial suitability and ecological constraints

GIS workflows usually stack several layers: solar resource surfaces, topography, land cover, exclusion masks, proximity measures and alternative multi-criteria weights. Recent studies have pushed these layers further, into transmission-corridor siting, the monitoring of land conversion, and geo-informatics methods that make the drivers of suitability easier to interpret (Cotti Piccinelli et al., 2026; Zhou, J. et al., 2026; Mohlehli & Nhamo, 2026). It helps to keep three ideas apart: physical feasibility, weighted suitability, and supply that can actually be connected at a reasonable cost. Having one does not guarantee the others.

Rooftop, ground-mounted, floating and dual-use PV also behave differently. Building geometry and shading shape distributed potential. Land take and the displacement of farming matter for ground-mounted plants. Floating PV raises questions about water governance and the environment. Lump them together as one uniform annual-energy resource and their very different costs, connection needs and siting profiles simply disappear (Anselmo et al., 2026; Sasmita et al., 2026; Liu et al., 2026).

Energy modelling, LEAP, and optimization boundaries

Scenario models explore internally consistent futures for demand, energy mix, emissions and technology uptake. LEAP is well suited to transparent energy accounting and scenario comparison. Even so, a standard LEAP energy-balance result should not be read as an optimized, plant-level siting decision, or as a verified distribution-network flow. Coupling models therefore calls for a clear line between scenario inputs, optional optimization extensions and external feasibility tests (El Hafdaoui et al., 2026; Villamizar-Villamizar et al., 2024).

What makes a model interface valuable is not how many programs appear in the workflow. It is whether a spatial attribute changes an energy-system choice, and whether a

downstream constraint can change that choice in return. GIS-based supply blocks can carry cost tiers and developable capacity, and LEAP scenarios can then test aggregate technology mixes. A study that wants to claim mathematically optimal site selection, however, needs a separate optimization or allocation routine. Saying so plainly is what makes a contribution testable.

Network flexibility and institutional constraints

A grid can only take so much solar. Transformer capacity, voltage rise, the timing of generation against demand, curtailment and reserve requirements all set limits. These limits can reorder otherwise attractive sites, and their size cannot be read off an annual irradiation map. Studies that combine distribution-network planning with source–network–storage coordination show why these trade-offs deserve attention (Wang, J. et al., 2025; Chen et al., 2026).

Governance needs the same discipline. It should be tied to specific constraints such as biodiversity exclusions, tenure or land-acquisition limits, investment eligibility, stakeholder preferences and participation procedures. These can enter a model as hard exclusions, transparent penalties or scenario-dependent criteria (Wang, H.-W. et al., 2022; Badelt et al., 2025). What we cannot do is claim that they have been observed in Gorontalo, because our dataset contains no locally identified records.

MATERIALS & METHODS

Review design, sources, and reproducibility

This is a structured evidence synthesis built on metadata and abstracts. We do not present it as a completed full-text systematic review or a registered meta-analysis. The authors worked from a date-stamped Scopus search history, two CSV exports, matching RIS exports, intermediate screening workbooks and a deduplicated final workbook. Searches were run on Thursday, 8 October 2026. Results were limited to publication years 2021–2026 and, in the Scopus interface, to journal articles and reviews written in English.

Search string A combined solar technologies, spatial or energy planning and site selection, and low-carbon or transition language. Search string B kept the solar block, swapped the spatial block for energy planning, energy system and transition terms, and added LEAP or Long-range Energy Alternatives Planning. The full strings follow.

Query A: TITLE-ABS-KEY (("solar energy" OR "solar photovoltaic" OR "solar PV" OR photovolta*) AND ("spatial planning" OR "spatial energy planning" OR "energy planning" OR "spatial optimization" OR "spatial optimisation" OR "site selection" OR siting) AND ("energy transition" OR "low-carbon transition" OR decarbonization OR decarbonisation OR "low carbon")) AND PUBYEAR > 2020 AND PUBYEAR < 2027.

Query B: TITLE-ABS-KEY(("solar energy" OR "solar photovoltaic" OR "solar PV" OR photovolta*) AND ("energy planning" OR "energy system" OR "energy transition" OR "low-carbon transition" OR decarbonization OR decarbonisation) AND (LEAP OR "Long-range Energy Alternatives Planning" OR "Long Range Energy Alternatives Planning System")) AND PUBYEAR > 2020 AND PUBYEAR < 2027.

Record reconciliation and eligibility

The main export holds 435 records and the LEAP export holds 33. Two intermediate relevance worksheets hold 145 main-query records and 25 LEAP-query records. Of the original 33 LEAP records, 25 were kept as potentially relevant and the other eight were excluded before merging. Four of those 25 already appeared in the 435-record main file, so the combined ALL_UNIQUE_456 worksheet contains 435 + 25 − 4 = 456 entries (Figure 1, Table 1). This is a reproducible screened-merge total, not a deduplication of every raw export; that would mean resolving each raw LEAP record separately. For the descriptive analysis, the authoritative inclusion list is the 168-row FINAL_RELEVANT_168 worksheet. We

disclose this discrepancy openly rather than smoothing it over.

