Economic value, challenges, and future perspectives for bamboo in Malaysia: Evidence synthesis, conceptual integration, and a research agenda

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Abstract

Purpose: This study critically synthesizes evidence on the economic value, industry constraints, applications and prospects of bamboo (Bambusoideae) in Malaysia and explains the conditions required to convert resource potential into a competitive and inclusive bamboo economy.

Design/methodology/approach: A PRISMA 2020-guided systematic literature review was conducted across Web of Science, Scopus and Google Scholar for publications issued between January 2020 and December 2025. From 352 records, 70 studies met the eligibility criteria. Modified Mixed Methods Appraisal Tool informed evidence weighting, while a hybrid deductive-inductive thematic analysis and cross-study synthesis were used to identify convergent findings, contradictions and knowledge gaps.

Findings: The evidence falls into four themes: economic value and market potential (n = 20), challenges and constraints (n = 18), applications and processing technologies (n = 19), and sustainability-focused future views (n = 13). Global demand and Malaysia's resources show high potential, but development faces weaknesses in land and institutions, investment, processing, standards, market, and supply chains. Pulp and paper are the quickest routes to scale, while composites, construction, food, biochar, and biorefinery are medium- and long-term opportunities.

Limitations and Research implications: The review is limited by the selected databases, English-language coverage, the 2020-2025 search period and the heterogeneity of study designs, which precluded meta-analysis. Future research should prioritise resource and productivity inventories, techno-economic feasibility, consumer and industrial demand, supply-chain governance, pest and disease resilience, lifecycle performance and policy evaluation.

Practical Implications: Malaysia should sequence sector development through a national coordination mechanism, harmonised land and tenure rules, resource mapping, quality standards, commercially located processing hubs, blended finance, contract-based feedstock systems, technical training and phased market development.

Originality/value: The review moves beyond a descriptive catalogue of bamboo uses by proposing an integrated Bamboo Value Realisation Framework that links policy and institutions, investment, technology, markets, and sustainability. It also provides a comparative interpretation, a phased implementation roadmap and a time-bound research agenda for Malaysia's transition towards a circular bio-based economy and SDG 8.

Keywords: Bamboo, Economic Value, Industrial Development, Circular Bioeconomy, Evidence synthesis, Malaysia.

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Introduction

Bamboo is one of the fastest-renewing lignocellulosic resources and can support construction, furniture, pulp, food, composites, bioenergy, and rural livelihoods. Its biological productivity and product versatility make it attractive to countries seeking renewable

materials, lower-carbon production, and diversified rural income (Rathour et al., 2022; Mousavi et al., 2022). Yet resource abundance does not automatically produce an internationally competitive industry. Economic value is realised only when reliable feedstock, processing capability, standards, finance, market demand, and environmental safeguards develop together.

Malaysia illustrates this development puzzle. The country possesses native and planted bamboo resources, a tropical growing environment, wood-processing capabilities, and access to regional markets, but its bamboo sector remains small relative to those of China, Vietnam, and Indonesia (Shah et al., 2021; Ahmad et al., 2025; Kamarubahrin et al., 2025a). Commercial activity is concentrated in primary or small-scale uses, while investment in industrial processing, engineered products, market standards, and integrated supply chains remains limited. The policy problem is therefore not whether bamboo has useful properties, but why those properties have not been translated into sustained economic value, employment, and market scale.

Prior research has established several parts of this problem. Materials studies document the mechanical performance of bamboo fibres and engineered products (Mousavi et al., 2022; Madhushan et al., 2023; Yu et al., 2024). Socioeconomic and value-chain studies identify income, employment, and enterprise opportunities (Mengstu et al., 2023; Samdin et al., 2024). Other work examines certification, biomass, construction, food, activated carbon, and circular biorefinery applications (Li et al., 2024; Heong et al., 2024; Yusof et al., 2025; Fu et al., 2025). Collectively, this literature confirms bamboo's technical and environmental promise, but it is dispersed across disciplines and frequently evaluates individual products or isolated constraints.

Three gaps remain. First, Malaysia-specific evidence on economic value, commercial readiness, and sector-wide constraints has not been integrated into a single explanatory account. Second, existing reviews tend to catalogue applications without showing how institutional support, investment, processing technology, supply chains, market formation, and sustainability interact. Third, the available evidence is dominated by laboratory, technical, and descriptive studies; comparative, longitudinal, and commercially grounded research remains limited. These gaps make it difficult to distinguish immediate opportunities from longer-term prospects and to identify the sequence of interventions required for implementation.

This review addresses the question: how can Malaysia convert bamboo resource potential into a competitive, inclusive, and sustainable industry? Four subsidiary questions guide the analysis: (1) what economic value and market opportunities are reported; (2) which constraints prevent value realisation; (3) which applications and processing technologies are commercially relevant; and (4) which policy, investment, market, and research priorities can support sector development?

Studying contributes in three ways. First, it integrates fragmented economic, technological, policy, and sustainability evidence through a cross-study synthesis rather than a purely descriptive summary. Second, it proposes a Bamboo Value Realisation Framework in which five complementary capabilities - policy and institutions, investment and finance, technology and infrastructure, markets and supply chains, and sustainability and inclusion - jointly determine sector performance. Third, it translates the synthesis into a phased implementation roadmap and a short-, medium-, and long-term research agenda. This advances the literature from identifying bamboo's potential to explaining the mechanisms and sequencing through which that potential may be realised.

The remainder of the paper explains the review protocol and evidence-appraisal process, presents the four thematic findings, compares Malaysia's development conditions with selected regional producers, develops the integrated conceptual framework, and concludes

with theoretical, practical, and policy implications, an implementation roadmap and priority research directions.

