



Review Article

Sustainability and Innovation in Malaysia's LNG Industry: A Systematic Literature Review



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Abstract

This study presents a systematic literature review of sustainability and innovation in Malaysia's Liquefied Natural Gas (LNG) industry, conducted in accordance with the PRISMA 2020 framework. Boolean searches across five databases (Scopus, Web of Science, ScienceDirect, SpringerLink, and Google Scholar), with no date restriction, returned 923 records; title, abstract, and full-text screening against predefined criteria yielded 15 studies. Eligible studies addressed at least one of four dimensions: energy-economic linkages, green technological progress, structural dynamics of the LNG sector, and international benchmarking and technology transfer. The review finds incremental, mainly technical progress in cleaner technologies and energy efficiency. Because the evidence is drawn from a small, technically oriented corpus, these gains are indicative rather than conclusive; quantitative, LNG-specific sustainability metrics are scarce, so the policy implications are directional rather than prescriptive. The principal challenges are regulatory fragmentation (notably PETRONAS's overlapping roles as regulator and operator), comparatively low RandD investment, and ageing infrastructure. Benchmarking against Qatar and Australia reveals capability gaps in carbon capture deployment. Working with companies across borders, especially those in Japan, creates opportunities to jointly develop carbon capture technologies. Key limitations are the small number of eligible studies ($n = 15$), the predominantly technical rather than socio-economic orientation of the corpus, and the exclusion of non-English publications.

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1. Introduction

The landscape of global energy supply and demand has fundamentally changed in the last 20 years, driven by three converging forces: a rapidly increasing climate urgency, disruptive technology transformation, and a more volatile geopolitical environment. Liquefied Natural Gas (LNG) has

emerged as a unique fuel in this turbulent shift from CO₂-intensive sources such as coal and oil, and as a source of energy security for countries, that is not always achievable with purely domestic energy supplies [1]. Malaysia plays a considerable role in this picture. The country is one of the top five LNG exporters in the world and has been a key contributor to the national economy, employment opportunities, and export revenues [2].

Malaysia's energy policy has been torn between domestic energy development priorities and growing international commitments, namely the Paris Agreement and Sustainable Development Goals (SDGs) [3]. Natural gas is recognised as a transitional fuel in the National Energy Policy 2022–2040, and renewable energy is also envisaged to play a larger role in the country's energy mix [4]. However, the environmental costs of the LNG industry, such as the emissions of methane, gas flaring, and the energy-intensive liquefaction, pose sustainability issues that require policy ambition to address [1]. Potential technological pathways are available, such as carbon capture and storage (CCS), digitalisation and hydrogen blending, but implementing such technologies on a global scale is not uniform and needs to be done locally.

Although the field of study in Malaysia on energy has been expanding, there is no research that has been conducted systematically in the field of energy innovation and sustainability in the LNG segment. The research conducted to date has focused more on the technical processes of optimising the design and development of new technology, to the point of largely omitting the socio-economic and governance factors that influence the actual adoption of a new technology [5]. The same is true for the comparative benchmarking of Malaysia's LNG operations with other international players, which is still very limited [5] and the institutional arrangements that facilitate or hinder sustainable innovation are also under-researched [6].

In this review, innovation is defined operationally as the adoption and adaptation of technologies, processes, and governance or business models that lower the emissions intensity or improve the sustainability of activities along the LNG value chain, covering upstream feed-gas, liquefaction, shipping, re-gasification, and carbon management. The definition is deliberately wider than hardware and takes in process and institutional innovation. This usage follows the Schumpeterian distinction between product, process, and organisational innovation [7] and its operational treatment in the OECD/Eurostat Oslo Manual [8]; the inclusion of institutional and governance change draws on the sectoral innovation systems tradition, which places firm-level innovation within wider institutional and policy structures [9]. The timing matters too: in a short span the National Energy Transition Roadmap (2023), the carbon tax planned for 2026 on the energy sector [10], and the phasing-in of the EU Carbon Border Adjustment Mechanism [11] have changed the policy and trade environment for Malaysia LNG, so a consolidated evidence base is more useful now than before.

This structured, systematic review addresses three explicit research questions:

- RQ1: What sustainability and innovation themes dominate the academic literature on Malaysia's LNG industry?
- RQ2: What methodological and disciplinary patterns characterise the available research, and where do evidence gaps remain?
- RQ3: What policy, technology, and governance barriers and enablers can be identified from the synthesised literature?

The paper proceeds as follows. Section 2 describes the review methodology. Section 3 presents thematic findings organised across four analytical dimensions, incorporating study characteristics for all 15 included studies. Section 4 develops theoretical and practical implications. Section 5 concludes with directions for future research.

2. Methodology

2.1. Review Design

This study is a systematic literature review conducted in accordance with the PRISMA 2020 framework [12]. Systematic search procedures, explicit inclusion and exclusion criteria, transparent screening, and a structured synthesis framework are applied throughout. The review is qualitative-synthetic rather than meta-analytic: the number of eligible studies ($n = 15$) is relatively small, which precludes formal meta-analysis but does not undermine the validity of a thematic synthesis. This is consistent with the present state of the field, as Malaysia-focused LNG sustainability research remains an emerging area.

2.2. Search Strategy

Five databases were searched: Scopus, Web of Science, ScienceDirect, SpringerLink, and Google Scholar. The Scopus and Web of Science were selected because of their thorough peer-reviewed indexing and citation functions. Applied energy and engineering journals were made available by ScienceDirect and SpringerLink. Grey literature and recent publications that were not indexed in other sources were added with the help of Google Scholar. For the first half of 2025, searches were made without any restriction on publication dates; thus, historical regulatory trends as well as contemporary studies were captured.

Boolean operators were used to create a search string of basic terms. An initial concept string combined the three basic terms:

((“Malaysia” OR “Malaysian”) AND (“liquefied natural gas” OR “LNG”) AND (“sustainability” OR “sustainable development” OR “innovation” OR “energy transition” OR “green technology” OR “carbon capture”))

Filters applied: TITLE-ABS-KEY field search in Scopus, Topic field search for Web of Science, Research Articles in ScienceDirect, Research Papers in SpringerLink. Boolean operators (AND, OR) and field-specific limiters were used in a uniform way. Duplicate records were removed before title and abstract screening.

To avoid missing relevant work through a narrow keyword set, the core concepts were broadened with common synonyms and adjacent terms before searching. The master Boolean string combined a geography facet, a gas-industry facet, and a sustainability-and-innovation facet: (“Malaysia” OR “Malaysian” OR “PETRONAS” OR “Bintulu” OR “Sarawak”) AND (“LNG” OR “liquefied natural gas” OR “natural gas” OR “gas industry” OR “oil and gas” OR “gas value chain” OR “liquefaction”) AND (“sustainability” OR “sustainable development” OR “decarbonisation” OR “emissions” OR “methane” OR “carbon capture” OR “carbon storage” OR “CCS” OR “energy transition” OR “green technology” OR “innovation”). It was then adapted to each database’s syntax (for example, the TITLE-ABS-KEY field in Scopus and the Topic field in Web of Science). This broadened master string, not the initial concept string above, was the version run across all five databases.