The final worksheet labels 105 studies as Include – Core (P1) and 63 as Include – Partial (P2). The wider ALL_UNIQUE_456 worksheet also marks 102 records as Background and 186 as Exclude. Core studies speak directly to the main integration questions, while partial studies contribute narrower methods that can be transferred. These labels are the authors' own screening judgements, not critical-appraisal grades. Full-text availability, risk-of-bias assessment and independent screening agreement were not available, so we make no stronger claims about study quality.

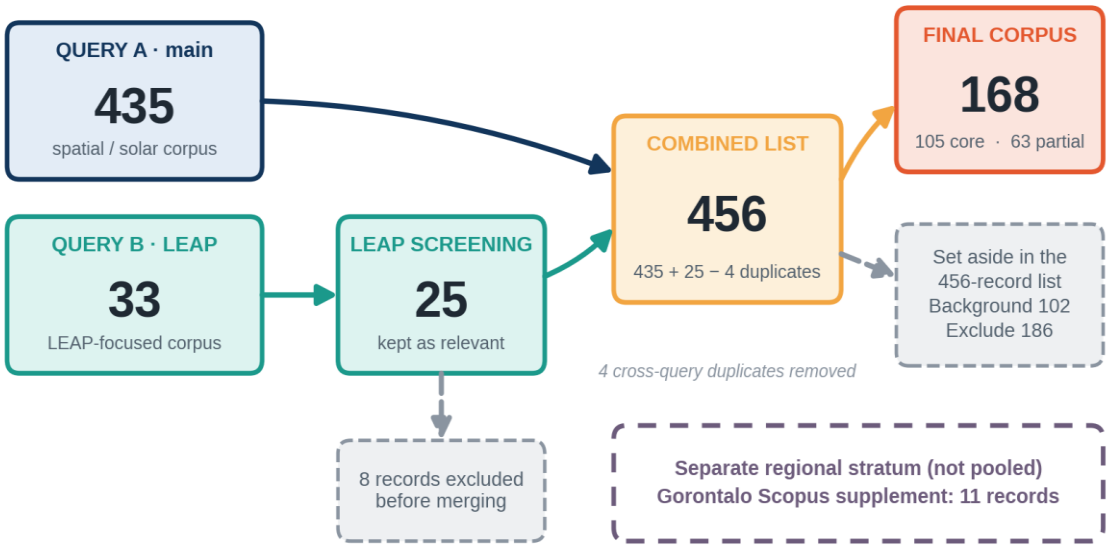


Figure 1. How 456 screened records became a 168-study corpus. The 11-record Gorontalo supplement is a separate stratum and is not pooled into the denominator.

Table 1. Documented record flow from search to final analysis corpus

Documented stage	Records	Interpretation
Query A export	435	Main spatial/solar corpus
Query B export	33	LEAP-focused corpus
Cross-query duplicates listed	4	Documented matched records
LEAP retained before merging	25	33 LEAP raw records screened to 25
Combined workbook ALL_UNIQUE	456	435 + 25 − 4 cross-query duplicates
Core	105	Included high-relevance studies
Partial	63	Included complementary studies
Final analysis corpus	168	105 core + 63 partial

Coding and analysis

The final workbook records title, authors, year, DOI, abstract, relevance level, source corpus and binary thematic columns. Annual frequencies were counted directly from publication years. Thematic prevalence came from the yes/no fields for GIS/spatial, energy planning/modelling, energy transition, grid/flexibility, governance/social and LEAP. These are overlapping descriptive codes, not mutually exclusive categories. Individual methodological comparisons were checked against the titles and abstracts at hand; where only metadata existed, we did not infer implementation details or effect sizes. No new records were taken from the internet.

RESULTS

Sample characteristics

The final corpus has 168 records spanning 2021–2026. Annual counts are 9 (2021), 7 (2022), 9 (2023), 19 (2024), 48 (2025) and 76 (2026) (Figure 2a). The weight of 2026

reflects the October sample, so it should not be read as a full-year trend against earlier calendar years. Of the 168 studies, 105 are core and 63 are partial. By source label, Main 435 contributes 147 studies and LEAP 25 contributes 21; the latter is the provenance label in the final worksheet, not the raw size of the LEAP export.