Methodology

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Systematic Review Framework and Protocol

The review followed the PRISMA 2020 framework to ensure a transparent sequence of identification, screening, eligibility assessment, and inclusion. Before searching, the authors defined the review questions, eligibility criteria, data fields, and thematic domains. The protocol focused on bamboo's economic value, market potential, industry constraints, applications, processing technologies, sustainability implications and policy relevance in Malaysia and comparable regional settings. Because the evidence included qualitative, quantitative, engineering, review, and case-study designs, the review used structured narrative synthesis rather than statistical meta-analysis.

Information Sources and Search Strategy

Table 1 outlines the systematic literature review search strategy adopted in this study, detailing the databases, search period, conceptual framework, and procedural criteria applied to ensure a transparent and replicable process. The review utilized three primary databases (i.e., Web of Science Core Collection, Scopus, and Google Scholar) covering publications from January 2020 to December 2025, with the final search conducted in January 2026. The core concept blocks combined bamboo-related terms with Malaysia-focused economic, industrial, and sustainability dimensions, while database-specific search fields (e.g., topic, title, abstract, and keywords) were employed to optimize retrieval. The procedure included structured screening and relevance-based selection, with limitations applied to English-language articles, reviews, case studies, and technical reports.

Table 1. Systematic literature review search strategy

Component	Details
Primary databases	Web of Science Core Collection; Scopus; Google Scholar
Search period	January 2020-December 2025; final database search completed in January 2026
Core concept blocks	Bamboo terms AND Malaysia/economic/industry/sustainability terms
WoS fields	Topic: title, abstract, author keywords and Keywords Plus
Scopus fields	TITLE-ABS-KEY
Google Scholar	Simplified Boolean string; first 500 results screened in relevance order to capture policy, regional and interdisciplinary sources not consistently indexed elsewhere
Procedure	
Limits	English-language articles, reviews, case studies and eligible technical reports

Web of Science and Scopus were selected because they provide structured indexing and reproducible field-based searches across business, forestry, engineering, and sustainability research. In Table 1, Google Scholar was included as a supplementary source because Malaysian bamboo studies, technical reports, and interdisciplinary publications are not always indexed consistently in the two citation databases. To preserve feasibility and

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transparency, the first 500 Google Scholar results were screened in relevance order; the procedure and stopping rule were fixed before screening.

The search syntax was adapted to the functionality of each database. The core string combined species and commodity terms ("bamboo" OR Bambusa OR Dendrocalamus OR Phyllostachys OR Guadua) with Malaysia and development terms (Malaysia OR "economic value" OR market OR industry OR application* OR process* OR challenge* OR constraint* OR policy OR sustainab* OR "circular economy" OR SDG*). Truncation and field commands were used in Web of Science and Scopus, whereas Google Scholar required shorter Boolean combinations. Searches were limited to the defined period and were supplemented by backward reference checking of eligible reviews.

Inclusion and Exclusion Criteria

Table 2 presents the inclusion and exclusion criteria designed to ensure that the reviewed studies are relevant, recent, and analytically robust. The review prioritizes research focusing on bamboo species or bamboo-based industries with clear economic or industrial analysis, particularly within Malaysia, while allowing comparative insights from Southeast Asia and other regions when transferable. Only publications from 2020–2025 are included, covering empirical studies, systematic and critical reviews, market analyses, case studies, and technical reports, while excluding non-analytical works such as editorials or opinion pieces. Additionally, only English-language sources or those with sufficient English content are considered to maintain consistency in evaluation.

Table 2. Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Species/topic focus	Bamboo species or bamboo-industry evidence with dedicated analysis	Non-bamboo studies or bamboo mentioned only incidentally
Geographical scope	Malaysia; Southeast Asia with direct Malaysian relevance; international comparisons with transferable insights	Contexts with no plausible relevance to Malaysia's resource, industrial or policy conditions
Publication period	Publications issued from 2020 to 2025	Publications before 2020
Study type	Empirical studies, systematic or critical reviews, economic and market analyses, case studies, and eligible technical reports	Editorials, opinion pieces and studies without an identifiable analytical basis
Language	English or an English full text available	Non-English publications without sufficient English information for appraisal
Outcome relevance	Economic value, market potential, applications, processing, policy, sustainability, SDG 8, supply chains or constraints	Purely aesthetic or laboratory evidence with no interpretable economic, industry or sustainability relevance

The criteria deliberately balanced Malaysia-specific relevance with comparative evidence. International studies were retained only when they provided transferable insight into processing systems, certification, market development, value chains, environmental performance or policy design. Pure material-science papers were included only when their findings supported an identifiable application or commercial pathway.

Study Selection Process

The search identified 352 records: 145 from Web of Science, 167 from Scopus and 40 from Google Scholar (Figure 1). After 74 duplicates were removed, 278 titles and abstracts were screened. Two reviewers independently applied the eligibility criteria after a calibration exercise on a common subset. Agreement reached 90% (Cohen's kappa = 0.86), and disagreements were resolved through discussion. Full texts were obtained for 122 records; 52 were excluded because they lacked substantive bamboo-economic evidence, failed the geographical or publication criteria, or did not provide an adequate analytical basis. The final synthesis included 70 studies.