Because Google Scholar does not return a stable or reproducible result set, its use followed a documented protocol. Results were sorted by relevance, and the first ten pages (about one hundred records) were screened. Retrieval was limited to English-language titles and abstracts, and grey-literature hits were kept only when the issuing body was identifiable, such as a government agency or an industry association. Records from all five databases were exported to a reference manager, where duplicates were removed automatically by DOI and title and then checked by hand. Records were excluded as low quality if they were non-peer-reviewed opinion pieces, gave no discernible method, or reported no verifiable data source.

The ten-page limit on Google Scholar was a practical response to its relevance-ranked, non-reproducible output. Because results are ordered by relevance, on-topic returns fell away quickly after the first several pages, and screening continued until successive pages yielded no further eligible records. This approach follows established guidance for using Google Scholar in evidence reviews, which recommends focusing on the leading relevance-ranked results [13]. This reduces the risk of selection bias but does not remove it, and the cap is noted as a limitation in Section 5.

As a robustness check, a supplementary search using the synonym-expanded string was run across the same databases. It surfaced additional adjacent material, such as work on methane abatement in Malaysia's upstream oil-and-gas sector and on LNG decarbonisation in other jurisdictions. Each of these records, however, was a duplicate already captured, was contextual rather than specific to Malaysia's LNG sector, or concerned non-LNG segments, and none met the inclusion criteria. The final set of fifteen studies therefore did not change. This suggests that the small corpus reflects a genuinely limited body of Malaysia-specific LNG sustainability research rather than an artefact of keyword selection, a point revisited in the limitations.

2.3. Inclusion and Exclusion Criteria

Studies were selected if they: (i) covered at least one of the four dimensions of the review; (ii) were in English; and (iii) communicated empirical, theoretical, or policy analytical findings that included a clear method or process for obtaining results. The main type of sources were peer-reviewed journal articles. Documents of policy, industry reports, etc. cited in included studies were used as additional contextual evidence but were not counted as included studies. Conference papers were accepted if they contained some peer-reviewed empirical information not published in a journal.

Studies were not included if: (i) it was not energy or LNG related; (ii) there was no clear methodology; (iii) it was a duplicate of another study (from multiple databases); (iv) it was an editorial, book review, or conference abstract with no substantive content; or (v) it was focused on non-LNG energy sectors with no crossover relevance.

2.4. Study Selection Process

The initial search returned 923 records. After 396 duplicates were removed, 527 records were screened on title and abstract, and 494 of these were excluded as irrelevant to Malaysia's LNG sector or to sustainability and innovation. The remaining 33 reports were retrieved and assessed in full against the inclusion and exclusion criteria. Of these, 18 were excluded (scope mismatch, $n = 8$; insufficient methodological transparency, $n = 5$; no LNG focus, $n = 5$), which left 15 studies for the final synthesis. The PRISMA 2020 flow diagram is shown in [Figure 1](#).

The search process may be limited by: database selection bias, Google Scholar ranking algorithms that may prioritise recently cited publications, and language bias because of non-English publications being excluded. The risk of missing out on high-impact studies was reduced by using cross-references across Scopus and Web of Science. A bias may be introduced towards engineering solutions rather than governance or behavioural solutions as the eligible pool is predominantly technically oriented research.

2.5. Quality Appraisal

Due to the diversity of the included studies, ranging from empirical quantitative analyses to policy evaluations and conceptual papers, a mixed-methods quality appraisal approach was used. Quantitative studies were assessed using criteria modified from the Critical Appraisal Skills Programme (CASP) checklist, including clarity of the research question, appropriateness of methods, data validity, and robustness of conclusions. Qualitative and policy-analytical studies were evaluated on methodological

transparency, evidence grounding, and the degree to which findings were supported by the data presented. Each study was rated as High, Moderate, or Low quality. No quality cut-off was applied for exclusion; all 15 included studies met the minimum threshold for inclusion. Applying this appraisal, 5 studies were rated High quality (Ahmed and Elfaki [14]; Chong et al. [15]; Dharfizi, Ghani and Islam [16]; Khan [17]; Lindstad et al. [18]), 8 studies were rated Moderate quality (Adekoya et al. [1]; Aktar, Alam and Harun [3]; Bekhet and Harun [19]; Begum et al. [20]; Ha et al. [5]; Labauge et al. [21]; Lai, Shad and Shah [22]; Lim and Goh [23]), and 2 studies were rated Lower quality but retained for thematic relevance (Bekhet and Abdullah [24]; Fangmeier [6]). The complete study characteristics, including limitations identified per study, are presented in Table 1 in Section 3.1.

The CASP qualitative checklist was adapted in three ways to suit the review's mix of study types. Two screening items were added, on the verifiability of the data source and the directness of relevance to Malaysia's LNG sector; checklist items specific to clinical research, which do not apply to techno-economic and policy studies, were dropped; and a graded High/Moderate/Lower scale replaced the binary judgement, so ratings could be applied consistently to quantitative, qualitative, and policy-analytical work.