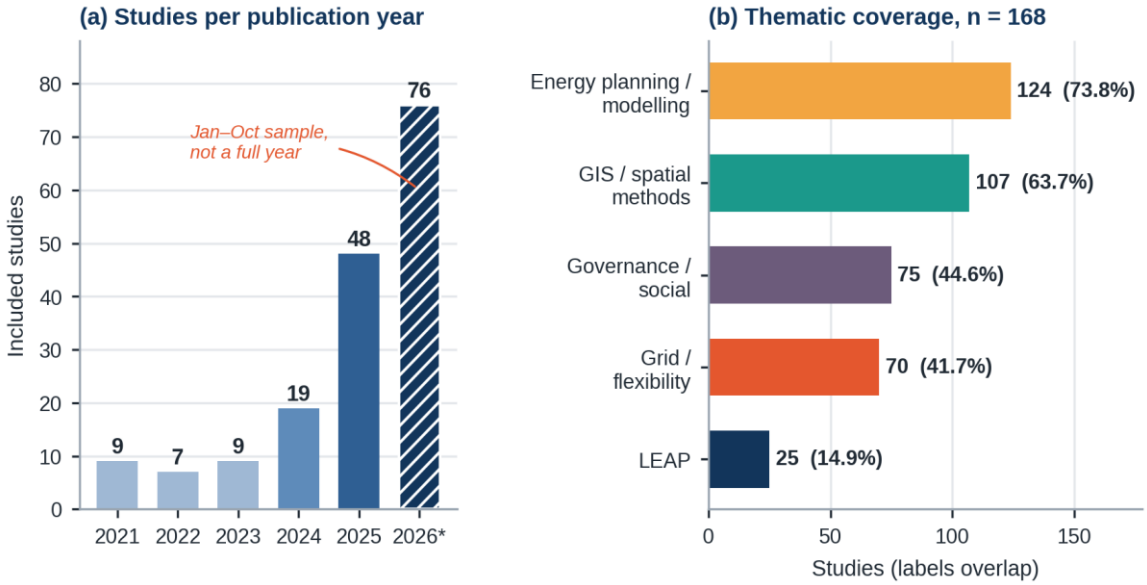


Figure 2. (a) Annual frequency of the 168 included studies; *2026 covers January to October only. (b) Non-exclusive thematic coding: a paper may be counted in more than one category. Percentages are shares of 168.

Overlapping methodological themes

Energy planning or modelling is coded in 124 of the 168 studies (73.8%), GIS or spatial methods in 107 (63.7%), governance or social dimensions in 75 (44.6%), grid or flexibility in 70 (41.7%) and LEAP in 25 (14.9%) (Figure 2b). Energy transition is marked for all 168 studies, which simply reflects the screening scope. These counts tell us which topics are represented in the sample. They do not show that a given method was implemented well, compared fairly or validated against data.

Comparative methodological evidence

Table 2 summarizes what each method cluster is used for and where it runs into limits. The selected studies show distinct capabilities, not the proven superiority of any one architecture. Satellite-derived maps of PV land conversion give time-based evidence for exclusions and land-take calculations (Cotti Piccinelli et al., 2026). Multi-criteria and corridor-siting approaches widen spatial feasibility beyond resource quality (Zhou, J. et al., 2026; Bertsiou et al., 2025). Dynamic suitability and emissions models link spatial ranking to transition outcomes, although how far the energy system responds inside the model differs between studies (He, J. et al., 2025; Sun et al., 2025). Long-term LEAP-linked analyses offer demand and emissions assessment, but they need a clearly specified method if spatial supply blocks or grid constraints are to be enforced (Sah et al., 2026; Villamizar-Villamizar et al., 2024).

Method cluster	Main decision output	Critical interface / limitation
GIS–MCDA siting	Candidate areas and ranking	Weight sensitivity; does not independently verify the future system mix
Remote sensing / geo-informatics	Observed land-use and solar-surface inventory	Accuracy depends on imagery, classifier and reference data

GIS-to-LEAP scenario coupling	Spatial supply constraints translated into aggregate scenario assumptions	Requires explicit conversion of zone capacity and costs, and limits on LEAP claims
LEAP-led transition scenarios	Demand, energy mix and emissions by scenario	Not itself evidence of geographic optimality or electrical stability
Network / flexibility screening	Indicative hosting and flexibility restrictions	Needs credible feeder or system data, or documented proxies
Governance and environmental screening	Exclusion or eligibility flags; alternative policy weights	Participatory assumptions and institutional feasibility remain context-specific

Table 2. Method clusters, decision outputs and critical interfaces

Regional evidence boundary: Gorontalo

A text scan of the titles and abstracts in the final worksheet found no record that names Gorontalo. It would therefore be unsupported to say that this 168-study corpus proves anything about Gorontalo's rooftop capacity, feeder voltage limits, local LEAP projections or grid-failure modes. Earlier versions of this manuscript included a separate Gorontalo-targeted search run on 4 October 2026, but those regional records are not part of the replacement 168-study dataset. Such case examples are left out of the evidence-based Results, and they should return only if they are documented independently in a clearly separated supplementary search.

Gorontalo-specific supplementary corpus

A separate Scopus export focused on Gorontalo returned 11 records published in 2022–2026. Matching by DOI and normalized title found no exact duplicate in the 168-study primary dataset. Ten records speak directly to solar deployment, energy-system or LEAP planning, distributed PV operation or grid-flexibility needs. The remaining paper maps lamtoro biomass for co-firing, and we kept it only as context for transferable regional resource mapping. Because the 168 international studies and the 11 regional records are different evidence strata, we analyse them separately and do not pool them into one screening denominator.