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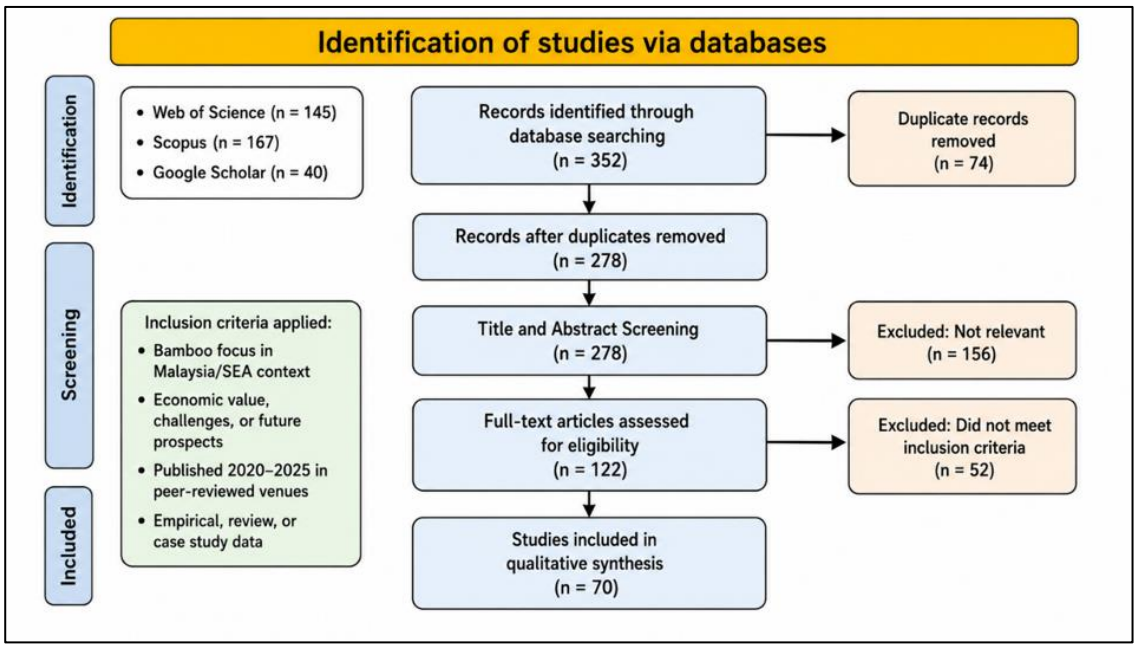


Figure 1. PRISMA 2020 flow diagram

Quality Appraisal

A modified MMAT assessed methodological clarity and evidence credibility across diverse study designs without aggregating all studies into a single score (Table 3). It checked if each had a clear question, an appropriate design, transparent procedures, credible analysis, and consistent conclusions. No studies were excluded solely based on appraisal, but those with incomplete reporting were used cautiously and not as primary evidence.

A standardised extraction form recorded author, year, country or region, study design, bamboo species or product, economic and market indicators, application, technology, constraints, sustainability outcomes, policy implications, and quality-appraisal observations. Data extraction was completed independently and cross-checked. The date of extraction, database source, and full-text decision were retained in the review log to improve auditability.

The thematic analysis combined deductive and inductive coding. In Table 4, Initial codes reflected the review questions: economic value, constraints, applications, and sustainability. During repeated reading, additional codes were added for land and tenure, market standards, supply-chain fragmentation, processing capability, investment, skills, certification, circularity, and policy coordination. Two researchers coded the studies independently, compared code definitions, and resolved differences by consensus. Cross-study synthesis then examined

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convergence, contradiction, evidence strength, contextual transferability, and the number of studies assigned to each thematic cluster.

Table 3. Modified MMAT appraisal domains and treatment in the synthesis

Appraisal domain	Assessment focus	Use in evidence synthesis
Research clarity and relevance	Clear question, objectives and direct relevance to bamboo value, industry or sustainability	Weakly aligned studies used only for contextual background
Design appropriateness	Method matches the research question and unit of analysis	Design limitations explicitly considered when comparing findings
Data and sampling transparency	Sources, cases, samples or experimental procedures adequately described	Poorly reported evidence not used to anchor quantitative estimates
Measurement and analysis	Variables, tests, coding or analytical procedures are credible and traceable	Inconsistent or unvalidated measures interpreted cautiously
Coherence of conclusions	Claims follow from results and limitations are acknowledged	Overstated claims downgraded during cross-study synthesis

Table 4. Evidence profile and role of each thematic cluster

Theme	Studies (n)	Principal evidence	Recurring limitation	Synthesis role
Economic value and market potential	20	Market assessments, household and value-chain evidence, socioeconomic reviews	Malaysia-specific cost, price and demand evidence remains limited	Establishes potential value and identifies where commercial evidence is strongest or weakest
Challenges and constraints	18	Policy, market, industry, case-study and stakeholder evidence	Few longitudinal evaluations of policy implementation	Explains the institutional and coordination failures preventing value realisation
Applications and processing technologies	19	Engineering, materials, processing and product-development studies	Many findings remain laboratory- or pilot-scale	Distinguishes immediate applications from medium- and long-term opportunities
Future perspectives and sustainability	13	Lifecycle, carbon, circular-economy, community and certification evidence	Limited Malaysia-specific field validation and trade-off analysis	Links economic development with SDG 8, circularity and environmental safeguards

Results

Profile of the Included Evidence

The 70 included studies span economic, forestry, engineering, sustainability and policy research. The corpus is strongest in technical feasibility and general sustainability claims, but comparatively weaker in Malaysia-specific investment costs, consumer demand, firm-level adoption, price formation and policy evaluation. This imbalance is important: technical

performance demonstrates what bamboo can do, whereas commercial and institutional evidence determines whether applications can scale. The synthesis therefore distinguishes demonstrated material capability from market readiness and treats quantitative claims as context dependent.