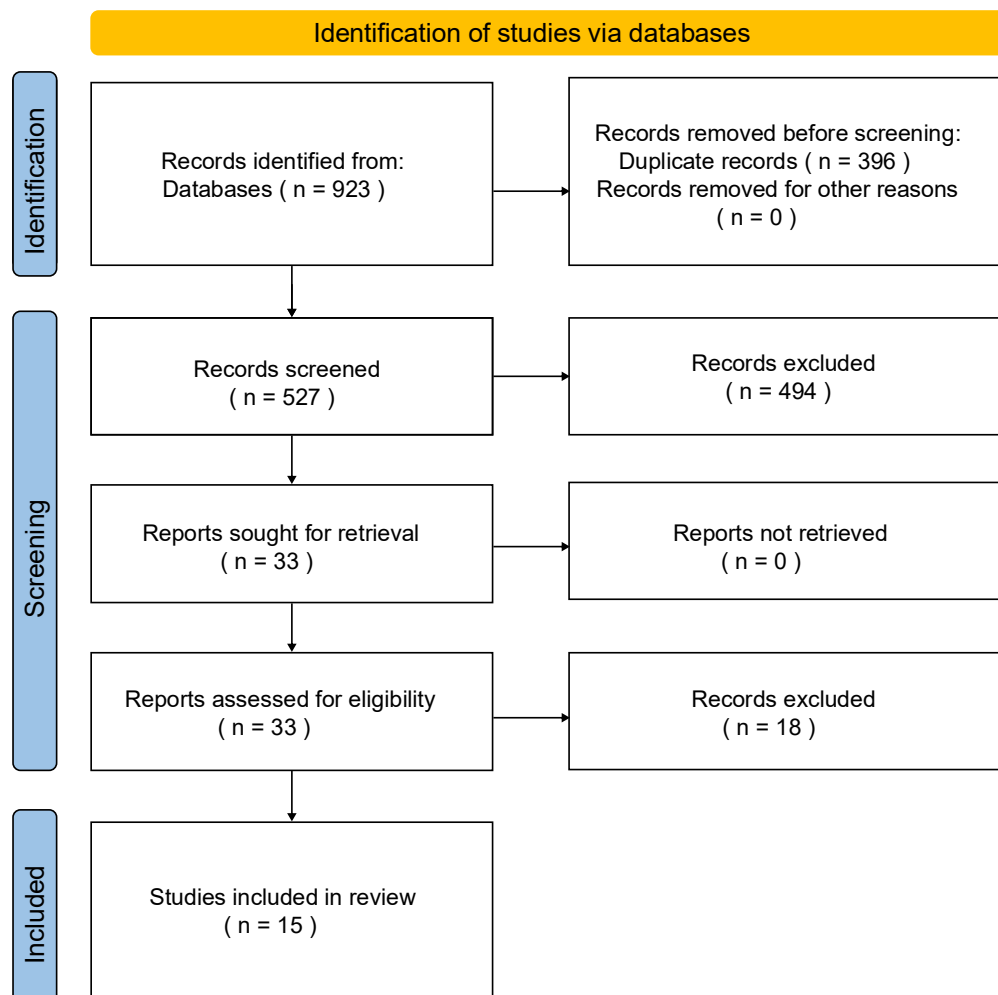


Figure 1. PRISMA flowchart of the study selection process.

2.6. Analytical Framework and Data Extraction

A standardised data extraction template was developed and applied to the studies that were included,

which captured: author(s) and year; study type and design; data source and/or context; sustainability dimension addressed; key finding; and limitations described by the authors and/or identified during the appraisal. Four dimensions, set a priori, were used to organise the thematic synthesis: (i) energy use and economic links; (ii) green technological progress and sustainable development; (iii) structural dynamics and strategic positioning; and (iv) international benchmarking and technology transfer.

3. Results

The synthesis that follows distinguishes three layers of evidence, so that the contribution of the reviewed literature stays separate from contextual data and from the authors' own inferences. The first layer is the empirical findings of the fifteen included studies (summarised in [Table 1](#) and classified by relevance in [Table 1b](#)); these are the primary evidence and underpin the strength-of-evidence judgement at the close of each thematic subsection. Secondly, quantitative data reflecting the sector's size, production, emissions, employment, and policy objectives are included, sourced from relevant industry, agency, and policy documents like those from PETRONAS, the Energy Commission, the International Energy Agency, and Malaysian government plans. These figures are identified as contextual, including in the notes to Tables 2 to 5, and situate the review rather than count as findings of the reviewed corpus. The third layer is statements that go beyond either category, such as the tentative three-phase model of energy-economic development and the international benchmarking inferences; these are flagged explicitly as the authors' interpretation.

3.1. Research Trends and Study Characteristics

The distribution of included studies over four thematic dimensions and four time periods is shown in [Figure 2](#). The temporal distribution results in a slow but significant shift in research focus. Prior to 2016, domestic scholarship focused on energy-economic relationships and was largely limited to setting out a baseline for LNG's contribution to GDP and national energy security [25], with limited involvement with sustainability frameworks. A transitional period was experienced between 2016 and 2019, where sustainable development concepts started to make it into the Malaysian energy research agenda. The orientation of the literature shifted noticeably from 2020 onward. Most of the studies included after 2020 address themes related to sustainable development, emissions reduction, or technology transition, reflecting Malaysia's increased focus on climate commitments following the 2015 Paris Agreement and the development of the National Energy Transition Roadmap in 2023 [26].

In terms of method, the early studies focused mainly on quantitative energy-economic modelling. The more recent literature has more and more become the realm of mixed-methods research, in which policy analysis and empirical measurement are combined. There is a significant research gap across the reviewed literature with regard to the governance structure and the dynamics of the stakeholders. The evidence base from 15 studies is small, and any trend narratives based on this evidence should be used with caution. This is not a matter of the search strategy, as the small corpus indicates the early beginnings of LNG sustainability scholarship specific to Malaysia. [Table 1](#) presents the complete study characteristics and quality appraisal summary for all 15 included studies.

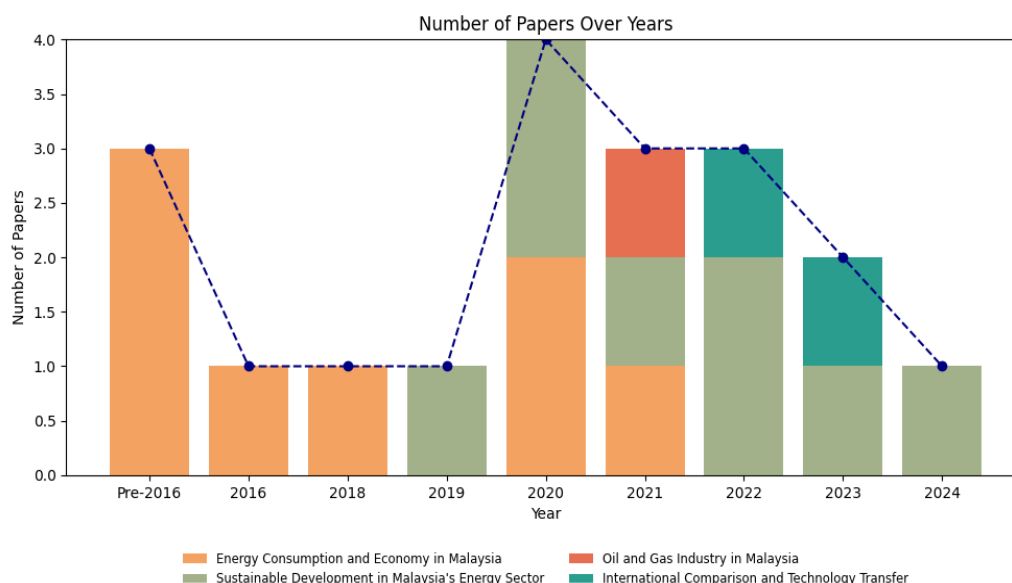


Figure 2. Research trends in the domain of sustainability and innovation in Malaysia's LNG industry.