Four strands complement each other. First, roof-geometry and building-scale photovoltaic studies show local siting potential. Second, LEAP–machine-learning and Tomini Bay planning studies give regional views of demand and scenarios. Third, local work on battery energy storage systems (BESS) and PV curtailment points to flexibility concerns. Fourth, papers on smart inverters and reactive power address voltage and low-voltage ride-through issues. Together they make an integrated planning agenda plausible. They do not show that the proposed GIS–LEAP–grid coupling has been built, optimized or validated in Gorontalo.

Policy triangulation: spatial planning, regional development, and grid investment

Four planning instruments add evidence of a non-bibliographic kind: the RUED (2019), RTRW (2024), RPJMD (2025) and RUPTL (2025). Provincial Regulation No. 2 of 2024 is the statutory spatial-planning instrument (RTRW 2024–2043). Its PDF could not be parsed reliably, so we make no clause-specific claims about zoning. Provincial Regulation No. 3 of 2025 formally establishes the Gorontalo RPJMD for 2025–2029; it was enacted and promulgated on 27 August 2025 (Regional Gazette of Gorontalo Province 2025 No. 03). Article 2 sets out principles that include sustainability and environmental awareness, and Article 3 stresses integration across government, participation, and efficient, equitable and sustainable use of resources.

The 11-page regulation we hold refers to an inseparable RPJMD annex (Article 4(7)), but that annex was not included. For this reason, specific program targets from the earlier draft are not presented as confirmed provisions of the enacted plan. PLN's RUPTL 2025–2034 is an approved electricity business plan that covers generation, storage and network investment, and its national capacity targets should not be read as allocations for Gorontalo.

Taken together, these documents point to a decision architecture that screens candidate solar zones against legally applicable spatial plans, models district-level demand and alternative transition scenarios, tests grid-hosting limits in priority scenarios, and aligns investment timing with RUPTL and regional development targets. These are design requirements drawn from triangulation, not simulated results. A future implementation should rely on verifiable GIS layers, documented policy versions and engineering inputs with explicit uncertainty bounds.

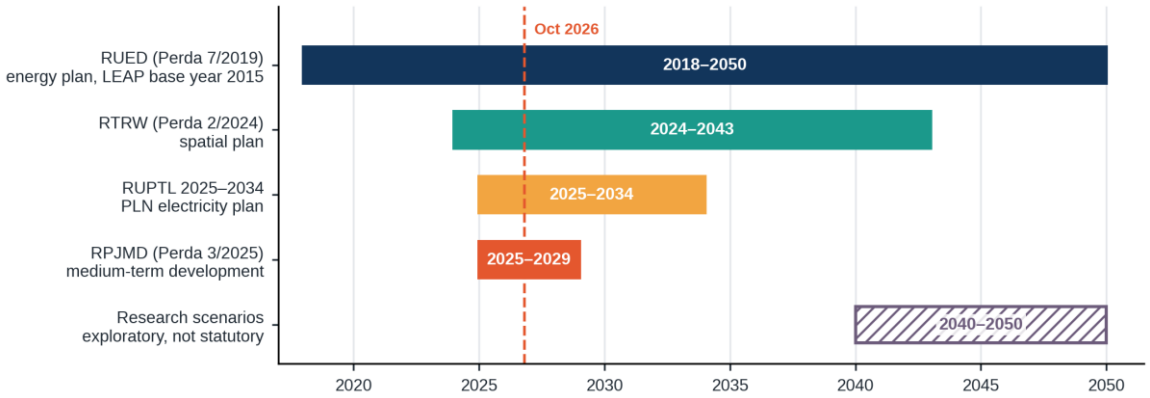


Figure 3. Four overlapping planning horizons. Exploratory research scenarios reach beyond the RPJMD and RUPTL and must not be read as statutory provincial commitments.

DISCUSSION

What the corpus does and does not support

The synthesis supports a practical methodological point. Spatial ranking, long-term transition pathways and network feasibility work at different spatial and temporal resolutions, so the links between them have to be specified, not assumed. GIS suitability studies, grid-aware network studies and energy-mix scenario analyses all support a closer look at these interfaces (Benalcazar et al., 2024; Wang, J. et al., 2025; El Hafdaoui et al., 2026). At the same time, topics that co-occur in a review cannot establish that earlier research has never achieved an integrated architecture. A defensible statement of the gap is narrower: within the reviewed and screened evidence, transparent specification of data exchange and testing of regional transfer remain insufficiently resolved.

