



Renewable Energy Transitions in Sarawak: Hydropower, Solar Hybrid Electrification, and Hydrogen Pathways

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ABSTRACT

Sarawak has emerged as a regional leader in renewable energy development in Southeast Asia, driven by abundant hydropower resources, strong state-led planning mechanisms, and strategic ambitions to transition toward a low-carbon economy. This paper examines the evolution of renewable energy in Sarawak through a review of policy frameworks, institutional governance, technological deployment models, and socio-environmental dynamics. The analysis focuses on three primary domains: (i) large-scale hydropower development under the Sarawak Corridor of Renewable Energy (SCORE), (ii) decentralized solar hybrid electrification initiatives in rural and off-grid regions, and (iii) hydrogen production and hydrogen mobility pilots linked to future export markets. Drawing upon government policy documents, academic literature, energy agency reports, and sectoral briefings, this study provides a critical assessment of the structural, political-economic, and socio-environmental dimensions of Sarawak's energy transition. The findings highlight the importance of state-driven governance frameworks, the need for socially inclusive electrification models, and the strategic yet uncertain positioning of green hydrogen within future global decarbonization markets.

1. Introduction

Energy systems in Southeast Asia are undergoing substantial restructuring driven by decarbonization imperatives, increasing electricity demand, and commitments to sustainable development [1-4]. Among regional jurisdictions, Sarawak represents a distinctive case in which renewable energy development has been strategically designed and centrally managed under state-led policy frameworks [5-7].

Unlike Peninsular Malaysia, which relies heavily on natural gas and coal-fired generation, Sarawak's electricity mix is dominated by large hydropower plants, supported by substantial river basin systems and hydrological resource endowment [8-10]. The institutionalization of the Sarawak Corridor of Renewable Energy (SCORE) has facilitated the development of energy-intensive industrial clusters by leveraging low-cost renewable electricity to attract high-value manufacturing and

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resource-processing activities [11-13]. Concurrently, the Sarawak Alternative Rural Electrification Scheme (SARES) demonstrates a complementary mode of decentralized energy provision designed to address energy access disparities in remote regions [14,15].

More recently, Sarawak has taken strategic steps toward positioning itself as a regional hydrogen production hub, enabled by hydropower-based electrolysis and supported by public–private collaborations under SEDC Hydrogen and PETROS [16-18]. However, socio-environmental concerns and geopolitical uncertainties persist, including Indigenous land rights, hydropower resettlement legacies, rural electrification maintenance challenges, and hydrogen market viability [19-22].

This study contributes to academic discourse by offering a multi-scalar analysis of Sarawak’s renewable energy system, integrating policy review, infrastructural development trajectories, and case study evaluation of hydropower, solar hybrid, and hydrogen initiatives [23,24].

2. Literature Review

2.1 Energy Transition Governance and State-led Development

Energy transitions are inherently political processes shaped by institutional configurations, resource geographies, and development priorities [23,25,26]. In Sarawak, renewable energy expansion has been characterized by centralized state control, long-term industrial planning, and strategic public enterprise leadership through Sarawak Energy Berhad and PETROS [5,8,13]. Comparative studies highlight that state-led governance models in Southeast Asia often enable rapid infrastructure deployment but raise questions of inclusivity and accountability [22,24].

2.2 Hydropower Systems and Socio-environmental Implications

Hydropower provides grid stability and supports energy-intensive industries, yet raises concerns regarding displacement, watershed modification, and Indigenous rights [19,20,27]. In Borneo, hydropower projects intersect with sensitive ecological landscapes and customary territorial claims, requiring robust social safeguards [10,28]. Global sustainability guidelines emphasize the importance of Free, Prior, and Informed Consent (FPIC) and biodiversity monitoring in hydropower governance [29].

2.3 Decentralized Energy and Rural Electrification

Distributed solar hybrid mini grids serve remote villages where grid extension is geographically and economically prohibitive [15,30]. The effectiveness of such systems depends on maintenance capacity, community participation, and institutional support [2,31]. Comparative studies across Asia-Pacific show that community-based energy models enhance resilience and reduce long-term costs when paired with local technician training and cooperative ownership structures [13,32].