Table 1. Study characteristics and quality appraisal summary of 15 included studies.

Author(s) and Year	Study Type	Data / Context	Dimension	Key Finding	Limitation
Adekoya et al. [1]	Review	Global LNG market data	Energy transition; market dynamics	CCS and digitalisation are key innovation levers for LNG decarbonisation	Does not disaggregate Malaysia-specific findings
Ahmed and Elfaki [14]	Quantitative	Panel data; 15 Asia-Pacific and Latin American economies (incl. Malaysia)	Green technological progress; GTFP	Green technological progress generates externality spillovers that support long-run sustainable growth	Cross-country (Malaysia one of 15); not specific to Malaysia or to LNG
Aktar et al. [3]	Policy analysis	Malaysia energy policy documents	Energy efficiency; SDGs	Energy efficiency policies lack enforcement mechanisms; voluntary measures are insufficient for targets	Policy framework focus; limited empirical measurement
Bekhet and Abdullah [24]	Quantitative	Malaysia agri. and energy data	Energy consumption; economic linkages	Energy use closely linked to sectoral output; broader economic energy dependencies demonstrated	Dated; agricultural focus limits LNG applicability
Berhet and Harun [19]	Quantitative	Malaysia electricity generation data	Energy mix; renewables	Non-renewable dominance persists;	Does not address LNG

				renewable integration necessary for sustainable electricity	export sector specifically
Chong et al. [15]	Energy flow analysis	Malaysia national energy statistics	Energy consumption patterns	Industrial sector dominates; LNG-linked petrochemicals represent significant embedded energy demand	Data cutoff limits current applicability
Dharfizi et al. [16]	Policy evaluation	Malaysia's fuel diversification 1981–2016	Energy security; fuel policy	Fuel diversification is partially effective; LNG dependency creates price exposure and energy security risks	Ends 2016; does not capture post-Paris Agreement shifts
Fangmeier [6]	Conceptual/Engineering	LNG-to-power infrastructure frameworks	Technology transfer; infrastructure risk	De-risking LNG-to-power infrastructure requires integrated regulatory and financing approaches	Abu Dhabi case study; Malaysia transferability needs qualification
Ha et al. [5]	Regulatory analysis	International maritime regulations	Regulatory gaps; LNG as marine fuel	Regulatory gaps between LNG carriers and LNG-fuelled ships create compliance uncertainty	Maritime focus; onshore LNG applicability limited
Begum et al. [20]	Empirical	Malaysia macro time series, 1970–2009	Energy consumption; CO ₂ emissions; growth	Economic and population growth raise energy use and CO ₂ emissions; in the long run, growth worsens emissions unless low-carbon technology is adopted	Aggregate national data; not LNG-specific
Lim and Goh [23]	Policy/legal analysis	Malaysia's natural gas market: law and policy	Gas market liberalisation; energy security; energy justice	Transitioning from regulated to liberalised gas pricing entails energy-justice trade-offs; low regulated prices strain revenue and weaken efficiency incentives	Peninsular Malaysia focus: qualitative policy analysis
Khan et al. [17]	Quantitative ARDL	Malaysia energy-growth panel data	Energy-growth nexus; policy implications	Bidirectional causality between energy	Aggregate energy; LNG-specific

				consumption and economic growth; growth-sensitive policy needed	causality not isolated
Labauge et al. [21]	Technical	Global CCS value chains	Carbon capture; decarbonisation	LNG infrastructure can accelerate CCS deployment; integrated CCS chains offer scalability advantages	Conference proceeding; peer-review level may vary
Lai et al. [22]	Conceptual	Malaysia OandG sector governance	Corporate sustainability; ESG	ESG reporting in Malaysia's OandG remains voluntary and inconsistent; governance gaps hinder green growth	Conceptual framework; limited empirical validation
Lindstad et al. [18]	Quantitative/Modelling	Maritime transport decarbonisation	LNG as a transition fuel; emissions	LNG viable transition fuel if methane slip controlled; engine technology and regulation jointly determine outcomes	Maritime focus; onshore LNG application indirect

To make the basis of the synthesis transparent, the fifteen studies are also classified by how directly they bear on the review's focus, using a tiered scheme (Table 2). Only two address Malaysia's LNG sector directly; the rest supply Malaysian energy-sector context, LNG evidence from other jurisdictions, or indirect background. That distribution is itself a finding: it shows how thin the directly relevant evidence base is, and it is the reason for the cautious tone of the synthesis below. Tier C and D studies are kept for the transferable mechanisms and comparative context they offer rather than as direct evidence on Malaysia's LNG sector, and their limited applicability carries through to the confidence judgements in each synthesis.

Table 2. Relevance classification of the 15 included studies.

Tier	Definition	Included studies (n)
A	Directly addresses Malaysia's LNG / oil-and-gas sector	Dharfizi et al. [16]; Lai et al. [22] (2)
B	Malaysian energy sector, not LNG-specific	Ahmed and Elfaki [14]; Aktar et al. [3]; Bekhet and Harun [19]; Chong et al. [15]; Begum et al. [20]; Khan et al. [17]; Lim and Goh [23] (7)
C	LNG-related but not Malaysia-specific	Adekoya et al. [1]; Fangmeier [6]; Ha et al. [5]; Labauge et al. [21]; Lindstad et al. [18] (5)
D	Indirect / contextual relevance only	Bekhet and Abdullah [24] (1)

3.2. Energy Consumption Patterns and Economic Linkages

The relationship between energy consumption and economic development in Malaysia is complex [20]; the interaction between sectors, technological capacities, and policy interventions is complex and, in a way, counterintuitive. According to the reviewed literature, the industrial sector is the primary energy consumer. It utilises substantial quantities of LNG for production and significant energy for petrochemical processing, as noted in reference [15]. The energy intensity of the LNG liquefaction plant is also high due to its capital-intensive nature, although incremental improvements in the plant are gradually loosening the association between increased production and overall energy consumption.

Several studies highlight the dual economic function of LNG, namely its high export value and high energy consumption in the country as an importer, thus posing competing demands on the country's energy supply [2,16]. This tension is sharper in Sarawak and Sabah as the share of LNG use in the region's energy demand is greater than in other parts of the country, considering the population size. [16] Historically, domestic gas prices are subsidised well below export parity, which weakens the incentive to invest in energy efficiency [23].

The economic linkages go beyond GDP and jobs. Fertilisers and oleochemicals are particularly relevant forward linkages with manufacturing sectors, which further illustrates LNG's macroeconomic relevance [2] but also mean that during times of price volatility there is systemic exposure [20]. Based on the literature reviewed, a tentative three-phase evolution for Malaysia's energy-economic approach has been identified: growth-oriented phase (before 2015); productivity-oriented phase (between 2015 and 2020); transition-oriented phase (afterward 2020). This characterisation should be considered a working hypothesis, as there is a relatively limited number of studies directly dealing with this periodisation. It is offered as a heuristic to guide future empirical testing, not as a validated model.

