Warsaw University of Life Sciences

Centre for Climate Research

Adhitya Rahmana

The Transition of Forest-Based Bioeconomy in Indonesia's Rural Area: Key Factors and Policy Implications

Transformacja biogospodarki opartej na zasobach leśnych na obszarach wiejskich Indonezji: kluczowe czynniki oraz implikacje dla polityki publicznej

Doctoral thesis

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Doctoral thesis prepared under the supervision of

Dr. hab. Nina Drejerska, Prof. SGGW

Centre for Climate Research

Second supervisor:

Dr. hab. Marcin Zbieć

Institute of Wood Sciences,

Department of Technology and Entrepreneurship in the Wood Industry

Warsaw 2026

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ABSTRACT

The global shift towards a forest-based bioeconomy requires balancing ecological preservation with economic progress. In developing nations like Indonesia, implementing macroeconomic policies at the grassroots level creates structural challenges. This dissertation explores the behavioural drivers and structural forces shaping the bioeconomy transition within rural micro and small forestry enterprises, contrasting the capital-intensive teak furniture industry with the community-reliant bamboo craft sector.

A mixed-methods approach is employed to bridge the gap between top-down mandates and localised realities. The theoretical framework integrates the Multi-Level Perspective, Entrepreneurial Ecosystems, and the Theory of Planned Behaviour. Partial Least Squares Structural Equation Modelling (PLS-SEM) analysed the technological adoption readiness and behavioural nuances of 150 rural entrepreneurs. Subsequently, a Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy-DEMATEL) analysis, based on evaluations from a grassroots expert panel, mapped the causal networks within the local ecosystems. Finally, Importance-Performance Map Analysis (IPMA) synthesised these findings into a Policy Positioning Matrix.

Empirical results highlight the highly localised nature of bioeconomy transitions. In the teak sector, technological adoption and existing entrepreneurial ecosystems serve as robust stabilising pillars, while severe biomaterial depletion demands strict regulatory safeguards. Conversely, the bamboo industry anchors its transition in local social capital, where a shared socio-ecological mentality acts as the primary catalyst for change despite systemic marginalisation from formal financing. The study concludes that applying a uniform national blueprint for bioeconomy governance is fundamentally flawed. Transition pathways are explicitly dictated by resource materiality and localised socio-technical regimes. The resulting Policy Positioning Matrix equips policymakers with an evidence-based tool to design decentralised, bottom-up regulatory frameworks.

Finally, this research contributes to the broader academic discourse by operationalising socio-technical transition theories at the micro-level of rural enterprises. By bridging macro-landscape pressures with individual cognitive behaviours, the study provides a replicable diagnostic framework for assessing informal forestry sectors in developing economies. Practically, it underscores that a sustainable bioeconomy transition must prioritise social inclusivity, ensuring that traditional, community-based industries are integrated into the global pursuit of green modernisation rather than marginalised.

STRESZCZENIE

Globalne przejście w stronę biogospodarki opartej na zasobach leśnych wymaga zrównoważenia ochrony ekologicznej z postępem gospodarczym. W krajach rozwijających się, takich jak Indonezja, wdrażanie polityki makroekonomicznej na szczeblu lokalnym rodzi wyzwania strukturalne. W rozprawie dokonano rozpoznania behawioralnych czynników i sił strukturalnych kształtujących transformację w kierunku biogospodarki w wiejskich mikro- i małych przedsiębiorstwach leśnych, zestawiając kapitałochłonny przemysł mebli tekowych z opartym na społeczności sektorze rzemiosła bambusowego.

Zastosowano badanie w schemacie metod mieszanych (mixed-methods), aby zniwelować lukę między odgórnymi regulacjami a lokalnymi realiami. Ramy teoretyczne integrują perspektywę wielopoziomową (MLP), ekosystemy przedsiębiorczości oraz teorię planowanego zachowania (TPB). Modelowanie równań strukturalnych metodą cząstkowych najmniejszych kwadratów (PLS-SEM) posłużyło do analizy gotowości do adaptacji technologicznej i niuansów behawioralnych 150 właścicieli wiejskich firm. Następnie zastosowano rozmytą metodę DEMATEL (Fuzzy-DEMATEL), opartą na ocenach oddolnego panelu ekspertów, która doprowadziła do zmapowania sieci przyczynowo-skutkowych w lokalnych ekosystemach. Wyniki te zsyntetyzowano za pomocą analizy mapy ważności i wyników (IPMA) w Matrycę Pozycjonowania Polityki (Policy Positioning Matrix).

Wyniki empiryczne podkreślają wysoce lokalny charakter transformacji biogospodarki. W sektorze tekowym adaptacja technologiczna i istniejące ekosystemy przedsiębiorczości stanowią solidne filary stabilizujące, podczas gdy poważne wyczerpanie biomateriałów wymaga ścisłych zabezpieczeń regulacyjnych. Z kolei przemysł bambusowy opiera swoją transformację na lokalnym kapitale społecznym, gdzie wspólna mentalność społeczno-ekologiczna działa jako główny katalizator zmian, pomimo systemowej marginalizacji w dostępie do formalnego finansowania.