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Economic Value and Market Potential

Table 5 provides a synthesized overview of the economic value and market potential of bamboo by comparing global evidence with the Malaysian context and drawing cross-study interpretations. The table highlights that, although the global bamboo market is substantial and continues to grow across multiple sectors, Malaysia's participation remains relatively small and underdeveloped. It also emphasizes that bamboo's economic contribution extends beyond raw material production, encompassing income diversification, value-added manufacturing, and access to specialized markets through certification systems. However, the realization of these opportunities depends heavily on the strength of value chains, processing capacity, and market structures rather than cultivation alone.

Global market and growth pathways

Reviewed studies consistently position bamboo as a significant renewable-material commodity used in flooring, furniture, textiles, construction, pulp, food, and emerging biorefinery products. Reported market estimates exceed USD 41 billion, although definitions and product coverage vary across studies (Kamarubahrin et al., 2025a; Ahmad et al., 2025). China dominates industrial processing and export-oriented product development, while Vietnam and Indonesia maintain stronger craft, furniture, biomass, and regional value-chain positions than Malaysia (Shah et al., 2021; Binfield et al., 2024). The evidence supports a growing market opportunity, but does not justify whether global growth will automatically translate into Malaysian market share.

Income, employment, and value addition

Value-chain and livelihood studies show that bamboo can diversify farm income through culm and shoot production and can generate additional employment in primary processing, manufacturing, distribution, and product development (Mengstu et al., 2023; Samdin et al., 2024). The scale of benefit depends on reliable buyers, accessible processing capacity, and the producer's position in the value chain. For Malaysia, the main economic loss is not the absence of biomass but the limited domestic conversion of biomass into graded, processed, and branded products. As a result, potential value remains uncaptured or shifts to downstream actors outside local production areas.

Certification and differentiated markets

Certification and eco-labelling can reduce buyer uncertainty and support access to environmentally sensitive markets, but they are effective only when traceability, quality control, and sufficient supply are already in place (Li et al., 2024). Malaysian participation remains limited, and certification costs may exclude small producers unless group systems, technical assistance, and shared auditing arrangements are introduced. Certification should therefore be treated as a market-enabling mechanism rather than a substitute for basic supply-chain development. Across the 20 studies, evidence converges on substantial potential but is less conclusive on realised profitability in Malaysia. The key research gap is the

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absence of comparable farm-budget, processing-cost, price, demand and investment-return data across species and product pathways.

Table 5. *Economic value and market potential of bamboo*

Economic dimension	International evidence	Malaysian condition	Cross-study interpretation	Representative sources
Reported global market value	More than USD 41 billion, depending on market definition	Malaysia captures a small and weakly documented share	Market growth is credible, but domestic market-share estimates require primary data	Kamarubahrin et al. (2025a); Ahmad et al. (2025)
Income diversification	Culm, shoot and processing income can supplement household earnings	Potential is constrained by uncertain buyers and fragmented supply	Benefits depend on value-chain participation rather than cultivation alone	Mengstu et al. (2023); Samdin et al. (2024)
Value-added manufacturing	Furniture, pulp, composites, construction, food and bio-based products	Domestic conversion capacity remains limited	Processing and standards are the key value-capture bottlenecks	Binfield et al. (2024); Yu et al. (2024)
Certification and eco-markets	FSC, PEFC and emerging bamboo-specific systems	Participation remains limited	Group certification and shared services may improve accessibility	Li et al. (2024); Samdin et al. (2024)

Challenges and Constraints

Table 6 summarizes the key challenges and constraints facing the Malaysian bamboo sector, highlighting that limitations occur across policy, market, supply chain, technical capacity, environmental risk, and finance dimensions. Major issues include unclear land tenure and weak coordination, low market awareness and standards, fragmented supply chains, limited processing infrastructure, and insufficient technical skills. These constraints collectively generate system-level effects such as delayed investment, unreliable supply and pricing, reduced product quality, and restricted value addition. The table also outlines practical responses, including policy harmonization, development of standards and testing protocols, strengthening cooperatives and contract systems, investment in shared processing facilities, and capacity-building initiatives through training and industry collaboration.

Policy, land, and institutional coordination

Policy uncertainty, state-level variation in land administration, unclear tenure arrangements, and fragmented institutional responsibilities discourage long-horizon investment in plantations and processing. These problems increase transaction costs for both smallholders and processors and make it difficult to secure feedstock contracts or financing. The Bamboo Industry Development Action Plan provides strategic direction, but the reviewed evidence indicates that implementation, inter-agency coordination, and state-level operationalisation remain uneven (Kamarubahrin et al., 2025a; Abu Bakar & Kian, 2025).

Table 6. Challenges and constraints in the Malaysian bamboo sector

Constraint	Specific issue	Severity	System-level effect	Executable response
Policy and land	Unclear tenure, variable state rules and weak coordination	High	Delays investment and prevents long-term feedstock commitments	Harmonise rules, provide model agreements and establish a coordination mechanism
Market development	Low awareness, uncertain quality and limited standards	High	Reduces buyer confidence and product substitution	Develop grades, testing protocols, demonstrations and procurement specifications
Supply chain	Scattered growers, weak aggregation, limited storage and logistics	High	Creates unreliable volume and price signals	Use cooperatives, contract supply and digital inventory systems
Processing infrastructure	Limited dedicated facilities and low commercial scale	High	Restricts domestic value addition	Develop location-based shared processing hubs after feedstock validation
Technical capacity	Limited skills, extension and industrial quality control	Medium-high	Raises failure rates and inconsistent product performance	Create training, certification and industry-university technical programmes
Biological and environmental risk	Pests, disease, moisture, climate and biodiversity concerns	Medium	Threatens productivity and social licence	Apply species-site trials, treatment protocols and environmental safeguards
Finance and investment	High initial uncertainty and weak private-sector participation	High	Prevents scale-up and experimentation	Use blended finance, pilot grants and risk-sharing tied to performance milestones

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Market formation and supply-chain fragmentation

Potential buyers face uncertain quality, inconsistent dimensions, limited volumes and the absence of widely adopted grades or specifications. Producers, meanwhile, hesitate to expand without assured demand. This creates a coordination failure: processors require reliable feedstock before investing, but growers require credible processors and buyers before planting. Fragmented smallholder production, weak aggregation, inadequate storage and limited logistics reinforce this “missing middle” between resource availability and industrial use (Shah et al., 2021).