2.4 Hydrogen as a Prospective Export Commodity

Hydrogen’s emergence as a decarbonization vector depends on production cost trajectories, market demand, infrastructure development, and trade partnerships [17,33,34]. Sarawak’s hydropower enables cost-competitive electrolysis, offering potential export advantage yet global hydrogen markets remain uncertain [18,21,35]. International analyses suggest that early movers in hydrogen can secure geopolitical visibility but face risks of stranded assets if demand fails to materialize [3,36].

3. Methodology

This study adopts a qualitative research design, structured through integrated document analysis and case-based comparative evaluation. The methodological approach is grounded in interpretive policy analysis, which emphasizes the institutional, socio-political, and economic contexts through which energy systems evolve [6,25,37]. Document-based approaches are widely used in energy transition studies to triangulate policy frameworks, technical deployment models, and socio-environmental outcomes [13,38]. Data sources include:

- i. Government strategy and planning documents, including the post-COVID-19 Development Strategy 2030 and SCORE Masterplan updates [5,11].
- ii. Corporate and technical reports from Sarawak Energy Berhad, PETROS, and SEDC Hydrogen, which outline operational parameters and project development trajectories [8,16,35].
- iii. Peer-reviewed journal publications on hydropower governance, rural electrification, and hydrogen markets [13,15,21,27].
- iv. International energy market assessments from the International Energy Agency, Asian Development Bank, and World Bank [4,12,17,39].

3.1 Research Design

The research design follows a multi-source document review to examine renewable energy development trajectories and their socioeconomic, environmental, and policy implications. This interpretive analytical framework situates energy projects within broader cultural, policy, and development contexts [22,23,40]. Comparative case study methods are employed to highlight differences in scale, governance, and social impact across hydropower, solar hybrid, and hydrogen initiatives [37,38].

3.2 Inclusion Criteria

Sources were selected based on:

- i. Direct relevance to Sarawak or Borneo-region renewable energy development, publication between 2020 and 2025,
- ii. Provision of empirical data, project scale descriptions, or policy implications, written in English or Bahasa Malaysia [24,32].

3.3 Analytical Framework

Table 1 shows the findings were synthesized using Cross-Comparative Thematic Analysis, producing three evaluation dimensions [13,37]:

Table 1

Evaluation characteristics of applying cross-comparative thematic analysis

Dimension	Evaluation Focus	Key Indicators
Technical	Feasibility & scalability	Installed capacity, grid integration, transmission reliability
Economic	Investment viability & market potential	Capital expenditure, tariff pricing, export market leverage
Environmental & Social	Sustainability & community impacts	Land-use change, emissions reduction, socio-cultural outcomes

This framework aligns with global sustainability energy assessment models [41-42] ensuring that Sarawak’s renewable energy pathways are evaluated against international benchmarks while remaining sensitive to local socio-political contexts.

4. Case Study

4.1 Case Study 1: Hydropower and Industrial Development under SCORE

Sarawak’s hydropower program anchored in the strategic vision of the Sarawak Corridor of Renewable Energy (SCORE), linking large-scale generation to industrial diversification and value-added manufacturing [8,11,12]. Major hydropower facilities, including Bakun (2,400 MW), Murum (944 MW), and Baleh (1,285 MW under development), supply stable baseload electricity to support energy-intensive sectors such as ferroalloys, aluminium processing, petrochemicals, and advanced materials [8,29,39].

From a developmental perspective, hydropower has enhanced state revenue, industrial employment, and regional infrastructure expansion [12,24]. However, scholarship emphasizes critical socio-environmental trade-offs, particularly in relation to Indigenous resettlement, watershed alteration, and land-use governance [10,19,27]. These concerns reflect broader dilemmas in resource-rich emerging economies, where low-carbon transition pathways remain entangled with contested territorial and ecological transformations [20,23].

4.2 Case Study 2: Solar Hybrid Electrification and Rural Energy Inclusion (SARES)

The Sarawak Alternative Rural Electrification Scheme (SARES) addresses persistent energy access gaps in remote settlements where grid extension is economically prohibitive [14,15,43]. The program deploys solar hybrid mini-grids, integrating photovoltaic generation with battery storage systems to support domestic electricity needs, small-scale businesses, and community-level services [30,31].