Wyniki badań dowodzą, że stosowanie jednolitego, ogólnokrajowego planu zarządzania biogospodarką jest zasadniczo błędne. Ścieżki transformacji są wyraźnie zdeterminowane przez różnorodność zasobów i lokalne reżimy społeczno-techniczne. Opracowana Matryca Pozycjonowania Polityki może dostarczyć decydentom oparte na dowodach narzędzie do projektowania zdecentralizowanych, oddolnych ram regulacyjnych.

INTRODUCTION

The transition toward a bioeconomy in developing countries is increasingly recognised as a strategy to align economic growth with environmental sustainability. As home to the world's third-largest tropical forest area (FAO & UNEP, 2020), Indonesia possesses a unique comparative advantage in pioneering a highly competitive, forest-based bioeconomy. However, translating this macro-level potential into rural forestry sectors often reveals a stark disconnect between national policies and local realities. Rather than capturing high added value, many rural regions remain entrenched in traditional resource extraction. Furthermore, weak governance and linear value chains frequently marginalise small-scale entrepreneurs at the grassroots level, hindering an inclusive bioeconomic transition

These systemic dynamics are particularly evident in the contrasting trajectories of two key commodities: teak wood and bamboo. The teak industry in Java is well-integrated into global markets but faces sustainability challenges, such as land management issues and exclusive, capital-intensive supply chains. In contrast, bamboo has great ecological potential but remains at a subsistence level. Its entrepreneurial ecosystem is severely underdeveloped, characterised by local actors who lack requisite access to technology, financing, and market knowledge. This sharp contrast renders teak and bamboo compelling case studies for unpacking the barriers and enablers of an inclusive bioeconomic transition at the grassroots level.

Existing studies of bioeconomy predominantly focus on macro-level policy and technological aspects (Leitão, 2016; Viaggi, 2019, 2025), while neglecting how entrepreneurial cognition and ecosystem structures interact at the rural level. This creates a critical blind spot in explaining why bioeconomy transitions fail in practice. However, these studies frequently neglect the role of local entrepreneurial ecosystems. At the micro level, policy models often wrongly assume that entrepreneurs will automatically adopt green innovations if financial incentives exist. Rural entrepreneurs are influenced by information limitations, a tendency to keep the status quo, and a reluctance to take risks. Therefore, understanding how entrepreneurs perceive control and environmental values is crucial for a successful transformation.

This dissertation addresses these gaps by using a hybrid analytical approach. It combines Partial Least Squares Structural Equation Modelling (PLS-SEM) to test factors influencing entrepreneurial behaviour and Fuzzy-DEMATEL to map cause-and-effect

relationships within the ecosystem. Specifically, this research contributes to the literature and policy by:

- Explaining why bioeconomy transitions are uneven in forest-based sectors.
- Integrating ecosystem analysis with entrepreneurial behaviour to understand local readiness.
- Proposing a Policy Positioning Matrix to support governments' design of targeted strategies for forest-based bioeconomy governance.

This study provides an evidence-based foundation to strengthen local entrepreneurial capacity and restore the economic resilience of rural communities in Indonesia. Therefore, this dissertation argues that forest-based bioeconomy transitions in rural Indonesia are not primarily constrained by technological gaps, but by mismatches between entrepreneurial cognition and ecosystem structures.

1 RESEARCH METHODOLOGY

1.1 Philosophical underpinnings of the dissertation

The forest-based bioeconomy transition is a complex phenomenon. It involves the mindset of entrepreneurs at the micro level, the business ecosystem at the meso level, and state regulations at the macro level. Therefore, this research cannot rely on a single, rigid methodology. Instead, this dissertation is built on a pluralistic philosophical approach (Mingers & Brocklesby, 1997). This hybrid approach integrates the logic of natural sciences, social sciences, and public policy into one cohesive analytical framework.

Ontologically, this study is grounded in the critical realism paradigm (Sharpe & Bhaskar, 1976). This paradigm views social reality as existing objectively but layered into three domains: the empirical (what we observe), the actual (events that happen), and the real (hidden causal mechanisms) (Hobbs, 2015). This perspective explains why the case study results for the teak and bamboo industries differ so much. Critical realism argues that causal mechanisms are never uniform. Instead, they depend heavily on their material context. This explains why capital power heavily dictates the teak industry, while local social and cultural ties drive the bamboo sector.