Processing, skills, and technical capability

Malaysia has limited dedicated capacity for strip production, fibre extraction, engineered bamboo, pulping, composites, and integrated biorefinery processing. Technical knowledge is dispersed across universities, agencies, and individual firms rather than embedded in scalable production systems. Skills shortages in treatment, drying, grading, quality assurance, and

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product engineering further constrain commercial reliability (Seman et al., 2025; Yusof et al., 2025).

Biological and environmental risks

Pests, fungi, termites, moisture sensitivity, and climatic variability can reduce product quality or plantation performance when species-site matching, harvesting, and treatment protocols are weak (Rathour et al., 2022; Hawanis et al., 2024). Environmental trade-offs also require attention. Poorly designed monocultures may affect biodiversity and water systems, whereas mixed or landscape-based approaches can improve resilience. The evidence, therefore, supports safeguards and site-specific management rather than unqualified plantation expansion.

The 18 studies show that the constraints are mutually reinforcing rather than independent. Addressing only cultivation, subsidies, or product promotion is unlikely to succeed if standards, processing, contracts, and market demand remain unresolved. This interdependence explains why previous initiatives have produced isolated projects rather than a self-sustaining industry.

Applications and Processing Technologies

Table 7 presents an overview of key bamboo-based applications by linking their level of industrial readiness with market opportunities, evidence requirements, and recommended actions. The table illustrates a clear progression from near-term opportunities—such as pulp and paper, food products, and activated carbon—toward more complex medium- to long-term pathways like composites, engineered construction materials, and integrated biorefineries. This structured mapping highlights that while bamboo has diverse application potential, each pathway requires different levels of technological validation, market development, and institutional support before it can be commercially realized.

Pulp and paper

Pulp and paper represent the most immediate industrial opportunity because the technology is mature, mills already understand fibre procurement, and bamboo can diversify raw material supply. Reported pulp yields of approximately 40-49% are technically competitive, but adoption requires mill-specific trials, fibre-quality specifications, continuous feedstock supply, and delivered-cost analysis (Rathour et al., 2022). The opportunity is therefore near-term only where existing mills and bamboo resource clusters can be connected economically.

Fiber-reinforced composites and engineered products

Bamboo fibre-reinforced composites and engineered bamboo can serve automotive, furniture, panels, insulation, and construction markets. The technical literature demonstrates promising strength-to-weight performance and environmental advantages, but commercial readiness varies with fibre treatment, matrix selection, moisture control, and manufacturing consistency (Mousavi et al., 2022; Yu et al., 2024; Shi et al., 2023). Malaysia requires pilot production and buyer validation rather than further laboratory characterisation alone.

Table 7. Applications, readiness, and evidence requirements

Application	Readiness	Opportunity	Critical evidence needed	Recommended action
Pulp and paper	Near term	Existing mill capability and established fibre market	Delivered-cost analysis, supply contracts and mill trials	Prioritise resource clusters near suitable mills
Activated carbon and biochar	Near-medium term	Growing environmental and energy applications	Commercial yield, quality consistency and buyer specifications	Pilot with existing biomass processors
Food and ingredients	Near-medium term	Existing consumption of shoots and emerging functional-food uses	Food safety, processing, shelf life and market demand	Develop species-specific food standards and SME processing support
Composites and panels	Medium term	Strong technical literature and multiple industrial uses	Pilot-scale economics, durability and buyer validation	Create shared fibre-extraction and testing facilities
Engineered construction products	Medium term	High sustainability appeal and product differentiation	Structural standards, tropical durability and demonstration projects	Link testing with public or industry pilot buildings
Integrated biorefinery	Long term	Potential for high value and waste minimisation	Commercial scale, co-product markets and integrated logistics	Develop only after feedstock and primary processing systems mature

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Construction applications

Bamboo culms and engineered products can be used for structural elements, flooring, panelling, and decorative applications. Market development is constrained by the absence of local design guidance, testing protocols, durability evidence, and acceptance within procurement and building practices (Fahim et al., 2022; Madhushan et al., 2023). Demonstration buildings and standards-based testing would provide stronger market signals than promotional campaigns without verified performance.

Food, activated carbon, and biorefinery pathways

Bamboo shoots and leaves support food and nutraceutical applications, while residues can be converted into activated carbon, biochar, energy, and biochemical feedstocks (Kong et al., 2020; Heong et al., 2024; Wijitkosum, 2023; Yusof et al., 2025). Integrated biorefinery concepts offer high long-term value by using multiple components and waste streams, but they require technology scale-up, stable feedstock, and markets for co-products (Fu et al., 2025; Gohain & Borgohain, 2025).

The 19 studies indicate a portfolio rather than a single “best” application. Near-term strategies should exploit existing industrial assets and established demand, whereas advanced composites, engineered products, and biorefineries should proceed through staged pilot validation. This sequencing reduces the risk of investing in high-technology facilities before feedstock and markets are established.