SARES is distinctive for its community-based operational model, wherein residents are trained to maintain system functions, strengthening long-term sustainability and reducing dependence on external maintenance networks [2,32]. Empirical studies show improvements in household welfare, digital connectivity, and income diversification following electrification [13,15]. Comparative evidence from Asia-Pacific mini-grid programs highlights the importance of local technician training, cooperative ownership, and decentralized supply chains for long-term viability [4,22].

4.3 Case Study 3: Hydrogen Development and Strategic Export Positioning

Sarawak has positioned itself as a first mover in green hydrogen production within Southeast Asia, supported by hydropower-driven electrolysis infrastructure and pilot-scale hydrogen mobility deployments [16,18,35]. The development strategy centers on three sectors:

- i. Hydrogen production hubs are co-located with hydropower plants,
- ii. Hydrogen refueling and mobility demonstration projects, including buses and passenger vehicles,
- iii. Future export capacity targeting Japan, South Korea, and Singapore [17,21,36]. Global hydrogen markets remain cost-sensitive and policy-contingent, meaning commercialization timelines depending on external demand signals and international energy pricing frameworks [3,34,35]. Comparative studies suggest that early movers can secure geopolitical visibility but face risks of stranded assets if demand fails to materialize [22,24]. Sarawak's hydrogen roadmap thus represents both strategic ambition and market uncertainty, requiring phased commercialization and regional integration [44,45].

5. Discussion

Sarawak's renewable energy development reflects a multi-layered transition pathway, in which large-scale hydropower, decentralized solar PV systems, and emerging hydrogen technologies fulfil different strategic, geographic, and socioeconomic functions [13,24,26]. These systems coexist rather than compete, operating within a complementary structural framework shaped by state-led planning and resource governance institutions [11,23].

5.1 Hydropower as Structural Backbone

Hydropower underpins grid stability and ensures low marginal generation costs, enabling long-term renewable baseload electricity supply to industrial clusters and export-linked manufacturing corridors [12,29,46]. Its infrastructural scale provides strong leverage in industrial policy and economic diversification, consistent with developmental state models [24,40]. However, hydropower also embodies ecological and social tensions, particularly regarding Indigenous land rights, biodiversity alteration, and watershed transformation [10,19,20]. These impacts necessitate enhanced resettlement governance frameworks, community benefit-sharing mechanisms, and continuous ecological monitoring [22,29].

5.2 Solar Hybrid Electrification as Equity-Oriented Development

Solar PV deployment under SARES performs a redistributive social function, extending electricity access to remote communities that would otherwise remain unconnected due to cost and terrain constraints [15,30,42]. Unlike industrial hydropower, the objective of solar hybrid systems is household welfare and rural livelihood enhancement, supporting education, healthcare, local entrepreneurship, and communication access [2,31,43]. However, maintaining system reliability in remote areas requires local technical capacity building, consistent supply chain support, and sustainable funding mechanisms for replacement components [4,13,32]. The success of SARES thus hinges on community participation, governance continuity, and post-installation support infrastructure rather than initial installation alone [22].

5.3 Hydrogen as Strategic Future Export Commodity

Hydrogen development occupies a forward-looking and market-contingent role. Its current deployment remains pilot-scale, driven by state ambition to position Sarawak as a regional hydrogen

hub servicing emerging demand from Japan, South Korea, and Singapore [16,18,35]. Hydrogen’s feasibility depends not only on hydropower availability, but also on international pricing structures, shipping technology maturation, and long-term offtake agreements [34,36,41]. While early-mover positioning enhances geopolitical visibility, the commercialization timeline remains uncertain and requires policy hedging to avoid stranded asset risk [21,24,33]. Table 2 shows the comparative evidence from Asia and Europe suggests phased commercialization strategies are essential to balance ambition with market realities [22,44,45].

