



A Conceptual Model for Sustainable Geothermal Direct-Use Development: Evidence from Muara Laboh, Indonesia

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ABSTRACT

This study analyzes existing conditions and indicative potential for geothermal direct use in Muara Laboh, West Sumatra; identifies enabling and constraining factors; and formulates a location-based conceptual model aligned with sustainable development. A qualitative case study used semi-structured interviews with 11 informants representing the geothermal operator, local government, nagari government and communities, business actors, and academics or experts, complemented by field observation and document analysis. Qualitative content analysis combined deductive and inductive coding, cross-thematic synthesis, and triangulation. Existing direct use is limited mainly to natural hot-spring bathing and micro-scale activities. Indicative opportunities occur in geothermal tourism, agricultural drying, and agroindustry, while aquaculture remains conditional on water-quality testing, temperature suitability, species selection, and safe heat-exchange design. Community acceptance was generally supportive but conditional. Strategic policy support exists, yet implementation is constrained by limited technical data, weak cross-sector coordination, low investment interest, limited capacity, and the absence of viable business models. A five-stage model is proposed: resource and local-needs mapping; application screening and prioritization; governance and financing; pilot implementation; and monitoring, evaluation, and scaling. Community participation, environmental protection, institutional coordination, and Triple Bottom Line/SDG performance measurement operate across all stages.

INTRODUCTION

Indonesia has substantial geothermal resources because of its tectonic setting along the Pacific Ring of Fire. Although geothermal development has expanded, utilization remains strongly concentrated on electricity generation. This orientation leaves part of the thermal resource value disconnected from local productive systems and from direct socioeconomic benefits that can be captured near geothermal fields (Pambudi, 2018; Darma et al., 2023). Direct use offers a complementary pathway because heat can be applied without first converting it into electricity, including for bathing and balneology, agricultural drying, greenhouse production, aquaculture, industrial process heat, and tourism (Lund, 2010; Lund & Toth, 2021).

Direct-use development is relevant to sustainable regional development because it can connect renewable thermal energy with existing local economic activities. When technically suitable, it may reduce conventional energy consumption, improve post-harvest processing, generate local value added, diversify tourism, and support micro and small enterprises. However, resource availability alone is insufficient. Temperature, flow rate, fluid chemistry, source-user distance, market demand, technology, financing, spatial compatibility, institutional capacity, and community acceptance must be considered together (ESMAP, 2022).

Muara Laboh Geothermal Field in South Solok Regency, West Sumatra, provides a relevant case. The field already supports geothermal electricity generation, while the surrounding regional economy includes agriculture, plantations, local tourism, and community-based enterprises. Field evidence shows that direct use remains dominated by natural hot-spring bathing and small-scale activities. Potential applications such as coffee, tea, and palm-sugar drying remain indicative, while a previous aquaculture attempt did not establish technical suitability. This creates a gap between geothermal resource availability and structured local direct-use development.

The literature indicates that social acceptance and governance are central to renewable-energy implementation. Community acceptance may depend on knowledge, trust, risk perception, participation, and the fairness of benefit distribution (Wüstenhagen et al., 2007; Renoth et al., 2023). Collaborative governance similarly requires shared objectives, role clarity, information exchange, trust building, and accountable decision-making among public, private, academic, and community actors (Ansell & Gash, 2008; Emerson et al., 2012).

Three gaps motivate this article. Empirical evidence on direct use in Muara Laboh is limited compared with geological, reservoir, and power-generation studies. Technical, social, economic, spatial-planning, and institutional factors are often discussed separately. Finally, policy support and resource potential do not automatically explain how a project should move from an idea to screening, financing, pilot testing, and scaling. The study therefore examines existing conditions and indicative opportunities; enabling and constraining factors; and a conceptual development model that connects implementation with sustainable development outcomes.

The contribution is an implementation-oriented framework. Triple Bottom Line (TBL) dimensions—People, Planet, and Profit—organize sustainability implications, while the Sustainable Development Goals (SDGs) distinguish actual contributions, potential contributions, and enabling conditions. The model is conceptual and intended to guide pre-feasibility assessment, stakeholder coordination, pilot development, and monitoring rather than replace engineering design or final investment appraisal.