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Future Perspectives and Sustainability

Table 8 presents a structured overview of sustainability opportunities in the bamboo sector by linking key dimensions, such as employment, circular production, climate mitigation, certification, and biodiversity, with the conditions required for effective implementation and their expected contributions. The table highlights that bamboo development can support inclusive economic growth (SDG 8), improve resource efficiency through circular use of residues, and contribute to climate mitigation via carbon storage and material substitution. However, these benefits are conditional on enabling factors such as inclusive contracts, aggregation systems, lifecycle assessment frameworks, and accessible certification and traceability mechanisms.

SDG 8, employment and inclusive value chains

Bamboo can support SDG 8 through cultivation, harvesting, processing, logistics, and enterprise development. The distribution of benefits, however, depends on contractual arrangements, access to finance, bargaining power, and the ability of smallholders and local firms to participate beyond raw-material supply (Samdin et al., 2024). Inclusive models require transparent pricing, aggregation services, technical support, and safeguards against transferring production risk disproportionately to growers.

Circular economy and climate value

Bamboo residues can be reused in biochar, energy, composites, and biochemical processing, allowing higher feedstock utilisation and lower waste. Lifecycle studies generally indicate environmental advantages over selected fossil- or mineral-intensive alternatives, but results depend on transport, treatment, resin, product life, and end-of-life assumptions (Shi et al., 2023; Fu et al., 2025). Malaysia-specific lifecycle and carbon accounting is therefore required before broad climate claims or crediting mechanisms are adopted.

Table 8. Sustainability opportunities and implementation conditions

Dimension	Opportunity	Implementation condition	Expected contribution
Employment and rural income	Jobs and diversified income across cultivation and processing	Inclusive contracts, aggregation, skills and transparent pricing	SDG 8 and rural development
Circular production	Use of residues for biochar, energy, chemicals and composites	Integrated product planning and markets for co-products	Higher resource productivity and less waste
Climate mitigation	Carbon storage and substitution of higher-emission materials	Malaysia-specific lifecycle and carbon-accounting protocols	Credible climate and procurement claims
Certification and traceability	Market assurance and responsible sourcing	Affordable group systems, digital traceability and auditing support	Buyer confidence and market access
Biodiversity and resilience	Mixed systems and landscape-level conservation	Site selection, species diversity, buffers and monitoring	Lower ecological risk and stronger social licence

Biodiversity and landscape safeguards

Bamboo development should not be equated with unrestricted monoculture expansion. Landscape planning, mixed systems, retention of natural vegetation, and biodiversity corridors can reduce ecological risks and improve resilience (Messier et al., 2021; Perumal et al., 2023). Sustainability must be embedded in land allocation, plantation design, certification, and monitoring rather than treated as an end-stage marketing label.

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Discussion

Why Malaysia Has Not Yet Realised Its Bamboo Potential

The central finding is that Malaysia's bamboo challenge is a system-coordination problem rather than a simple shortage of resources or technology. The evidence reveals a "missing middle" between biological availability and commercial demand. Growers lack long-term purchase commitments; processors lack assured feedstock; investors lack cost and market evidence; buyers lack standards and reliable products; and agencies operate through partially separated land, forestry, industrial, SME, and environmental mandates. Each actor, therefore, waits for another part of the system to develop first.

This interpretation helps explain why Malaysia trails regional producers despite having favourable growing conditions and established wood-based industries. China's bamboo economy benefits from dense processing clusters, specialised suppliers, standards, export networks, and sustained product development. Vietnam has stronger craft and SME linkages and more established regional manufacturing channels, while Indonesia combines community-based production with furniture, handicraft, and biomass applications (Shah et al., 2021; Binfield et al., 2024; Ahmad et al., 2025). Malaysia has useful capabilities, but they remain insufficiently connected. The relevant policy lesson is not to replicate another country's scale, but to build complementarity among domestic institutions, feedstock systems, processors and markets.

Table 9 provides a comparative interpretation of selected Asian bamboo industry models, highlighting differences in development patterns, enabling strengths, persistent constraints, and lessons transferable to Malaysia. The table shows that countries such as China, Vietnam, and Indonesia have developed more mature and integrated bamboo industries through strong processing capacity, established market linkages, and coordinated production systems, while Malaysia remains at an early and fragmented stage despite having resource potential and supporting industries. This comparison underscores that industrial success is not determined solely by resource availability but by the degree of coordination across value chains, institutions, and markets.

The synthesis supports an integrated conceptual framework in which economic value emerges from five complementary capabilities. Policy and institutions establish land access, tenure security, coordination, and safeguards. Investment and finance convert credible opportunities into plantations, processing, and enterprise development. Technology and infrastructure provide treatment, grading, processing, quality assurance, and skills. Markets and supply chains create demand, contracts, logistics, standards, and traceability. Sustainability and inclusion protect ecological integrity and determine whether benefits reach smallholders, workers, and local enterprises. Weakness in any one capability can constrain the entire system, meaning that isolated interventions have diminishing returns when complementary conditions are absent.

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Table 9. Comparative interpretation of selected Asian bamboo-industry models

Country	Dominant development pattern	Enabling strength	Persistent constraint	Transferable lesson for Malaysia
China	Cluster-based industrialisation with broad product portfolios and export networks.	Processing depth, standards, specialised suppliers and market scale.	High resource concentration and uneven producer inclusion.	Develop coordinated clusters and standards but include smallholder safeguards.
Vietnam	Export-oriented SME and craft/manufacturing linkages.	Skilled production networks and market connections.	Quality consistency and upgrading constraints.	Connect SMEs to shared technology, design and quality services
Indonesia	Community production combined with handicraft, furniture and biomass uses.	Strong local knowledge and diverse applications.	Dispersed supply and variable quality.	Use aggregation and contract systems while retaining community participation.
Malaysia	Early-stage and fragmented development with selected technical capabilities.	Resource potential, research capacity and existing wood-based industries.	Weak coordination, standards, processing scale and market formation.	Build the missing institutional and processing middle before pursuing large-scale expansion.