In line with this ontology, the research epistemologically adopts methodological pluralism. It combines the empirical-positivist tradition with systems thinking. On one hand, the empirical perspective is applied using the PLS-SEM method. Here, entrepreneurial behaviour and technology adoption are treated as variables that can be measured and tested. However, because statistics often only capture surface-level trends, this study also uses the Fuzzy-DEMATEL method (Si et al., 2018; Wu & Lee, 2006). This systemic approach is needed to dig into deeper layers of reality. The goal is to map cause-and-effect relationships, separating the main drivers (*net-cause*) from the passive outcomes (*net-effect*) in the entrepreneurial ecosystem.

Axiologically, this research does not remain passively neutral. It adopts a transformational paradigm that actively supports sustainability values (Midgley, 2003). The main goal is not just to describe the current situation, but to design a new, fairer governance model for rural communities. IPMA and Fuzzy-DEMATEL integrated, this research aims to fix policy biases that often push small businesses aside. Then, this philosophical framework ensures that the final policy recommendations are scientifically solid yet deeply connected to local realities.

1.2 Problem statement, research questions and objectives

The shift toward a bioeconomy is often viewed as the ultimate solution to balance environmental conservation with national economic growth. However, this macro-level concept frequently hits a wall when introduced to rural areas. A significant gap exists between ambitious national plans and the daily realities of rural communities (Zhang et al., 2022). Policies are largely designed from the top down. As a result, they tend to overlook the social structures, resource limitations, and cultural ties that keep local business ecosystems alive (Zellweger et al., 2018).

Governments often assume that rural entrepreneurs will naturally adopt green practices if they receive technology and financial support. The reality on the ground is much more complex. Small business decisions are deeply rooted in daily habits, survival needs, and close family networks within their communities (Zehra & Usmani, 2021). If policymakers keep ignoring these basic human factors, their programs might worsen the divide between large-scale industries and community-based enterprises. Because of this, it is necessary to dig deeper into how entrepreneurial behaviour and local ecosystems interact, ensuring that future policies hit the mark.

Driven by these challenges, this research seeks to answer a series of key questions. The inquiry moves from identifying core drivers to analysing entrepreneurial behaviour, mapping the ecosystem, and designing better governance solutions.

The specific research questions guiding this dissertation are:

RQ1: What are the main drivers of the bioeconomy transition in the rural forestry sector?

RQ2: How does entrepreneurial behaviour shape the readiness of local actors to adopt bioeconomy practices?

RQ3: What cause-and-effect relationships within the local entrepreneurial ecosystem determine the success of bioeconomy initiatives?

RQ4: What governance strategies can effectively close the gap between macro-level policies and local realities?

The shift toward a bioeconomy is no longer just an environmental goal. It is now a global necessity to separate economic growth from fossil fuels. In Indonesia, this change offers a strategic way to use forest resources sustainably while developing rural areas. However, this transition faces major barriers in the field. These include unequal access to technology, land conflicts, and fragmented government policies. To overcome these

deadlocks, Indonesia needs a policy framework that fits the actual capacity of micro and small enterprises (MSEs). This research is built on three pillars: entrepreneurship for value creation, technological innovation for efficiency, and socio-ecological resilience for sustainability. Based on these pillars, the study compares capital-intensive teak furniture businesses with community-based bamboo craft enterprises.

Teak and bamboo represent two opposite sides of Indonesia's forest bioeconomy. Teak is part of a highly regulated and capital-intensive industry. In contrast, bamboo is a flexible, community-driven sector. This research aims to find ways to balance rural profits with environmental protection. To achieve this, the study has four specific objectives:

1. **Develop a conceptual framework** by evaluating how entrepreneurship, innovation, and socio-ecological resilience work in rural settings.
2. **Examine behavioural differences** among business actors. Using structural modelling (PLS-SEM), this phase identifies whether sustainability prerequisites work the same way across different sectors.
3. **Map cause-and-effect relationships** within the entrepreneurial ecosystem. By using the Fuzzy-DEMATEL method, the research identifies "entry points" for policy by separating root causes from mere symptoms.
4. **Create an evidence-based governance model**. This is achieved by building a **Policy Positioning Matrix**. This tool combines importance-performance analysis (IPMA) with Fuzzy-DEMATEL to design better strategies for the government.

1.3 Research hypotheses

To address the core research questions, this dissertation leans on a rigorous quantitative approach. The primary focus is to unpack the structural ties between entrepreneurial behaviour, the capacity to adopt technology and innovations, and how ready rural areas are for a bioeconomy transition. This is pursued through a specified definition of these concepts and an examination of the interrelations between them, expressed through seven operational hypotheses:

H1: Source of Biomaterial (SUB) positively influences the development of the Entrepreneurial Ecosystem (EES).

H2: Social Capital (SCP) has a positive effect on the Entrepreneurial Ecosystem (EES).

H3: The Entrepreneurial Ecosystem (EES) positively drives Sustainable Technology Adoption (TEA).