LITERATURE REVIEW

The analytical framework combines geothermal direct-use principles, community acceptance, collaborative governance, spatial-development policy, TBL, and the SDGs. Elkington's TBL framework expands performance assessment beyond financial outcomes by integrating social, environmental, and economic dimensions (Elkington, 1997). Here, TBL is an evaluative lens rather than a causal statistical model. People covers participation, local employment, capacity building, access to benefits, communication, trust, and distributive fairness. Planet addresses resource efficiency, possible displacement of conventional fuels, fluid management, environmental protection, and cascade utilization. Profit concerns value added, energy-cost efficiency, market viability, local income, and business continuity.

These dimensions connect to SDGs 7, 8, 9, 11, 13, and 17, while SDGs 2 and 12 are relevant as conditional future contributions through agricultural applications and resource efficiency (United Nations, 2015; Kementerian PPN/Bappenas, 2023). Direct-use feasibility remains site-specific. Low- to medium-temperature resources can support multiple applications, but resource temperature, flow, chemistry, continuity, distance, and process demand determine the feasible technology. Because geothermal fluids may contain dissolved minerals, gases, or corrosive constituents, productive applications may require heat exchangers to transfer heat to a clean secondary medium (Lund & Toth, 2021; ESMAP, 2022).

Social acceptance is treated as a dynamic implementation condition. The absence of open opposition cannot be equated with uniform acceptance. Acceptance is interpreted through stakeholder knowledge, perceived benefits and risks, trust, participation opportunities, communication quality, and fairness in benefit distribution (Wüstenhagen et al., 2007; Anggreta et al., 2022; Renoth et al., 2023). Collaborative governance provides the institutional logic for implementation because direct use involves local government, the geothermal operator, investors, businesses, communities, academics, and prospective heat users (Ansell & Gash, 2008; Emerson et al., 2012).

METHODOLOGY

This research used an exploratory and explanatory qualitative case-study design focused on the ecosystem of geothermal direct-use development in Muara Laboh and its associated socioeconomic area. Fieldwork was conducted from 15 June to 2 July 2026. Observations and stakeholder interviews in South Solok Regency were conducted on 15–19 June, followed by additional interviews with academics or experts on 2 July 2026.

Primary data were obtained through semi-structured interviews and field observations. Informants were selected purposively based on knowledge, authority, experience, or direct involvement and were expanded through snowball sampling. Eleven informants participated: one geothermal operator/community-development representative, four local-government representatives, two nagari/community representatives, two business actors, and two academics or experts. The number was determined by information adequacy and repetition of substantive themes rather than statistical representativeness.

Table 1. Informant composition and analytical contribution

Stakeholder group	Code	n	Main contribution
Geothermal operator	OPR	1	Community development, stakeholder relations, local needs and partnership opportunities
Local government	PEM	4	Energy, spatial planning, tourism, agriculture, investment, policy and coordination
Nagari/community	MASY	2	Perceived benefits and risks, acceptance, local needs
Business actors	USA	2	Market, indicative revenue, operations and barriers
Academics/experts	AHL	2	Technical interpretation, validation and comparative learning

Secondary data included academic literature, technical reports, spatial-planning documents, the regional medium-term development plan, company documents, CSR planning material, statistics, and relevant regulations. Document status was explicitly differentiated so that enacted policies, draft spatial plans, future planning agendas, and internal company plans were not treated as equivalent evidence.

Data were analyzed using qualitative content analysis (Mayring, 2004; Krippendorff, 2018). Deductive codes were derived from the analytical framework—existing utilization, application potential, community acceptance, policy and spatial planning, governance, implementation barriers, and TBL outcomes—while inductive coding captured issues emerging from the field data. Similar codes were grouped into categories and compared across stakeholder groups. Cross-thematic synthesis then linked technical, social, institutional, economic, and policy findings.

Credibility was strengthened through source and method triangulation, informant confirmation, peer debriefing, and an audit trail (Lincoln & Guba, 1988; Creswell & Poth, 2016). Interview evidence was compared with observations and documentary evidence. The study does not claim statistical

representation of the whole Muara Laboh population, nor does it establish final technical or financial feasibility. Resource measurements, laboratory fluid analysis, detailed engineering, market appraisal, and investment modeling remain necessary before implementation.

RESEARCH RESULT AND DISCUSSION

Existing Direct Use and Indicative Development Opportunities

The evidence shows that geothermal direct use in Muara Laboh remains limited, fragmented, and dominated by natural manifestations. Existing activities consist mainly of hot-spring bathing, recreation, and micro-scale commerce around bathing facilities. The study found no evidence that these activities were integrated with residual heat from the geothermal power plant through cascade utilization. The present configuration therefore represents natural direct use rather than a technologically integrated local heat economy.