Synthesis of evidence: The link between energy use and economic activity in Malaysia is the corpus's most strongly supported theme. A robust energy-growth relationship is most directly evidenced by the ARDL causality analysis of Khan et al. [17] for Malaysia over 1971–2014, and is complemented, though not independently confirmed, by Chong et al. [15], which maps Malaysia's energy flows, and by Dharfizi et al. [16], which evaluates fuel-mix diversification. Support is weaker, and largely indirect, for claims specific to LNG, because most of these studies treat energy in aggregate rather than separating out the LNG value chain; the sector-specific figures in Table 3 therefore rest on contextual industry and agency sources rather than on the reviewed studies. The evidence partly conflicts on the direction of causality between consumption and growth, and it is effectively silent on the price-efficiency mechanism. The claim that subsidised domestic gas pricing dampens efficiency investment is asserted but not directly tested for the LNG segment. On balance, confidence in the energy-economy linkage is moderate-to-high, since it rests on three of the five High-rated studies; confidence in the LNG-specific economic claims is low, because they draw mainly on Moderate-rated, Lower-rated, or contextual sources. On the quality appraisal, the core energy-growth finding rests on High-rated studies (Khan [17], Chong [15], Dharfizi et al. [16]) and is reported with confidence, while the weaker, LNG-specific extensions draw on Moderate- and Lower-rated work and are treated as tentative.

The bidirectional reading of the energy-growth relationship needs one caveat. It rests on a single Malaysian time-series study [17], and the wider empirical literature reports mixed directionality depending on the period, variables, and estimator used. The relationship is better treated as context-dependent than as a settled, symmetric causal link, and the policy inferences drawn from it remain tentative.

Table 3. Energy-economic indicators of Malaysia's LNG sector.

Indicator	2015	2020	2022	Data Source
LNG Contribution to GDP (%)	5.2	6.1	5.8	National Energy Balance [27]
Energy Intensity (MJ/USD)	8.7	7.9	7.4	National Energy Balance [27]
Domestic Gas Consumption Share (%)	41	38	35	PETRONAS Annual Review [28]
Employment in LNG Sector (thousands)	52	58	62	DOSM Labour Survey [29]

Note. The figures in Table 3 come from the contextual industry, agency, and government sources cited in the table (for example, the Energy Commission, the International Energy Agency, PETRONAS, and the Department of Statistics Malaysia). They provide context for the review and are not findings of the fifteen included studies.

3.3. Technological Progress and Sustainable Development

The literature reviewed suggests both that Malaysia is moving towards using LNG more sustainably and that concurrently, there are structural and policy hurdles that repeatedly hinder greener LNG operations. One of the included studies, Ahmed and Elfaki [14], is a cross-country panel analysis of green technological progress and long-run sustainable economic growth across fifteen Asia-Pacific and Latin American economies, Malaysia among them [14]. Its central finding, that green technological progress produces externality spillovers that support long-run sustainable growth, reinforces the economic case for accelerating low-carbon innovation. That result holds at the cross-country level, however, and not specifically for Malaysia or for the LNG sector.

Industry and agency reporting indicates that renewable energy integration in LNG operations in Malaysia remains low, reported at around 6.8% of total energy input, compared to 15–20% among leading practices in Australia and Norway [27]. This gap is attributed in the literature to existing gas-fired infrastructure lock-in and the absence of mandatory technology performance standards comparable to those in the European Union [3]. RandD investment patterns reinforce this picture: industry reports cited in the included literature indicate that approximately 1.2% of LNG sector revenues is dedicated to RandD in Malaysia, compared to around 2.5% in leading producer countries, a gap that constrains the pace of sector-internal innovation [28].

Policy theories are found throughout the literature that position policy as both enabling and restricting. Malaysia has always lacked strict emissions standards and technology requirements that drive adoption of clean energy in similar jurisdictions [3]. The literature proposes hybrid instruments that integrate carbon pricing with technology subsidies and performance standards as the most promising approach to getting these instruments adopted in a way that does not affect export competitiveness [3].

Synthesis of evidence: Evidence that green technological progress contributes to long-run sustainability is moderately well supported in the broader literature, including the cross-country panel of Ahmed and Elfaki [14] in which Malaysia is one of fifteen economies, and consistent with the green-economy findings of Yong [30] and the renewable-integration outlook of IRENA [31]. The support thins, however, once it is narrowed to LNG-specific technologies. Claims about carbon capture, digitalisation, and liquefaction-efficiency gains are weakly supported within the reviewed corpus and depend heavily on the contextual sources summarised in Table 4. No included study directly evaluates the in-service performance of these technologies in a Malaysian LNG facility, a clear evidence gap; and the reported tension between commercial and sustainability objectives [22] is noted but not quantified. Because the strongest single study here is high rated while the others are Moderate or Lower, confidence

is moderate for the general proposition that technological progress supports sustainability, and low for any specific quantitative claim about Malaysia LNG decarbonisation technologies. On the quality appraisal, the strongest in-corpus support here is a single High-rated but cross-country study [14]; the LNG-specific claims rest on weaker or contextual sources and are treated as tentative.

Table 4. Key dimensions of green technological progress in Malaysia’s LNG sector.

Dimension	Measurement Approach	Observed Impact	Data Source
Carbon Intensity	CO ₂ emissions per LNG unit produced	12% reduction since 2015	PETRONAS [28]
Renewable Integration	Share of renewables in LNG operations	~6.8% of the total energy input	Energy Commission Report [27]
RandD Investment (% of revenue)	Revenue allocated to clean technology	1.2% vs. 2.5% in leading LNG nations	PETRONAS Sustainability Report [28]

Note. The figures in Table 4 come from contextual industry and agency sources cited in the table (for example, PETRONAS and the Energy Commission). They are provided for context and are not findings of the fifteen included studies.

3.4. Structural Dynamics and Strategic Positioning of Malaysia’s LNG Sector

The LNG industry in Malaysia is highly vertically integrated. PETRONAS is an unusual entity, holding the combined responsibilities of a regulator and the main commercial player, and there are instances when commercial revenue motives may limit investments for sustainability purposes, as identified in the reviewed literature [22]. There are claims that these tensions are strongest in the context of state-owned enterprises (SOEs) where the creation of shareholder value, national energy policy, and ESG considerations must be balanced.