H4: The Entrepreneurial Ecosystem (EES) positively affects the formation of Socio-Ecological Mentality (SOM).
H5: The Entrepreneurial Ecosystem (EES) directly and positively impacts Bioeconomic Transformation Intentions (BOT).
H6: Sustainable Technology Adoption (TEA) positively influences Bioeconomic Transformation Intentions (BOT).
H7: Socio-Ecological Mentality (SOM) positively affects Bioeconomic Transformation Intentions (BOT).

All operational hypotheses in this study are set up to be tested through Partial Least Squares Structural Equation Modelling (PLS-SEM). In practice, this means taking abstract theoretical concepts and grounding them as precisely measurable latent variables. The measurement indicators are drawn straight from validated instruments in the existing literature. This step ensures that any cause-and-effect relationship proposed is backed by solid, objective statistical metrics.

On an empirical level, these hypotheses look at what drives business actors on the ground. For example, does an entrepreneur's attitude toward environmental sustainability or the social pressure they feel from subjective norms genuinely push them to adopt bioeconomy practices? The model also digs into mediating effects. It examines how much perceived behavioural control can bridge that frustrating gap between just having an intention and taking real action.

Furthermore, this empirical testing takes place within the complex reality of rural areas, capturing data from actors in both the teak and bamboo sectors. Bringing in such diverse resource backgrounds is intentional. It proves that the proposed behavioural framework is robust enough to make sense of innovation adoption across wildly different field conditions. The precise details of each operational hypothesis (H1 through H7) are mapped out at the end of Chapter 3, right after the conceptual framework is established. Grounding the research in this kind of measurable statistical testing ensures that the final governance policy recommendations are genuinely evidence-based.

1.4 Research Approach

This study employs a mixed-method design that combines quantitative structural modelling with systems mapping. The choice of this design is driven by a practical need to unpack the complexity of the forest-based bioeconomy transition. Rather than merely stacking statistical tools without a clear purpose, this dissertation assigns a specific

analytical function to each method. These methods are then integrated into a single, logical evaluation sequence.

In this dissertation, the Entrepreneurial Ecosystem (EES) is deliberately conceptualised and operationalised through a dual-level analytical approach, reflecting the complexity of socio-technical transitions. Firstly, at the micro-cognitive level (analysed via PLS-SEM in Chapter 4.2), the operationalisation shifts to the individual entrepreneur's perspective. In alignment with the Theory of Planned Behaviour (TPB), the structural model strictly measures the entrepreneurial ecosystem as 'Perceived Ecosystem Conduciveness'. Secondly, at the macro-systemic level (analysed via Fuzzy-DEMATEL in Chapters 4.3 and 4.4), the ecosystem is treated as an objective structural network comprising tangible pillars (e.g., government policies, capital availability, and research institutions). Here, the focus is on mapping the actual causal relationships and systemic bottlenecks to formulate macro-policy interventions. This distinction is critical: while the DEMATEL maps the objective reality of the ecosystem's architecture, the PLS-SEM evaluates how the subjective perception of that very ecosystem psychologically drives the entrepreneurs' intentions to adopt sustainable technologies and bioeconomic transformations.

The dissertation process is structured into three interconnected stages, where the output of one phase directly informs the next. The methodological integration is designed as follows:

- **Stage 1: Testing Causal Relationships (PLS-SEM).** The first phase focuses on evaluating the behaviour of business actors at the micro-level. It uses Partial Least Squares Structural Equation Modelling (PLS-SEM) to test the relationships between latent variables such as entrepreneurial intention, social norms, and sustainability behaviour. PLS-SEM was chosen because it can simultaneously model complex relationships and mediating effects, even with a moderate sample size (Hair et al., 2019). This stage specifically answers: *What factors significantly determine the transition readiness of local entrepreneurs?*
- **Stage 2: Mapping Ecosystem Structures (Fuzzy-DEMATEL).** Once the key determinants are identified by the SEM model, the focus shifts to the meso-level business ecosystem. Traditional statistics often fail to capture the hidden cause-and-effect structures between ecosystem factors. To solve this, the study applies the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy-DEMATEL) method. Relying on insights from an expert panel, this approach maps the causal

structure of the ecosystem. The fuzzy approach is utilised to handle the natural ambiguity in human judgment. This stage answers: *How do entrepreneurial ecosystem factors influence each other, and which ones act as root causes (net-causes)?*

- **Stage 3: Determining Policy Priorities (IPMA).** The final stage translates the statistical findings and system maps into practical governance recommendations. It uses Importance-Performance Map Analysis (IPMA) as an analytical extension of the SEM model. IPMA goes beyond merely checking if a variable is significant; it measures its actual performance on the ground. By combining the priority map from IPMA with the causal structure from Fuzzy-DEMATEL, the research can formulate highly targeted policy interventions. This stage answers: *Which policy areas must the government prioritise?*

The integration of these three methods makes the research framework highly cohesive. PLS-SEM provides empirical evidence of the key determinants, Fuzzy-DEMATEL unravels the underlying system structure, and IPMA translates both insights into actionable governance priorities. Further details regarding the field sampling strategy, construct operationalisation, and the selection of the expert panel are discussed in the subsequent data collection section.