Figure 2 illustrates the Integrated Bamboo Value Realisation Framework for Malaysia, which conceptualizes bamboo development as a coordinated system linking resources, institutions, markets, and sustainability outcomes. The framework begins with the resource base and regional context, which must be supported by coordinated capability formation across five key pillars: policy and institutions, investment and finance, technology and infrastructure, markets and supply chains, and sustainability and inclusion. These interconnected components highlight that value creation depends not on isolated interventions, but on the alignment of governance, financing, technical capacity, and market mechanisms to enable efficient and scalable industry development.

The framework contributes theoretically by reframing bamboo development as a problem of complementary capability formation. Resource endowment is a necessary input but not a sufficient explanation of sector performance. Value realisation depends on the interaction and sequencing of institutional, financial, technological, market, and sustainability capabilities. The framework also explains why technically successful pilot products may fail commercially when standards, supply, finance, or buyer adoption are missing.

Theoretical Implications

The review extends resource-based explanations of bamboo development in three respects. First, it distinguishes technical potential from value realisation, thereby avoiding the assumption that superior material properties inevitably produce market success. Second, it identifies complementarity among enabling capabilities: an improvement in processing technology has limited sector-wide value without feedstock security, standards, and demand. Third, it introduces spatial and institutional transferability into the synthesis. International

evidence is useful not because development models can be copied directly, but because it reveals which combinations of institutions, clusters, skills, and market mechanisms repeatedly support industrialisation.

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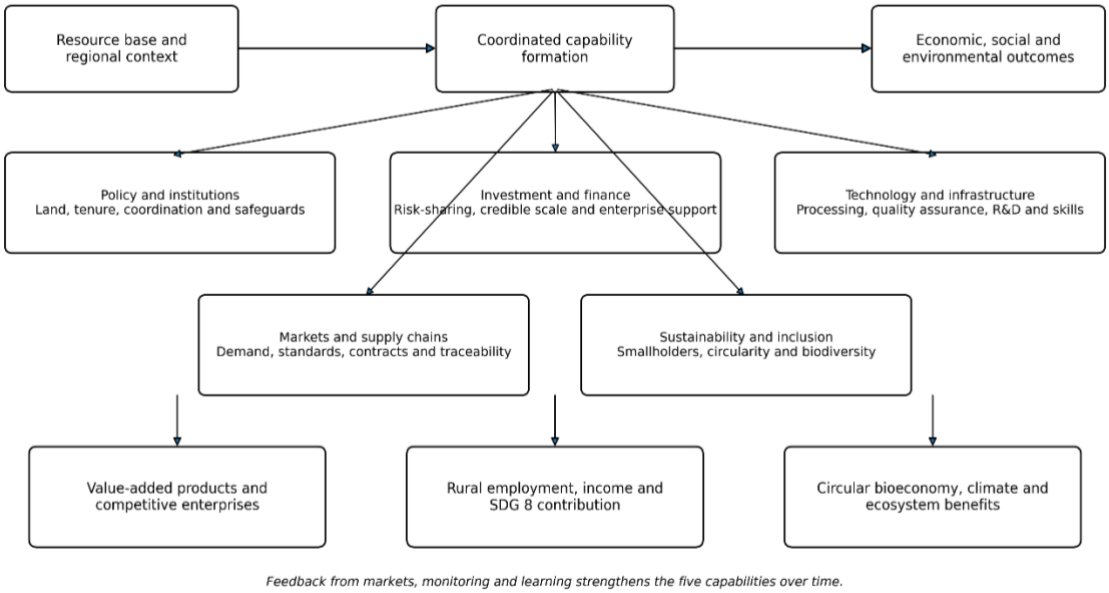


Figure 2. Integrated Bamboo Value Realisation Framework for Malaysia

Practical and Managerial Implications

For firms, immediate decisions should be based on verified feedstock, product specifications, and committed buyers rather than broad market-growth claims. Existing mills and biomass processors should test bamboo through limited-volume commercial trials, and document delivered cost, yield, treatment requirements, and quality variation. SMEs should use shared processing, testing, and design facilities where individual investment is uneconomic. Grower-processor contracts should specify species, dimensions, moisture, harvesting age, delivery schedules, price adjustments, and responsibility for rejected material. These measures directly reduce information and coordination risk.

Policy Implications and Implementation Roadmap

Policy should move from dispersed project support to sequenced sector building. A national coordination mechanism should align federal and state agencies, while implementation should occur through geographically defined resource-processing-market clusters. Public support should be conditional on resource evidence, buyer participation, environmental safeguards, and measurable performance. Subsidies that create plantations without processing or markets risk reproducing the existing coordination failure.

Table 10 outlines a phased implementation roadmap for developing the Malaysian bamboo sector, emphasizing a structured transition from foundational coordination to large-scale market integration. The roadmap is divided into three stages: (1) foundation building, which focuses on establishing national coordination mechanisms, resource mapping, policy alignment, and pilot clusters; (2) commercial scale-up, which prioritizes the development of shared processing hubs, financing mechanisms, supply agreements, and product validation;

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and (3) market consolidation, which aims to expand competitive clusters, integrate biorefinery systems, and strengthen domestic and export markets. Each phase is supported by clearly defined actors, ranging from government agencies to industry players, and measurable indicators to track progress, ensuring accountability and performance-based development.