The technologies adopted in the sector have developed across successive generations of liquefaction trains. Conventional cascade refrigeration was used at the Bintulu LNG complex from commissioning in 1983, and subsequent trains transitioned to mixed-refrigerant techniques, yielding incremental efficiency gains [28]. Today, approximately 40% of Malaysia’s liquefaction capacity is over 25 years old, which simultaneously poses an efficiency challenge and a retrofit opportunity [28,32].

Concentration in the supply chain remains a structural risk. Malaysia’s LNG exports have been concentrated on North Asia, with over 70% of its output historically going to Japan, South Korea and China, with the latter being the biggest importer [32]. The findings are also in line with the broader energy economics literature on the effects of price distortions, and supported by Dharfizi et al. [16], who found that subsidised domestic gas pricing for power generation significantly reduces the cost-recovery signals, which would otherwise encourage efficiency investment. Adoption of innovation is not uniform across the value chain: whilst digitalisation has moved at a faster pace in upstream exploration, the users of midstream liquefaction have more reasons for being conservative when introducing technology to ensure operational continuity.

Workforce capability is identified in the literature as a major enabler of continued innovation. Approximately 25,000 technical specialists are reported to work in Malaysia’s LNG industry, and their competencies are reportedly becoming more interdisciplinary, spanning data science, environmental management, and process engineering [28]. These evolving skill requirements will need to be addressed through ongoing coordination between government, education providers, and industry to align workforce development programmes with the sector’s changing needs.

Synthesis of evidence: The structural account is well supported as description: high vertical integration, PETRONAS’s dual role as regulator and dominant operator, and the concentration of exports in North-Asian markets. It draws on Dharfizi et al. [16] and Lai et al. [22] for the governance dimension and on industry data (Table 5) for the market-structure figures. Support is weaker for the

causal claim that these structural features systematically constrain sustainability investment. That claim is plausible and is partly evidenced by the governance studies, but it is not tested directly, and no study in the corpus isolates the effect of state ownership on LNG sustainability outcomes. The sources rarely conflict, but there is a notable gap in primary, Malaysia-specific evidence on institutional and stakeholder dynamics, which echoes the governance gap identified earlier. Confidence is moderate-to-high for the descriptive structural claims and moderate for the interpretive claim about commercial-versus-sustainability tensions, which rests on two Moderate-to-High-rated governance studies together with contextual data. On the quality appraisal, the descriptive account is reported with reasonable confidence, drawing on High- and Moderate-rated studies (Dharfizi et al. [16], Lai et al. [22]), whereas the causal claim that structure constrains sustainability investment is left as a hypothesis for testing.

The dual role has a clear legal origin. Under the Petroleum Development Act 1974 (Act 144), the entire ownership of, and the exclusive rights to explore, exploit, and obtain petroleum onshore and offshore Malaysia, are vested in PETRONAS, which is also empowered to license contractors and to control downstream activity [33]. By statute, then, PETRONAS is at once the custodian and licensor of the resource and the dominant commercial operator, and it reports to the Prime Minister rather than to an independent sector regulator. Concentrating ownership, licensing authority, and commercial interest in one entity gives rise to the regulator-operator tension that governance studies describe, and it helps explain why sustainability goals can be subordinated to commercial and fiscal priorities. No included study analyses the Act directly, so this legal-institutional channel is an evidence gap rather than an established finding.

Table 5. Comparative overview of the LNG sector's scale and decarbonisation initiatives.

Performance Indicator	Malaysia	Qatar	Australia	Source
Total Liquefaction Capacity (MTPA, 2024)	32.0	77.1	87.6	IGU [34]
LNG Exports (MT, 2024)	27.73	77.23	81.04	IGU [34]
Operational CCS Capacity (MTPA CO ₂)	3.3 (Kasawari, comm. 2026)	2.0 (Ras Laffan, operational)	4.0 (Gorgon, operational)	IGU [32]; PETRONAS [28]
GHG Emissions Intensity (g CO ₂ -eq/MJ, regional avg.)	>20 (Southeast Asia)	<20 (Middle East)	~20 (Asia-Pacific)	IEA [35]
Share of Liquefaction Capacity >20 Years Old (est.)	~40% (Bintulu Trains 1–3, 1983–1995)	<15% (majority post-2010)	~30% (NWS, 1989)	PETRONAS [28]; IGU [32]

Note. The comparative figures in Table 5 come from contextual industry and agency sources, as cited, and are provided to benchmark the review. They are not findings of the fifteen included studies.

3.5. International Benchmarking and Technology Adoption Pathways

Through comparative analysis of the literature reviewed, it is found that Malaysia is still lagging behind the top exporting countries of LNG, in the present case, Qatar and Australia, with regard to performance. The gaps are most pronounced in the scale of CCS deployment, integration of renewable energy and digital technologies in liquefaction operations. Comparative observations in this review, however, are indicative and do not provide a precise comparison of direct efficiencies at the plant level because of the limited availability of publicly reported country-specific operational data.

CCS is a significant gap and a new area of progress. Malaysia's Kasawari CCS project with an initial capacity of 3.3 million tonnes per annum (TPA) CO₂ when operational is one of the largest offshore CCS projects in the world but is still smaller than Australia's Gorgon (4 million tpa) operational since 2019 and Hammerfest in Norway (1 million tpa) operational since 2008 [28,32]. The

gap is not just a technical inability to develop CCS; the price of voluntary carbon markets in Malaysia is around USD 15 per tonne of carbon, whereas compliance carbon markets in Europe are at USD 60–90 per tonne of carbon [35].

Workforce mobility programmes represent an underutilised but high-potential channel for tacit knowledge transfer. Existing exchanges with Japanese and Australian LNG operators have largely taken the form of short-term technical training rather than extended secondments [36]. Expanding these into longer-duration, joint problem-solving engagements could substantially strengthen Malaysia’s capability to adapt acquired technologies to local operating conditions. Malaysia’s well-developed LNG infrastructure and strategic geographical location offer a credible basis for positioning the country as a collaborative pioneer in sustainable LNG development for tropical operating environments.

Synthesis of evidence: The benchmarking theme relies most heavily on evidence from outside Malaysia. The case that LNG can serve as a transition fuel and anchor CCS value chains rests on Lindstad et al. [18] and Labauge et al. [21], while the regulatory and infrastructure gaps are shown by Ha et al. [5] and Fangmeier [6]. All of these concern non-Malaysian settings, so applying them to Malaysia is an inference rather than a finding. The comparison with Qatar and Australia, and the technology-transfer mechanisms in Table 6, are documented from contextual industry and agency sources (including the 2022–2024 PETRONAS–JERA and JOGMEC initiatives) rather than from peer-reviewed studies. The strongest supporting study is High-rated [18], but because the directly relevant Malaysian material is contextual rather than empirical, confidence in the comparative-capability and technology-transfer claims is low-to-moderate, and they are presented as indicative pathways rather than established results. On the quality appraisal, these rest on non-Malaysian studies spanning High to Lower quality (Lindstad [15], Labauge [21], Ha [5], Fangmeier [6]); because applying them to Malaysia is an inference, the benchmarking conclusions are the most tentative in the review.