1.5 Data collection and sampling strategy

The empirical data collection occurred over a three-month period from July to September 2023. This process was systematically divided into two distinct sequential phases. This dual-phase approach aligns perfectly with the established mixed-methods blueprint. The first phase executed a broad quantitative survey to power the PLS-SEM analysis. Subsequently, the second phase conducted targeted expert interviews to construct the Fuzzy-DEMATEL causal maps.

The teak furniture industry was exclusively investigated within Jepara Regency. Jepara is globally recognised as the historic epicentre of Indonesian woodcarving. However, the actual production nodes are heavily concentrated in the surrounding rural villages. These rural peripheries provide the essential spatial context for studying grassroots industrial dynamics. Operating within these strict rural constraints forces micro-enterprises to navigate unique logistical and ecological bottlenecks daily. Figure 1 presents the Administrative Map of Jepara Regency for the year 2020. It details the territorial boundaries of seventeen mainland districts alongside the Karimunjawa

archipelago. The map serves a critical function beyond mere geographical reference. This spatial visualisation directly justifies the sampling framework deployed for the empirical survey. Spatially, the map confirms the research focus on rural furniture production clusters outside the urban centre. The primary target areas specifically encompass historic woodcarving centres like Pakis Aji, Tahunan, and Bangsri districts. This specific site selection aligns with the methodological need to observe grassroots industrial dynamics. Data acquisition within these rural peripheries was conducted strictly face-to-face to guarantee field validity.

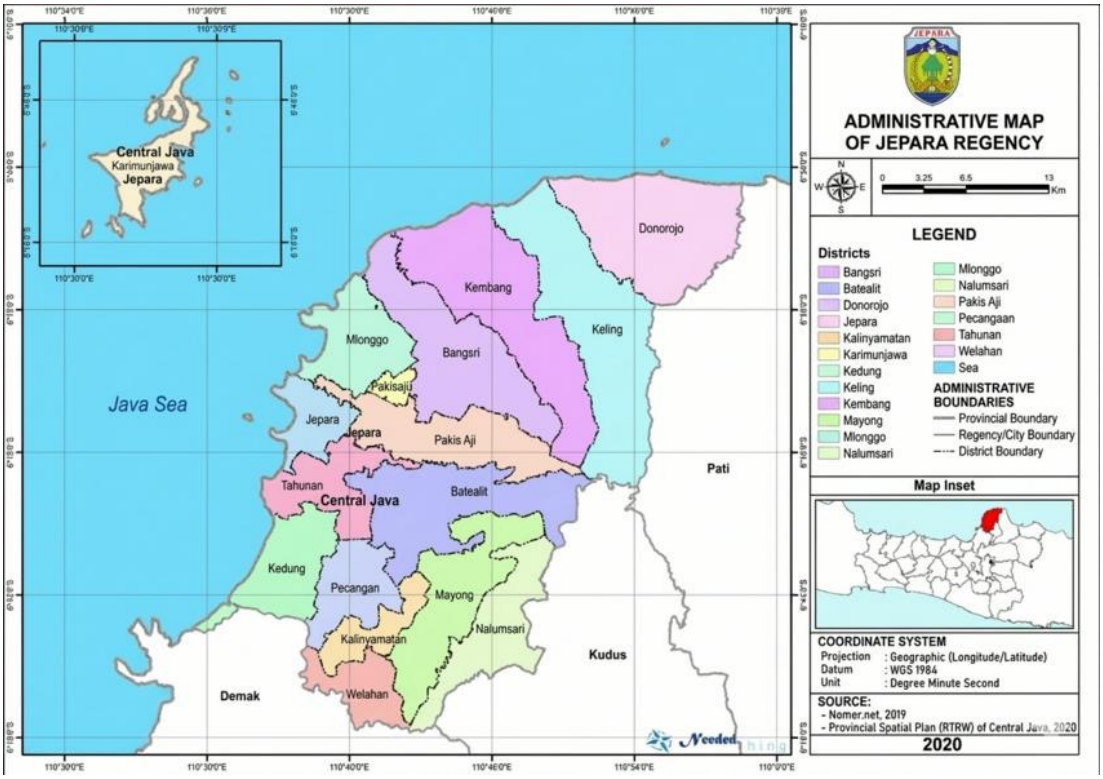


Figure 1. Jepara Regency Map

Source: Based on The Regional Development Plan of Jepara Regency 2023-2026 (Jepara Regency Government, 2022).