5.4 Comparative Strategic Roles

Table 2

Comparative synthesis highlights Sarawak’s multi-scalar renewable energy model

Dimension	Hydropower	Solar Hybrid Electrification	Hydrogen Development
Primary Function	Industrial and grid baseload supply	Rural energy access & equity	Future export-oriented fuel production
Scale	Utility-scale (GW)	Community-scale (kW–MW)	Pilot to industrial scale (pre-commercial)
Economic Maturity	High	Moderate	Low / emerging
Social Impact Sensitivity	High (land & resettlement)	Low–moderate	Low currently, but future land demand possible
Strategic Value	Sustains industrial growth	Strengthens rural inclusion	Positions state in global energy transition markets

This comparative synthesis illustrates Sarawak’s multi-scalar renewable energy model, where hydropower provides economic competitiveness, solar hybrid systems ensure social equity, and hydrogen initiatives project future-oriented international positioning [11,13,24].

6. Policy Implications and Future Prospects

Sarawak’s renewable energy trajectory demonstrates the importance of coherent state-led governance, long-term infrastructure planning, and adaptive socio-environmental management [11, 13,26]. To sustain progress and ensure equitable transition outcomes, several strategic policy considerations must be addressed.

6.1 Strengthening Indigenous and Community Participation

Hydropower development has historically intersected with sensitive questions of territorial rights, cultural identity, and community agency [10,19,20]. Strengthening Free, Prior, and Informed Consent (FPIC) processes and ensuring co-managed land stewardship is essential to avoid social fragmentation and to ensure long-term legitimacy [29]. Participatory governance models and localized benefit-sharing schemes can improve trust and outcomes [22,24].

6.2 Enhancing Post-Installation Sustainability in Solar Hybrid Systems

While SARES has successfully expanded electricity access, post-installation operational continuity remains a structural challenge. Policy adjustments should prioritize:

- i. Local technician training and certification,
- ii. Dedicated rural maintenance funds,
- iii. Spare parts supply chain decentralization, and

- iv. Community-owned energy cooperatives [15,30,32].

Such measures strengthen rural resilience and ensure long-term functional sustainability rather than temporary electrification gains [4,13,31].

6.3 Structuring Hydrogen Market Positioning

Table 3 shows the hydrogen development should proceed through phased commercialization to minimize market exposure risk. Three strategic phases are recommended [3,34,36]:

Table 3

Hydrogen development proceeds through phased commercialisation

Phase	Time Horizon	Strategic Action
Pilot-Scale Consolidation	2024–2030	Expand hydrogen buses, refuelling infrastructure, and industrial demonstration hubs.
Regional Market Integration	2030–2040	Secure bilateral export agreements with Japan, Korea, Singapore.
Global Commodity Positioning	2040+	Scale green ammonia and liquid hydrogen export terminals aligned with global maritime fuel transitions.

This staged approach aligns technology readiness with commercial certainty and geopolitical stability [18,24,46].

6.4 Regional Grid Interconnection Opportunities

Sarawak's emerging role within the Borneo Renewable Energy Hub offers opportunities for ASEAN electricity trade, particularly with Kalimantan considering Indonesia's new capital Nusantara development [44,47]. Cross-border interconnection can reinforce regional energy security while advancing decarbonization [22,24]. Comparative evidence from other ASEAN interconnection projects highlights the importance of harmonized regulatory frameworks and transparent tariff structures [4,31].

7. Conclusion

Sarawak represents a distinctive model of state-coordinated renewable energy transition, combining large-scale hydropower, solar hybrid electrification, and pioneering hydrogen development [8,11, 13]. Hydropower provides a low-carbon industrial baseload, solar hybrid systems strengthen rural inclusion and social development, and hydrogen initiatives position Sarawak as a future-oriented regional clean energy hub [3,12,24].

However, sustainable long-term progress requires:

- i. Strengthened indigenous and community participation [10,19,20,29].
- ii. Institutionalized post-installation support for rural electrification [15,30,32].
- iii. Phased and risk-aware hydrogen commercialization [18,34,36] and
- iv. Adaptive governance frameworks are responsive to evolving market, technological, and ecological dynamics [22,23].

Sarawak's renewable energy transition illustrates how resource endowment, political will, and strategic planning can align to produce a multi-scalar, equitable, and globally relevant energy transformation pathway [4,44]. Continued policy refinement and stakeholder engagement will determine the durability and inclusiveness of this transition in the decades to come [45,47].

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