Proposed GIS–LEAP–screening architecture (conceptual, not validated)

We suggest five stages (Table 3, Figure 4). Stage 1 is a spatial inventory: assemble solar irradiation, slope, land cover, excluded or regulated areas, candidate rooftops and land units, settlement-demand proxies and available grid nodes, and record the source, date, resolution and uncertainty of each variable. Stage 2 builds developable-supply blocks: GIS polygons are translated into a project-level or zonal table with an ID, area, candidate PV capacity (MW), estimated generation profile or capacity factor, network distance, eligibility flag, cost band and uncertainty class. Stage 3 runs LEAP scenarios that compare baseline, accelerated solar, land-protection and network-constrained adoption assumptions under consistent demand and emissions accounting. If a cost-optimal zonal allocation is claimed, a separate optimizer must be implemented and disclosed, since basic LEAP scenario accounting is not proof of globally optimal site allocation.

Stage 4 is a network and flexibility screen. Selected scenario increments are checked against available transmission or distribution capacity, the match between generation and demand through the day, possible curtailment, and likely storage or reinforcement needs. Where data are scarce, every screening metric should be labelled a

proxy, and claims about voltage stability or exact hosting capacity should be avoided. Stage 5 covers governance and iteration: apply protected-area exclusions and transparent policy and tenure criteria, compare sensitivity cases, and send rejected or expensive zones back to the supply-block dataset. The contribution is the explicit round trip of information, not the invention of GIS, multi-criteria analysis, LEAP or grid modelling.

Table 3. Modules of the proposed architecture, with the data passed on and the validation needed

Module	Input to next stage	Feedback / validation needed
GIS site inventory	Site ID; developable km²; resource; exclusions	Source resolution; independent land checks
Supply-block calculator	Capacity (MW); yield (MWh); capex tier; access cost	Weight and land sensitivity; assumption log
LEAP scenario layer	Energy mix, demand, emissions, proposed solar additions	Energy-balance checks; scenario plausibility
External grid screening	Connection risk; flexibility cost tier; rejection flag	Utility data or cautious proxy bounds
Governance screen	Permit, land and justice constraint or risk class	Policy-document review; stakeholder validation

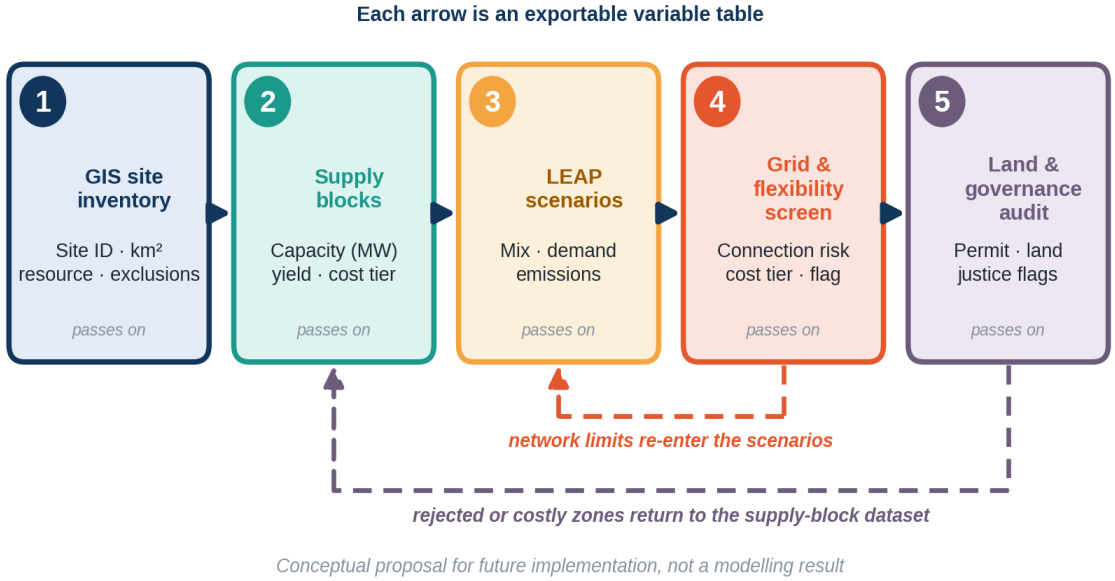


Figure 4. Operational specification of the proposed workflow. Each arrow denotes an exportable variable table. This is a proposal for future implementation, not a map or modelling result produced in this review.

Novelty and testable hypotheses

A stronger case for originality is a question that can be tested. Does a transparent GIS-to-LEAP interface with grid and governance feedback change decisions compared with GIS-only site ranking and LEAP-only energy scenarios? A follow-up study in Gorontalo could compare three configurations: C1, independent GIS site rankings; C2, GIS-derived supply blocks passed into LEAP scenarios; and C3, C2 plus external network and governance feedback. Outcomes would include changes in selected capacity by zone, the feasible energy share, indicative cost classes, exposure to land and ecological conflict, and scenario robustness. This article provides the evaluation design but reports no values or performance claims for C1–C3.