Table 10. Phased implementation roadmap for the Malaysian bamboo sector

Phase	Time horizon	Priority actions	Principal actors	Measurable indicators
Phase 1: Foundation	0-2 years	Establish national coordination mechanism; complete resource and processor inventory; harmonise model land/tenure arrangements; identify priority product standards; select two or three pilot clusters; create digital feedstock registry	Federal and state forestry/industry agencies, standards bodies, universities and industry associations	Verified resource map; agreed governance structure; model contracts; standards work plan; pilot cluster baselines
Phase 2: Commercial scale-up	3-5 years	Develop shared processing and testing hubs; introduce blended finance and risk-sharing; implement contract supply and aggregation; conduct mill and product trials; train growers and processors; support group certification and traceability	Public finance institutions, processors, SMEs, grower groups, technical institutions and buyers	Operating hubs; signed supply contracts; product approvals; trained participants; processing utilisation; jobs and income generated
Phase 3: Market consolidation	Beyond 5 years	Expand competitive clusters; develop engineered products and integrated biorefineries; strengthen export and green procurement channels; integrate lifecycle and carbon evidence; evaluate policy effectiveness and environmental outcomes	Industry-led clusters with government oversight, research partners and market institutions	Domestic and export sales; certified products; waste utilisation; private investment leverage; lifecycle performance; equitable value distribution

Priority Research Agenda

Future research should close decision-relevant gaps rather than continue producing disconnected application studies. Priority should be given to evidence that reduces uncertainty for land allocation, investment, production, market development, and environmental governance. The agenda below differentiates questions that can support immediate pilots from those requiring longer-term observation and scale-up.

Table 11 provides a research gap and priority matrix for the Malaysian bamboo sector, linking key evidence needs with research questions, methodologies, time horizons, and decision-making relevance. It identifies gaps in resource availability, feasibility, market demand, supply-chain governance, processing, environmental resilience, and policy. Each gap is linked to targeted questions, like finding viable production areas or reliable supply models, supported by methods such as spatial analysis, pilot trials, lifecycle assessments, and case studies. The inclusion of short-, medium-, and long-term timelines clarifies which evidence supports immediate pilots and which aids long-term sector growth.

Table 11. Research gap and priority matrix

Evidence gap	Priority question	Recommended design	Horizon	Decision use
Resource availability and productivity	Where are commercially accessible bamboo resources, and what yields and qualities are achievable by species and site?	National inventory, geospatial mapping and multi-site growth trials	Short term	Cluster selection and feedstock planning
Techno-economic feasibility	Which product pathways are profitable at realistic delivered feedstock, processing and financing costs?	Pilot-scale techno-economic analysis and sensitivity testing	Short-medium term	Investment screening and financing design
Market demand and standards	Which industrial and consumer segments will adopt bamboo, at what quality and price?	Buyer surveys, conjoint or choice studies, procurement trials and standards validation	Short-medium term	Product prioritisation and demand creation
Supply-chain governance	Which contracts, cooperative or nucleus models provide reliable supply and fair value distribution?	Comparative case studies, contract experiments and longitudinal value-chain analysis	Medium term	Inclusive business-model design
Processing and product durability	How do Malaysian species perform under commercial treatment, tropical exposure and repeated production?	Industrial trials, durability testing and quality-control studies	Medium term	Standards, warranties and scale-up
Pest, disease and climate resilience	Which species-site-management combinations minimise biological and climatic risks?	Longitudinal field trials and integrated pest-management research	Medium-long term	Plantation risk management
Circularity, lifecycle and carbon	What are the net impacts of priority bamboo products under Malaysian supply chains and end-of-life systems?	Lifecycle assessment, material-flow analysis and verified carbon accounting	Medium-long term	Green claims, procurement and carbon mechanisms
Policy effectiveness and regional comparison	Which combinations of incentives, governance and cluster strategies produce durable industry outcomes?	Quasi-experimental evaluation and comparative studies with Asian producer countries	Long term	Policy adjustment and institutional learning

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Limitations

The review has four limitations. First, it covers English-language publications indexed in three search systems and may omit relevant local-language or unpublished industry evidence. Second, the 2020-2025 period provides current evidence but limits historical analysis. Third, study designs and outcome measures are highly heterogeneous, preventing statistical meta-analysis and direct comparison of all numerical estimates. Fourth, much of the evidence concerns technical feasibility or international contexts; transfer to Malaysia requires field,

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market, and policy validation. These limitations reinforce the need for transparent primary data and study-level supplementary extraction files in future updates.

Conclusion

Bamboo is a strategically relevant but institutionally underdeveloped component of Malaysia's bio-based economy. The evidence confirms multiple economic pathways, from pulp, food and activated carbon to composites, engineered construction and integrated biorefineries. The main barrier is not a lack of possible applications; it is the absence of a coordinated system that links land and tenure, reliable feedstock, investment, processing, standards, markets, skills and safeguards. This explains why resource availability and technical research have not yet produced substantial commercial scale.

The review's principal contribution is the Bamboo Value Realisation Framework, which shows that five complementary capabilities must develop together. In the short term, Malaysia should establish governance, resource evidence, standards, contracts and commercially grounded pilots. The medium term should focus on shared processing, finance, skills and validated products, while longer-term investment can support engineered materials, circular biorefineries, and wider export or green-procurement markets. Future research should prioritise techno-economic, market, supply-chain, lifecycle, and policy-evaluation evidence. A sequenced and measurable approach would allow bamboo to contribute more credibly to rural livelihoods, competitive value chains, circular production, and SDG 8.

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