Hot-spring tourism nevertheless provides an existing market base. Facilities are managed by local government, private actors, and communities, and visitors are predominantly local or regional. Interview-based estimates placed gross annual receipts of bathing businesses at approximately IDR 250–300 million, but these values were not verified against audited accounts and should be treated only as indicative. Accessibility, facility quality, destination management, marketing, water-quality assurance, temperature control, waste management, visitor safety, and investment remain key constraints. The tourism segment is therefore a plausible quick-win for revitalization because demand and basic utilization already exist, but expansion requires professional management and pre-feasibility analysis.

Agriculture and plantations form a stronger productive-development opportunity. The surrounding land use is dominated by agricultural and plantation activities, and local-government informants identified coffee, tea, and palm sugar as commodities for which geothermal heat could potentially support drying. Such applications may reduce weather dependence, improve process control, and create local value added. However, this potential remains indicative. Resource temperature and flow, source-user distance, seasonal production volume, heat demand, exchanger design, capital and operating costs, product quality, and market conditions must be assessed before investment.

Aquaculture is more conditional. A local business had previously attempted fish cultivation associated with a hot-spring tourism site but experienced repeated crop failure. This cannot establish that geothermal aquaculture is inherently infeasible. Rather, it demonstrates the importance of separating the use of geothermal heat from direct exposure to geothermal fluid. Water chemistry, acidity, dissolved minerals, gases, temperature, species selection, and heat-exchange design must be tested. Accordingly, aquaculture is classified as a conditional option requiring controlled pilot testing rather than an immediately recommended application.

Table 2. Existing and indicative geothermal direct-use applications in Muara

Application	Current status	Laboh	
		Development potential	Key preconditions
Hot-spring tourism	Existing, locally oriented	Revitalization and integrated geothermal tourism	Water quality and safety, facilities, destination management, market plan, investment
Agricultural drying	Not yet implemented	Coffee, tea, palm sugar and other post-harvest processes	Resource and demand data, heat exchanger, production volume, market and financial pre-feasibility
Agroindustry	Not yet implemented	Thermal processing and local value addition	Process-heat demand, business model, infrastructure and investment
Aquaculture	Previous attempt unsuccessful	Conditional	Water/fluid quality, temperature, species suitability, safe indirect heat exchange, pilot test

Community Acceptance and Strategic Policy Support

Community acceptance was generally supportive at the time of data collection, but the evidence supports a conditional rather than universal interpretation. Earlier concerns included environmental risk, land issues, misunderstanding of geothermal technology, and comparisons with unrelated extractive disasters. Over time, socialization, project experience, employment, infrastructure improvements, and community-development programs were reported to have reduced some concerns. Nevertheless, differences in knowledge and perceived benefits remain, and continued acceptance depends on transparent information, meaningful participation, trust, risk communication, and fair benefit distribution.

This distinction matters for direct-use projects because local communities may become users, operators, business partners, or parties affected by land and resource decisions. Acceptance therefore needs to be built into project design from the beginning rather than treated as a communication task after technical decisions have been made. This finding is consistent with studies that identify trust, transparency, participation, and benefit sharing as recurring determinants of geothermal acceptance (Anggreta et al., 2022; Renoth et al., 2023).

Spatial and development policies provide strategic support but remain only partly operational. The applicable South Solok spatial plan accommodates geothermal development, while the regional development plan and planning discourse recognize geothermal resources and tourism/agricultural development. However, draft revisions and future detailed spatial plans cannot be treated as legally effective instruments until enacted. More importantly, strategic recognition has not yet been translated into a direct-use action

program with priority locations, responsible agencies, financing, investment profiles, permitting pathways, annual targets, and performance indicators. The key problem is therefore an implementation gap rather than complete policy absence.

Implementation Constraints and Collaborative Governance

The dominant constraints identified by informants were limited baseline technical data, low investment interest, weak cross-sector coordination, limited implementation capacity, and the absence of viable business models. These constraints interact. Investors require credible information on the heat source, prospective users, market size, infrastructure, environmental risk, licensing, capital requirements, revenue models, and risk allocation. Without pre-feasibility evidence, promotion of resource potential alone is unlikely to generate investment-ready projects.