Evidence-to-decision translation and explicit model handoffs

The reviewed evidence points to a planning workflow whose parts stay distinguishable. A geospatial suitability assessment ranks

feasible land and rooftop opportunities. An energy-accounting and scenario module explores the timing and scale of changes in demand and supply. A network-screening stage flags nodes that may be constrained. A policy review asks whether shortlisted locations are compatible with land-use and development instruments. These are proposed research operations, not outputs from a GIS or LEAP simulation in this review. Keeping that distinction visible answers a concern reviewers often raise: a plausible conceptual structure should not be mistaken for validated optimization.

The first handoff should be an auditable candidate-site inventory, not just a coloured suitability raster. Useful fields include a stable site or zone identifier; coordinates or polygon geometry; source data and acquisition date; a solar resource proxy; terrain and land-cover attributes; excluded-area flags; rooftop or ground-mounted type; nominal feasible area; estimated technical capacity under stated assumptions; an energy-yield profile where supported; distance to substations or feeders; and a categorical uncertainty rating. A location may stay in the report even when it is excluded from deployment, as long as the reason is explicit. Rooftop and ground-mounted inventories should not be merged without correcting for their very different capacity and connection constraints.

In a first-generation interface, site blocks can be grouped by geography, siting class, indicative connection category and generalized supply cost. That keeps meaningful spatial variety without pretending that every rooftop or parcel is an individually optimized LEAP technology. If the LEAP implementation is a scenario-accounting model, the availability of supply blocks can enter as a bounded input, and alternative allocation portfolios can be compared outside LEAP. Claiming mathematical co-optimization would require a real coupling algorithm, an objective function and a documented solution procedure, none of which has been run here.

The second handoff should turn modelled capacity and generation choices into a grid-check register. It can list the connection node, commissioning year, solar capacity, representative production profiles, minimum and maximum demand conditions, and a set of screening indicators. Voltage rise, reverse flow, line and transformer loading, frequency-response needs and curtailment exposure are all relevant, particularly because the local Scopus supplement includes papers on PV curtailment, BESS and inverter control. Those papers, however, do not offer a province-wide hosting-capacity map, and they cannot justify saying that a particular future Gorontalo site has already passed a grid-feasibility test.

The final handoff links model alternatives to implementation decisions: preferred typology, expected time horizon, indicative policy compatibility, unresolved permitting or land requirements, the need for grid studies, affordability indicators and environmental conflict flags. The policy documents act as decision constraints and planning assumptions; they are not journal articles in the review denominator. Where the RTRW is not available in a legally and technically readable form, spatial exclusions remain proposed categories, not verified polygon-level legal determinations.

Policy horizons and jurisdictional consistency

Four planning horizons overlap, and they are easy to confuse (Figure 3). The RUED sets an energy-planning horizon through 2050. The Gorontalo RTRW is Provincial Regulation No. 2 of 2024 (2024–2043). The enacted RPJMD is Provincial Regulation No. 3 of 2025 (2025–2029), promulgated on 27 August 2025. The approved PLN RUPTL covers 2025–2034. Research projections to 2040–2050 reach beyond the RPJMD and RUPTL horizons, so they must be described as exploratory scenarios and not as statutory provincial investment commitments.

The RUPTL is formally approved under Ministerial Decree No. 188.K/TL.03/MEM.L/2025. Its approval text

gives national figures for planned generation and storage, together with a national renewable-generation target for 2034. None of these can be assigned to Gorontalo, and national or all-Sulawesi figures must not be converted into provincial quotas. A provincial model should therefore distinguish three geographic resolutions: Indonesia, the interconnected Sulawesi system, and individual Gorontalo zones or feeders. Capacity added in an interconnected system may serve load outside the province, and the reverse can also be true.

Unlike the earlier Rancangan Akhir, Provincial Regulation No. 3 of 2025 has a clear enactment and promulgation date. Article 4(7) makes the detailed RPJMD annex a legally inseparable part of the regulation. The enacted PDF we hold contains only the 11-page regulation and its explanatory notes, so precise sectoral programs, figures and targets cannot yet be checked against the annex. The earlier draft can help with navigation but cannot replace the final annex. Likewise, until the RTRW PDF and its authoritative map schedules can be read, no claim of parcel-level legal suitability should be made.

A practical cross-document consistency matrix would give each spatial option its own status against RTRW zones, RPJMD development priorities and RUPTL grid-investment sequencing. It would record the source page, the authoritative document version, the applicable year, the classification rule and the verification status. Conflicts, such as excellent irradiation inside an environmentally restricted area, or demand growth that arrives before the grid connection can be upgraded, should stay visible in the results instead of being absorbed into a single weighted score.

Comparative baselines, sensitivity analysis and validation agenda

The value of linking GIS with scenario planning can be tested against deliberately simple baselines. Baseline A would rank candidate zones by annual solar irradiance alone. Baseline B would use GIS–MCDA with land and distance criteria but no long-term energy feedback. Baseline C would use an aggregate LEAP scenario with homogeneous solar supply assumptions. The linked workflow could then be assessed for differences in selected zones, generation portfolios, connection exposure, cumulative land demand and sensitivity to uncertain inputs. Until that comparison is done, claims of better accuracy, lower cost, higher renewable penetration or optimal siting remain hypotheses, not results.