Conversely, the bamboo craft sector was examined within Tasikmalaya Regency. This region represents a quintessential rural agricultural landscape located in West Java. The bamboo enterprises here operate deeply embedded within traditional village networks. This deep rural embedding provides a natural setting to observe the industry. It allows for the capture of the pure influence of socio-ecological mentality and social capital. Both regions represent the socio-economic realities of Indonesia's rural forest-

based bioeconomy. The figure presents the Administrative Map of Tasikmalaya Regency in West Java for the year 2024. This spatial plan meticulously delineates the administrative sub-district boundaries across the entire expanse of the regency. This spatial visualisation illustrates the geographical landscape for the bamboo craft research. The primary target area of this research is the bamboo craft centre within Leuwisari District. Leuwisari District represents the highly ideal spatial characteristics required for a rural business ecosystem. This specific site selection aligns with the methodological necessity to observe the pure influence of social capital. Data acquisition within this specific rural hinterland was rigorously executed through direct face-to-face field visits.

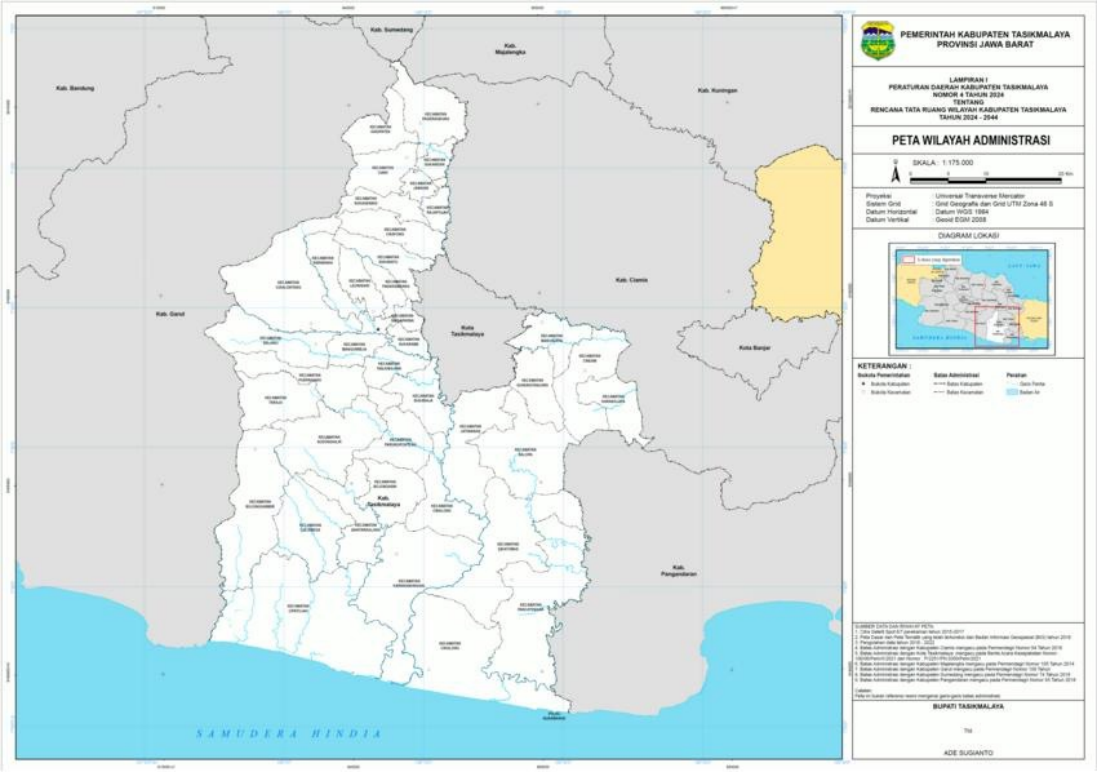


Figure 2. Tasikmalaya Regency Map

Source: The Regional Regulation Number 4 of 2024 Concerning 'Rencana Tata Ruang Wilayah Kabupaten Tasikmalaya Tahun 2024-2044' (Tasikmalaya Regency Government, 2024).

Phase 1: Quantitative Survey for PLS-SEM The first phase targeted micro and small enterprise (MSE) owners operating in the rural forestry sector. Specifically, the study compared the capital-intensive teak furniture industry with the community-based bamboo craft sector. A purposive sampling strategy was employed. To ensure data validity, respondents had to meet strict inclusion criteria: they must be active business owners or managers with a minimum of three years of operational experience. A total of

150 valid responses were collected, distributed evenly with 75 respondents from the teak sector and 75 from the bamboo sector. Based on established methodological guidelines (Hair et al., 2019), this sample size safely exceeds the standard "10-times rule."

Although the research contrasts two distinct rural industries of bioeconomy, a formal Partial Least Squares Multi-Group Analysis (PLS-MGA) was not explicitly conducted. The primary methodological objective of this study is not to mathematically test moderation effects between groups, but rather to evaluate two fundamentally different socio-technical baseline models (a capital-intensive regime vs. a labour-intensive niche). Therefore, the comparison presented is typological and heuristic. By modelling them separately, the study preserves the unique systemic integrity and distinct VIF characteristics of each commodity's ecosystem without forcing them into a constrained, homogenised comparative statistical parameter.