Governance is equally important. Local government can act as coordinator and integrate energy, agriculture, tourism, environment, investment, spatial planning, MSME development, and community empowerment. The geothermal operator can provide information and technical coordination within its mandate, but need not become the principal owner of direct-use projects. BUMDs, cooperatives, farmer groups, community organizations, local businesses, and private investors can assume ownership or operating roles depending on the project. Universities can support technical assessment, monitoring, and model validation. This distribution of roles is consistent with collaborative-governance theory, in which interdependent actors need formal coordination, shared objectives, and transparent decision processes (Ansell & Gash, 2008; Emerson et al., 2012).

Triple Bottom Line and SDG Implications

TBL analysis requires a strict distinction between benefits already realized from geothermal power generation and benefits specifically attributable to direct use. Under People, existing direct-use benefits are presently limited to recreation and micro-enterprise activity, while broader employment, infrastructure, and CSR benefits are mainly associated with the power project. Future direct-use projects could broaden participation through farmer groups, MSMEs, cooperatives, and local employment. Under Planet, geothermal direct use offers potential resource-efficiency gains and reduced conventional-fuel use, especially through cascade utilization, but this study did not quantify emissions, water quality, biodiversity, or energy savings. Environmental benefits therefore remain potential until measured. Under Profit, current direct-use economic value is limited to bathing and micro-commerce, while larger value creation depends on tourism revitalization, agricultural drying, agroindustry, and viable business models.

Table 3. Triple Bottom Line interpretation of geothermal direct use

Dimension	Current evidence	Potential development	Interpretation
People	Recreation, micro-enterprise; wider social benefits mainly linked to PLTP	Farmer/MSME/cooperative participation, local jobs, benefit sharing	Direct-use benefits realized only on a limited scale
Planet	Natural hot-water use; no direct-use environmental performance measurement	Energy efficiency, conventional-fuel displacement, cascade use, safer fluid management	Potential; requires measurement and verification
Profit	Bathing revenue and micro-commerce	Agricultural value added, agroindustry, tourism, energy-cost savings	Limited current value with stronger future potential

The SDG mapping follows the same attribution discipline. SDG 7 is clearly supported by the operating geothermal power plant, whereas direct-use contribution remains limited. SDG 8 may expand if productive applications create jobs and local value added. SDG 9 is relevant through infrastructure and innovation, particularly post-harvest technology. SDG 11 is connected to integration with spatial and regional development. SDG 13 remains potential because the study did not quantify avoided emissions. SDG 17 is particularly important because implementation depends on partnership among government, operator, investors, businesses, academia, and communities. SDGs 2 and 12 may become relevant if agricultural drying improves post-harvest performance and cascade utilization increases resource efficiency. This differentiated mapping avoids overstating sustainability outcomes before projects are implemented and measured.

Proposed Conceptual Model

The synthesis produced a five-stage conceptual model that converts resource potential into a structured development process. Stage 1 establishes the baseline through resource characterization, user and market mapping, spatial status, local needs, and social-economic data. Stage 2 screens and prioritizes applications using technical, market, social, environmental, spatial, institutional, and acceptance criteria. Based on current evidence, hot-spring tourism revitalization can be treated as a quick-win candidate; agricultural drying is a productive priority after pre-feasibility assessment; and aquaculture remains conditional.

Stage 3 establishes governance and financing. A cross-sector mechanism defines project ownership, operator roles, revenue logic, financing sources, risk

allocation, benefit-sharing arrangements, and regulatory responsibilities. Stage 4 implements a limited pilot project to test technical, economic, social, environmental, and institutional feasibility. Stage 5 monitors TBL and SDG indicators, improves the technology and business model, and determines whether the project should be scaled, replicated, modified, or discontinued. Community participation, transparency, environmental protection, capacity building, and stakeholder coordination operate across all five stages. Monitoring results feed back into earlier stages, creating an adaptive learning cycle.