Evaluation measures should be fixed in advance. For spatial screening, they include the area left after legal exclusions, how sensitive the suitability rankings are to alternative MCDA weights, and agreement with known facilities or independently assessed feasible zones. For scenario accounting, useful checks are the annual energy balance, consistency between capacity factors and generation, the plausibility of demand drivers, and how robust technology trajectories are under cost and demand alternatives. For network screening, results must be compared with actual engineering constraints or independently modelled reference feeders before any conclusion about system stability. For governance screening, reproducible rule application and documentary traceability are more defensible than false precision in stakeholder-acceptance scores.

A structured uncertainty register should follow the variables through every module. Resource estimates vary with the weather source or representative year. Land area and roof availability vary with map accuracy and exclusion rules. Capacity and generation depend on module density and performance ratio. Demand depends on population, industrial development and electrification assumptions. Storage and grid needs depend on hourly operating profiles. At a minimum, a future implementation should compare low, central and high cases for demand and investment cost, alternative land-use exclusions and several MCDA weighting schemes. The share of candidate areas or technology choices that stay unchanged

across these alternatives would be a defensible robustness metric.

Where core and partially relevant studies are separated, conclusions should be stratified by strength of evidence. The 105 core studies can support claims closely tied to the review questions. The 63 partially relevant papers can illustrate adjacent technologies, methods or governance mechanisms, but they should not be quietly pooled to infer how common, or how well-performing, a specific GIS–LEAP coupling architecture is. In the same way, the regional set of 11 can speak to local applicability and knowledge gaps, but it is too small and was selected differently, so it cannot show that no integrated model exists anywhere in the wider literature.

Revised research gap and contribution boundary

The gap is not that GIS, MCDA, LEAP, network simulation or policy analysis are missing as separate approaches; all of them are well established. The defensible gap is narrower. It concerns whether location-specific solar supply constraints are passed transparently to long-term scenario choices, whether those choices are returned to network and land-use feasibility assessment, and whether this iterative workflow is documented well enough for data-constrained provincial planning. The review offers an operational research protocol and a comparative validation agenda for that integration. It does not claim a new algorithm, nor that it has shown a better-performing model.

This framing also protects the Gorontalo case from over-interpretation. Existing local evidence covers several important elements: roof-level PV potential, LEAP-based regional scenarios, PV intermittency and storage, curtailment and frequency support, and distribution-voltage control. In the records we screened, these appear as separate strands. Their coexistence shows that an integrated research question is relevant, but fragmentation is not proof that integration is new anywhere in the world. A later empirical article should state and test falsifiable improvements against independent and coupled baselines.

We therefore describe this work as a structured integrative literature review, based on metadata and abstracts, with a supplementary regional evidence layer and planning-document triangulation. Without systematic full-text appraisal, prospective registration and a tested synthesis procedure, calling it a fully validated systematic review or a finished spatial-optimization study would go beyond what the evidence allows.

Gorontalo Regional Energy Plan (RUED): documentary evidence

Provincial Regulation No. 7 of 2019 established Gorontalo's Regional Energy Plan (RUED-P), with a planning horizon that runs to 2050. Under Articles 4–5, the RUED annexes contain the provincial energy situation, scenarios, targets, policies and program matrices, and they serve as reference material for regional development planning, electricity planning, budgeting and cooperation across sectors. These materials are documentary evidence and are not counted as Scopus-indexed studies (Government of Gorontalo Province, 2019).

The RUED itself reports that its projections of provincial energy demand and supply were built with LEAP, using 2015 as the base year, and its modelling structure separates demand, supply, transformation and key assumptions. The proposed GIS–LEAP research interface should therefore be presented as an extension of existing LEAP-based regional planning, not as the first use of LEAP in Gorontalo. A defensible new contribution would be to operationalize site-level spatial constraints, feasible photovoltaic capacity, grid accommodation and cross-policy consistency as explicit inputs to updated regional scenarios (Government of Gorontalo Province, 2019, RUED annex, pp. 11, 43–44).

The RUED reports an indicative provincial solar resource potential of 1,218 MW (the RUEN-derived figure in its Table 2.9). Its LEAP scenario projects renewable shares in the primary energy mix of 15.4% in 2025 and

37.9% in 2050 (Table 2.19). These are historical potential estimates and modelled policy-scenario projections from a 2015 baseline. Neither the installed photovoltaic capacity nor the actual energy mix in October 2026 can be inferred from them, and the total renewable share must not be mistaken for a solar-specific share (Government of Gorontalo Province, 2019, RUED annex, pp. 39, 48).

Before any future empirical model is run, the RUED's demand and generation parameters should be re-baselined against the newest verified PLN, BPS and ESDM series. The RUED can supply historical scenario definitions and a policy reference for validation. The RTRW supplies land-use eligibility, the enacted RPJMD provides medium-term development alignment, and the RUPTL provides planned power-system investment. Grid reliability and the chronology of curtailment need dedicated engineering data or a separate network and time-series assessment; LEAP outputs alone do not establish network feasibility (Table 4).