This research instrument was specifically designed for structural equation modelling (SEM-PLS) analysis. This questionnaire (see ANNEX 1) aimed to analyse the bioeconomic transition within the timber and bamboo-based industrial sectors. The questionnaire structure was systematically divided into two main sections and one ethical consent form. This specific design ensured the comprehensive collection of empirical data from grassroots business actors. Completing this entire instrument took approximately 20 to 30 minutes.

The first section focused on the demographic profile and the entrepreneurial ecosystem conditions, with such data as the business owner's age and the enterprise's establishment year. Respondents were required to detail their initial motivations for starting the manufacturing business. They had also identified the primary initial funding sources used to capitalise their enterprises. The operational aspects were mapped through specific inquiries regarding employee numbers and the annual turnover scale. Data extraction proceeded to the identification of the primary raw material supply chains. This instrument questioned the locations of material sources and the primary obstacles in procurement. The questionnaire subsequently recorded sales market orientations and specific expectations for future governmental assistance.

The second section formed the core instrument measuring entrepreneur behaviour within the bioeconomic transition. This section exclusively utilised a five-point Likert scale to validate the latent variable indicators. The first indicator group measured the certainty of availability and the legality of raw material supplies. The second group evaluated social capital. The third group assessed the mentality concerning climate

change issues and ecological sustainability. The fourth group investigated the efficiency of sustainable technology adoption within the actual production process. The fifth group highlighted the entrepreneurial ecosystem. The final group measured entrepreneurs' intention to support the path of transformations

This survey instrument concluded with a strict personal data protection consent form. Respondents were guaranteed confidentiality rights and protected from third-party misuse of enterprise information. Entrepreneur participation in this research study was entirely voluntary without any form of coercion. Direct compensation, through shopping vouchers for respondents who agree to participate, was provided. This ethical transparency was highly crucial to prevent bias and strictly maintain response validity.

Phase 2: Expert Panel for Fuzzy-DEMATEL. Once the grassroots data was secured, the second phase shifted focus to system-level experts. The Fuzzy-DEMATEL method does not require a massive sample size. Instead, it demands deep, highly specialised knowledge to map out complex cause-and-effect relationships. Because of this, the expert panel was selected using a strict purposive expert sampling approach. A small, focused panel of 10 experts is widely accepted as the standard practice for structural mapping techniques like DEMATEL, provided the experts hold significant authority in the field. Additionally, the expert panel for the Fuzzy-DEMATEL analysis was deliberately restricted to 10 key grassroots representatives (association leaders and community group heads). Government officials and macro-policymakers were intentionally excluded to prevent the tendency for formal authorities to project idealised regulatory scenarios rather than operational realities. This exclusive reliance on knowledge gatekeepers, actors who actively navigate supply chain frictions daily, ensures that the generated causal maps reflect the actual, unvarnished structural bottlenecks of the rural forest-based bioeconomy from a strict bottom-up perspective.

Rather than pulling in theoretical academics or distant policymakers, this study deliberately formed an "Entrepreneurship Cluster" for the expert panel. The panel comprised exactly 10 key representatives, perfectly balanced between the two studied sectors. To capture the complex realities of the capital-intensive teak industry, the study brought in five seasoned insiders (Table *1*).

Table 1. List of Fuzzy-DEMATEL panellists

Entrepreneurship Cluster	List of Representatives
Teak Wood Furniture	4 committees of Indonesian Furniture and Craft Association for Jepara 1 committee Indonesian Teak Wood Entrepreneurs Association
Bamboo Crafts	5 business group leaders

Source: own.

To mitigate the inherent risks of personal bias and subjectivity within expert panels, this study utilised a Fuzzy logic approach. The mathematical algorithm of Fuzzy logic functions as a buffer; it accommodates the ambiguity of human linguistic assessments, balances varying perceptions, and prevents extreme individual opinions from skewing the final computation. Consequently, the resulting ecosystem maps represent an objective and mathematically sound structural consensus rather than a collection of subjective opinions.

The second research instrument utilised the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method. This questionnaire (see on ANNEX 2) specifically measured the causal relationships within the entrepreneurial ecosystem. This instrument also evaluated the ecosystem's impact on bioeconomic transformation elements. The questionnaire structure was systematically divided into two main matrix assessment sections. The assessment scale utilised a specific range from zero to four points. The number zero represented a complete absence of influence between two variables. The number four indicated a structurally very strong level of influence.

The questionnaire focused on cross-assessments among eight entrepreneurial ecosystem elements. These elements included government policy support and the availability of financial providers. Experts also evaluated geographical proximity and direct relations among industrial actors. The instrument examined the influence of pro-environmental consumer trends and local culture. Other elements covered specific human resource competencies and cross-sectoral coordination strategies. Collaborations with universities completed the ecosystem element list in this first section. Experts had to compare the reciprocal influence levels among all these ecosystem elements.