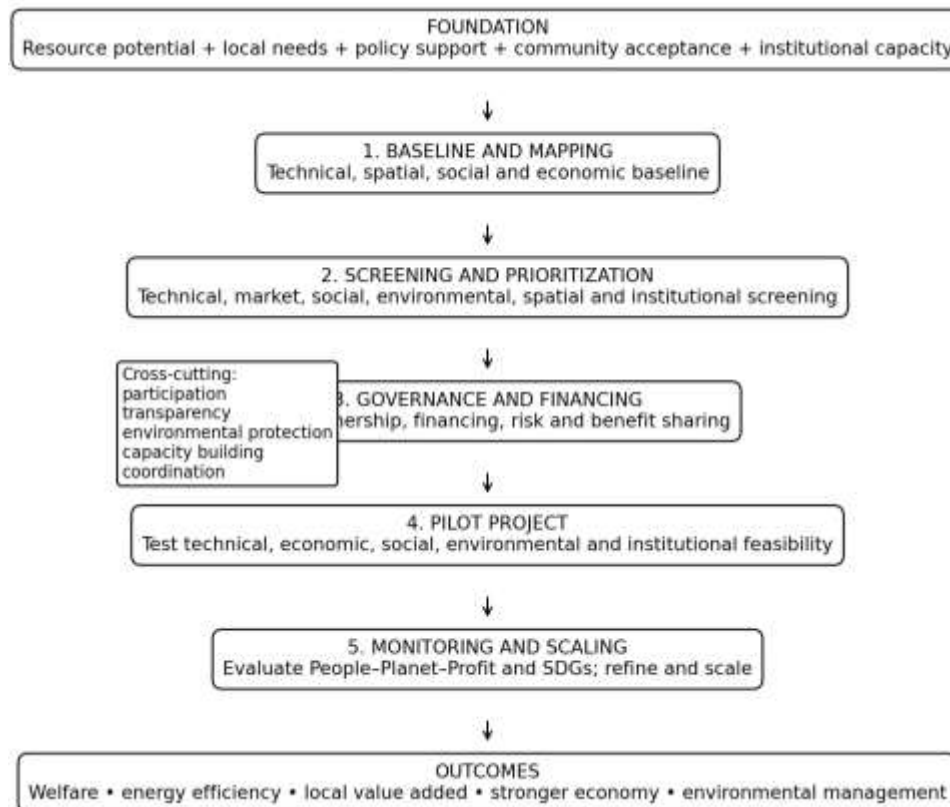


Figure 1. Five-stage conceptual model for sustainable geothermal direct-use development in Muara Laboh (adapted from the thesis synthesis, 2026)

The model is intentionally a decision framework rather than a predictive model. It does not establish causal coefficients, final engineering design, or investment feasibility. Its value lies in sequencing decisions and clarifying evidence requirements. This directly addresses the implementation gap identified in the case: strategic support and social acceptance can coexist with stalled implementation when technical baselines, governance, financing, and business models are absent.

CONCLUSIONS AND RECOMMENDATIONS

Geothermal direct use in Muara Laboh remains limited and is dominated by natural hot-spring bathing and micro-scale economic activities. Indicative opportunities are strongest in tourism revitalization, agricultural drying, and agroindustry, while aquaculture remains conditional. None of these alternatives should be presented as finally feasible because this study did not conduct

detailed resource measurements, engineering design, market analysis, or financial appraisal.

Community acceptance is generally supportive but conditional on knowledge, perceived benefits and risks, trust, participation, communication, and distributive fairness. Spatial and regional-development policies provide strategic support, but operational implementation remains constrained by limited technical data, weak coordination, low investment interest, limited capacity, and the absence of viable business models. The central challenge is therefore not simply resource availability; it is the institutional and analytical process required to convert potential into an implementable project.

The proposed five-stage model—baseline and mapping; screening and prioritization; governance and financing; pilot implementation; and monitoring and scaling—provides a structured pathway for this conversion. For practice, South Solok Regency should establish a cross-sector coordination mechanism, prepare investment-ready pre-feasibility packages, and begin with manageable pilot projects. Hot-spring tourism can be revitalized as an early action, while an agricultural drying pilot can test a productive use case. Each project should incorporate community participation, environmental safeguards, clear benefit-sharing mechanisms, and measurable People–Planet–Profit indicators.

ADVANCED RESEARCH

Future research should validate the model through expert judgment, focus groups, Delphi, AHP, or MCDA and should quantify technical and financial feasibility. Priority measurements include temperature, flow rate, fluid chemistry, source-user distance, heat demand, investment and operating costs, market demand, energy savings, and avoided emissions. Larger-sample quantitative research on community acceptance can complement the present qualitative findings. Such work would allow the conceptual model to evolve into a validated decision-support framework for Muara Laboh and comparable geothermal regions.

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