Table 4. RUED evidence-to-model traceability (historical policy evidence versus proposed analysis)

Verified RUED element	Interpretation	Proposed use in GIS–LEAP interface
Perda No. 7/2019; RUED through 2050; Arts. 4–5	Adopted regional energy policy, not a journal study	Check scenario and planning-horizon consistency
LEAP-based demand/supply projection; baseline 2015	Prior regional modelling precedent	Compare updated assumptions rather than claiming first LEAP use
Solar resource potential 1,218 MW (RUEN source)	Indicative regional resource, not buildable or installed PV	Constrain GIS candidate capacity; test uncertainty
Renewables 15.4% (2025), 37.9% (2050)	Historical projected total renewable primary energy share	Benchmark policy scenarios, not solar-only capacity or actual results
RUED sector demand, socio-economic assumptions, programme matrices	Historical sectoral parameters and governance evidence	Recalibrate demand, map implementers and funding options

Regional policy-to-model operationalization

The policy documents are contextual and statutory planning sources. They are not part of the 168-study Scopus evidence count or the supplementary 11-study Gorontalo corpus. The principal instruments are Perda Gorontalo No. 2/2024 (RTRW 2024–2043), the enacted Perda Gorontalo No. 3/2025 (RPJMD 2025–2029) and PLN RUPTL 2025–2034 (approved by Ministerial Decree No. 188.K/TL.03/MEM.L/2025). Policy-alignment checks, however, are proposed analytical steps and not completed legal compliance determinations (Table 5).

Article 2(1)(f)–(g) of Perda 3/2025 covers sustainable and environmentally conscious development, and Article 3(b)–(d) concerns policy integration, participation, and equitable and sustainable use of resources. These normative principles can inform alternative MCDA weighting scenarios, exclusion review and governance-audit fields. The regulation does not, however, demonstrate technical PV suitability, nor does it validate a GIS–LEAP model. Because Article 4(7) treats the RPJMD annex as an inseparable part of the regulation, and the PDF we hold has none of it, exact sectoral targets and geographic program allocations must be checked against the official annex before they are written into model constraints. The earlier Rancangan Akhir is kept only as a preparatory source, not as the operative legal instrument. Reliable RTRW spatial annexes are likewise still needed to validate site-level land-use designations.

Table 5. Policy sources, planning parameters and verification requirements

Source / standing	Planning parameter	GIS / LEAP transfer	Verification requirement
RTRW 2024–2043; Perda 2/2024	Protected zoning, land function, siting permissions	Binary spatial exclusion / regulatory flag by candidate block	Obtain readable gazette, spatial map and articles before legal exclusion
RPJMD 2025–2029; Perda No. 3/2025 enacted	Enacted principles and regional development planning; annex-specific targets unverified	Scenario priority weights and consistency narrative	Confirm detailed targets against the enacted annex (not supplied)
PLN RUPTL 2025–2034; approved	Planned supply, storage, transmission and load outlook	Baseline expansion and network screening assumptions	Extract project-specific Sulbagut / Gorontalo values and dates
Regional Scopus supplement; 11 records	Local roof PV, LEAP, BESS, inverter and curtailment	Candidate technical parameters and scenario plausibility	Verify full texts, boundary conditions and transferability

The full 168-record DOI, title and screening register and the list of 11 regional studies are provided in a separate companion Word appendix. The register sits outside the manuscript pagination, and it is not a set of full-text appraisals.

Limitations and publication integrity

Five limitations set the scope of interpretation.

1. Titles and abstracts do not reveal all equations, calibrations and validation data.
2. Screening codes show thematic relevance, not methodological quality.
3. The pre-merge LEAP screening and the later exclusions should appear as separate steps if a PRISMA-style chart is prepared.
4. The final corpus has no title or abstract that explicitly mentions Gorontalo, so local generalization stays speculative until regional evidence is retrieved and appraised independently.
5. The proposed architecture has not been implemented, so claims about efficiency, accuracy, optimality and reliability remain hypotheses.

These constraints belong in the abstract and conclusion, not in a footnote.

CONCLUSION

The re-analysed 168-study corpus shows that spatial techniques and energy-system methods are widely used in current research on solar transitions. The descriptive labels identify 107 GIS or spatial studies, 124 on energy planning or modelling, 70 on grid or flexibility, 75 on governance or social dimensions and 25 relevant to LEAP, with overlapping membership. The main contribution of this review is a transparent, falsifiable specification for carrying site-level physical and land-use constraints into scenario analysis, and for returning system and governance feedback to spatial choices. It should be read as an unvalidated conceptual framework, not as a new simulation result for Gorontalo. The next steps are clear: document the pre-merge screening flow, obtain independent region-specific data, and compare isolated and coupled planning configurations under uncertainty.

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