Table 6. Verified technology transfer mechanisms in Malaysia’s LNG sector (2022–2024).

Mechanism	Description	Key Partners	Status / Outcome	Source
Joint Venture	MLNG Dua and Tiga at Bintulu; PETRONAS majority shareholder with operational co-management	Shell, Mitsubishi, Nippon Oil, Sarawak State Government.	In operation since 1983 (Trains 1–3 commissioned 1983–1995); proprietary licences limit independent modification of core processes	PETRONAS [28]; GIIGNL [37]
Licensing – Liquefaction Tech.	Air Products AP-C3MR™ process technology for all Bintulu trains; 2nd and 3rd MCHE replacements contracted in 2023	Air Products and Chemicals (USA)	Active; PETRONAS installed the first MCHE in-house (2022) demonstrates partial capability absorption	Air Products [38]
Cross-Border CCS Consortium	MoU with Japan METI and JOGMEC (2022–2023) for CO ₂ capture in Japan and storage in Malaysia; Storage Study Agreement 2024	JOGMEC, JERA, JAPEX, JGC, KLine, JFE Steel	Feasibility studies are ongoing; two JOGMEC advanced CCS projects involve Malaysian storage sites; target 2030 operations	PETRONAS [39]; Offshore Energy [40]
Methane Monitoring Collaboration	JGC Group commissioned via JOGMEC MoU (March 2023) to develop methane detection methods offshore Malaysia	JGC Corporation (Japan)	Technical study phase; offshore measurement challenges (wind/sea conditions) identified; methods under development	Offshore Energy [40]

Vendor Partnership – Equipment	Air Products is supplying two MCHE replacement units for the MLNG Dua extension programme	Air Products and Chemicals (USA)	Contracted; first unit installed in-house in 2022 and operational, growing absorptive capacity at plant level	Air Products [38]
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4. Discussion

Taken together, the 15 studies included in this synthesis suggest that Malaysia's LNG industry is at a strategic inflection point: the direction of travel toward greater sustainability is clear, but the pace of change remains contested. The reviewed evidence indicates gradual progress on cleaner-technology adoption and energy efficiency improvement. Simultaneously, the literature consistently points to structural, regulatory, and institutional constraints that limit both the depth and the speed of the sustainable transition. Epistemic caution is warranted given the small number of eligible studies, the predominance of technically oriented research within the corpus, and the limited temporal scope of several studies.

The finding that is most consistently and strongly supported across studies is the tension between the highly significant economic reliance on LNG exports and the commitment to sustainability in Malaysia. Bekhet and Harun [24], Dharfizi et al. [16], and Lai, Shad and Shah (2021) each address the issue from a different methodological perspective, each identifying mechanisms that make it difficult for Malaysia to decarbonise in a timely fashion if its current energy pricing, regulatory design or investment patterns remain unchanged [5,7,14]. The convergence of methodologically varied studies provides a good level of confidence in this diagnosis, although the magnitude of the effect is not precisely known, as most analyses are aggregated.

In contrast, there is more diversity in the literature on effectiveness of technology transfer, and this literature should be read with caution. While proprietary licensing is generally accepted as such to be a limitation on deep technology absorption, the evidence to support this in Malaysia's LNG context is lacking from the current body of literature. The cases of verified technology transfer are documented in Table 5, but the review of academic literature does not include any systematic measures of absorption rates or long-term capability outcomes.

Special care should be taken when conducting international benchmarking. Analytically useful comparisons are drawn with Qatar and Australia, but these are constrained by significant differences in resource endowment, the age profile of facilities, domestic pricing regimes, and governance structures, differences that the reviewed literature does not consistently account for. In the results section, several of the numerical comparisons are drawn from industry or policy reports rather than peer-reviewed primary research. These figures should be read as illustrative rather than empirical.

Malaysia's LNG sustainability path provides a real-life example of the late-mover dynamics of industrialisation in capital-intensive energy sectors. In certain areas, leapfrogging in technology is clearly possible; however, there is a need for greater domestic innovation leadership, which involves more in-depth RandD capabilities in the country than Malaysia currently has. This finding helps to broaden the ongoing debates on technology innovation systems in resource-dependent economies and is in line with the theoretical frameworks that emphasise absorptive capacity as a key factor in the effective transfer of technology.

Across the reviewed literature, the most practical implication identified is the need for a coherent carbon pricing policy aligned with Malaysia's NDCs. At present, the voluntary market arrangement does not offer enough economic incentive for large-scale deployment of CCS or renewable energy in

LNG. A compulsory, increasing carbon price, possibly including trade safeguards, would better align private investment choices with national sustainability goals. The included studies also point toward further plant-level efficiency improvements; in particular, recent industry and agency analysis indicates that investing in methane leak detection and recovery at existing facilities is cost-effective, and that many abatement measures are available at low or moderate cost, though direct empirical validation in the Malaysia LNG context remains limited [35].

Evidence published after the review's search window adds to this. A recent Malaysia-specific marginal abatement cost analysis of the upstream oil-and-gas sector estimates that 57-63% of methane emissions could be cut at zero or negative net cost, that a 30% reduction is achievable at a net revenue of about USD 5-7 million, and that abatement is broadly cost-neutral at a gas price near USD 5.5/MMBTU, mainly by rerouting vented gas and replacing pneumatic devices [41]. The constraint on methane progress, then, is less cost than measurement, regulation, and incentives, and the incremental technical progress documented in the corpus may understate what is economically available. The same study warns that inexpensive abatement should not entrench fossil-fuel lock-in at the expense of deeper decarbonisation. Because this work postdates the search, it is treated here as contextual rather than as part of the reviewed corpus.

The following methodological shortcomings must be explicitly mentioned when analysing the studies included. There is an over-emphasis on technical research, rather than socio-economic research, leading to an imbalanced evidence base focused on engineering solutions rather than behaviour and governance. The types and extent of literature selected to include in the database may have been biased against literature in other languages, especially literature produced within the local context, which might have captured alternative views of technology transfer dynamics. Research in the future needs to look at the political economy of Malaysia's energy transition from different perspectives, focusing on the influence of the power dynamics amongst the various stakeholders on the uptake of new technologies [42].

5. Conclusion

This systematic review, which examined sustainability and innovation within Malaysia's LNG industry, synthesised 15 eligible studies. The results indicate, although they do not conclusively prove, that Malaysia has achieved measurable progress in cleaner technology adoption and energy efficiency improvement, while continuing to face structural challenges in scaling up sustainable practices throughout the entire LNG value chain. The dual nature of the LNG sector, as both a national economic pillar and a significant domestic energy consumer, generates tensions that existing policy frameworks have not yet fully resolved.

Comparisons with other major LNG-exporting countries such as Qatar and Australia are useful for identifying key capability gaps: the scale of deployment of CCS, integration of renewable energy in CCS, and deployment of digital technology at liquefaction facilities. Significant progress is being made in the co-development of technology through active cross-border partnerships with Japanese entities such as JOGMEC, JERA, and JGC. However, the technology licensing of core liquefaction still has a proprietary nature, which limits the potential depth of domestic innovation capability.

One caveat applies to this comparison. It rests on installed capacity and regional-average emissions intensity (Table 4) rather than on plant-level, production-normalised metrics such as emissions per tonne of LNG produced, which the reviewed corpus does not report for Malaysian facilities. Relative efficiency and sustainability performance against Qatar and Australia should therefore be read as indicative, and facility-level normalised data is itself a priority evidence gap.

Two policy developments are changing the competitive backdrop for these capability gaps. At home, Malaysia announced in Budget 2025 a carbon tax to take effect in 2026, covering the iron, steel, and energy sectors initially, with revenue earmarked for green research and technology [10]. Abroad, the European Union's Carbon Border Adjustment Mechanism (CBAM) entered its definitive phase in January 2026 [11]. Its scope should be stated precisely: CBAM currently covers iron and steel, cement, aluminium, fertilisers, electricity, and hydrogen, and does not yet apply to LNG, so the direct, immediate exposure of Malaysian LNG exports is limited. It still matters, for two reasons. The scope is expected to widen toward oil-and-gas-related products before 2030, and it signals a broader shift to carbon-content-based trade measures to which an export-oriented, emissions-intensive sector is exposed. A domestic carbon price and an emerging carbon-trade regime together strengthen the economic case for the methane-abatement and CCS investments discussed above, and they raise the cost of doing nothing.

The call for coherent carbon pricing also has to reckon with the political economy of a state-dominated sector. PETRONAS is both the regulator by statute and the largest single contributor to federal revenue, so a domestic carbon price interacts with the government's fiscal dependence on the company, and the long-standing subsidised domestic gas price limits how far a carbon signal can be passed through to users. Carbon pricing in Malaysia's LNG sector is therefore as much an institutional and fiscal design problem as a technical one, and its credibility will depend on how the dual role set out above is managed.

Table 7. SWOT synthesis of sustainability and innovation in Malaysia's LNG sector (authors' interpretation, grounded in the reviewed studies and the contextual sources cited).

Strengths: an established, large-scale LNG export base and long operating history (Bintulu, since 1983); national project and technical capability concentrated in PETRONAS; early methane-reduction targets and active CCS initiatives such as Kasawari.	Weaknesses: a thin Malaysia-specific peer-reviewed evidence base on LNG sustainability; under-researched governance and socio-economic dimensions; dependence on proprietary, externally licensed liquefaction technology; ageing assets and lower RandD intensity than leading peers; and subsidised domestic gas prices that weaken efficiency incentives.
Opportunities: methane abatement that is largely cost-effective or revenue-positive [41]; cross-border technology co-development (JOGMEC, JERA, JGC); CCS value-chain development; carbon-tax revenue earmarked for green RandD [10]; and continued regional demand for gas as a transition fuel.	Threats: emerging carbon-trade measures (the EU CBAM, with scope expansion toward oil-and-gas products under consideration) [11] and the 2026 domestic carbon tax raising compliance costs [10]; late-mover dynamics relative to Qatar and Australia; long-run demand and transition risk for gas; and fossil-fuel lock-in if cheap abatement substitutes for deeper decarbonisation [41].

Note. This SWOT is an interpretive synthesis and belongs to the third evidence layer defined in Section 3. The internal factors (Strengths, Weaknesses) draw on the reviewed studies and Tables 1-5; the external factors (Opportunities, Threats) draw on the contextual policy and trade sources cited and on literature postdating the search [10], [11], [41]. It organises the findings rather than adding an empirical result.

There are a number of qualifications to the conclusions of this review. Overall, the eligible study base (15 papers) is rather small and has a strong technical focus, which restricts the extent of synthesis of governance and socio-economic aspects. Locally produced insights may not have been included as a result of the exclusion of non-English publications. Some of the most important numerical indicators in the results section are based on industry and policy documents and should be read as such.

A further limitation is temporal. The systematic search was completed in early 2025, and the relevance-ranked Google Scholar component was capped at ten pages, so a small body of very recent

work was not captured by the systematic process and is discussed here only as contextual evidence. This includes 2025 analyses of methane marginal abatement costs [41] and the quickly growing literature on carbon-tax readiness and CBAM exposure. Because the policy area is moving fast, some findings, especially those tied to the 2026 carbon tax and to CBAM's evolving scope, may date quickly, so the most useful next step would be a living review, updated periodically as new evidence and instruments mature.

Future research should focus on: longitudinal studies on the effectiveness of policy for the National Technology and Innovation Sandbox, Malaysia and the carbon market mechanisms; comparative studies between medium-sized LNG exporters like Indonesia and Algeria; political economy analysis of energy transition in Malaysia, which includes stakeholder power analysis; and interdisciplinary research between the financial market analysis and energy policy analysis, to understand the capital flow towards the sustainable LNG investment.

These directions are not equally urgent. For Malaysia's Nationally Determined Contribution and its 2050 net-zero target, two gaps come first: primary, measurement-based evidence on methane and fugitive emissions across the LNG value chain, and Malaysia-specific evaluation of CCS and liquefaction-efficiency performance in service. Both are prerequisites for credible target-setting, and both were the weakest-supported areas in this review. For regulators, and the Energy Commission in particular, the practical step is to require facility-level emissions measurement and reporting and to align the coming carbon price with the abatement-cost evidence, so that the cheapest methane reductions happen first.

The gap in stakeholder and political-economy analysis can be approached concretely. A workable first step is a power-interest mapping of the principal actors, namely PETRONAS and its upstream contractors, the Ministry of Economy and the Ministry of Finance, the Energy Commission, the Sarawak and Sabah state entities (Petros and SMJ Energy), and affected communities, combined with process tracing of how sustainability decisions are actually taken. For the empirical gaps identified above, the priority datasets are facility-level methane measurements (for example, under the Oil and Gas Methane Partnership 2.0 and satellite monitoring), PETRONAS sustainability and emissions disclosures, the National Energy Balance, and, once available, carbon-tax compliance records.

Declaration of Conflict of Interest

The authors declared no conflict of interest with any other party on the publication of the current work.

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