1.6 Data analysis

1.6.1 Partial Least Squares Structural Equation Modelling (PLS-SEM)

The operationalisation of data analysis in this study relies on the partial least squares structural equation modelling (PLS-SEM) algorithm. The choice of this variance-based estimation is not merely a technical preference but a methodological response to the model's complex and asymmetrical architecture. PLS-SEM offers tactical advantages in the form of high flexibility. This tool can accommodate various types of measurement scales without being constrained by rigid assumptions of normal distribution. It does not require strict multivariate normality, and its resilience to medium sample sizes makes it a methodologically consistent approach for predictive and exploratory purposes in the context of medium-sized samples in emerging economic landscapes (Hair et al., 2021; Sarstedt et al., 2024).

Because the research instrument was constructed in a hybrid manner, this algorithm was executed through a two-stage approach. This procedure explicitly separates the testing parameters between reflective constructs, in which indicators purely serve as manifestations of latent variables, and formative constructs, in which indicators act as their causal components. A comprehensive summary of the PLS-SEM evaluation matrix in this study is presented in Table *2*. The first stage was fully dedicated to verifying the integrity of the measurement model (outer model). In the reflective block, validation was conducted through three layers of stringent metrics.

Table 2. Evaluation Requirements of SEM-PLS Modelling

TEST	APPLICATION	REFERENCES
Indicator Reliability (Outer Loadings)	Low-loading items (<0,708) indicate poor measurement, review surveys	(Hair et al., 2014)
Internal Consistency (Cronbach's α, Composite Reliability)	If reliability < 0,7, revisit instrument design or item wording	(Hair et al., 2014)
Convergent Validity (AVE)	AVE < 0,5 implies weak construct, review item relevance	(Fornell & Larcker, 1981; Hair et al., 2014)
Collinearity (VIF)	High VIF (>5): eliminate overlapping indicators to improve clarity	(Chin, 1998; Hair et al., 2014)
Indicator Significance (Outer Weights)	t-stat ≥ 1,96 (p < 0,05) → signifies	(Hair et al., 2014; Sarstedt et al., 2016)

Absolute Relevance (Outer Loadings)	If the weight is not significant, outer loading (≥ 0,50)	(Hair et al., 2014)
Redundancy Analysis (Validity of Formative Constructs)	Correlation between formative constructs and single reflective constructs (global single items) ≥ 0,70	(Chin, 1998; Hair et al., 2021)
Structural Paths (t/p-values)	Path ($p < 0,05$) → signifies	(Hair et al., 2021)
Explained Variance (R^2)	High R^2 indicates strategic focus areas; low R^2 requires new variables	(Chin, 1998; Hair et al., 2021)
Effect Size (F^2)	• 0,02–0,14: Small effect; the variable contributes but is not the primary driver. • 0,15–0,34: Medium effect; the variable has a significant impact. List of Fuzzy-DEMATEL panellists and substantively significant impacts. • ≥0,35: Large Effect; this variable is the key driver in the model.	(Cohen, 2013)

Source: own, based on the references included.

First, internal consistency reliability was ensured through Cronbach's alpha and composite reliability (CR) values with a conventional threshold of > 0,70. Second, convergent validity was assessed through the attainment of outer loadings (> 0,70) and average variance extracted (AVE > 0,50). Third, discriminant validity was tested based on the latest heterotrait-monotrait ratio (HTMT) criterion. The HTMT threshold was set below 0,90, providing a strong indication that the constructs had adequate discriminant validity.

In contrast, the evaluation of the formative block employs entirely different logic. Instead of examining the correlations among indicators, the focus shifts to inspecting collinearity. The variance inflation factor (VIF) value must be below 5,0 to minimise the risk of excessive multicollinearity. This formative validity is subsequently confirmed by testing the significance of the outer weights to ascertain the absolute contribution of each indicator to its latent variable. Once the measurement model demonstrates sufficient evidence of validity and reliability, the anchor of the analysis shifts to the second stage: evaluation of the structural model (inner model). The model's predictive capacity is measured through the coefficient of determination (R^2), whereas the effect size (f^2) is used to track the specific magnitude of each pathway relationship. Considering the

nonparametric nature of PLS-SEM, drawing statistical conclusions regarding causality cannot refer to standard normal curves. Therefore, the significance of each path coefficient is determined through intensive bootstrapping procedures with 5,000 resampled subsamples. This mechanism allows for a more robust empirical estimation of parameter significance as the basis for the acceptance or rejection of hypotheses.

1.6.2 Fuzzy decision-making trial and evaluation laboratory

In addition to the structural testing of PLS-SEM, this study adopts a second analytical instrument, namely, the fuzzy decision-making trial and evaluation laboratory (Fuzzy-DEMATEL). This methodological choice was made specifically to dissect the cause-and-effect interdependencies within the entrepreneurial ecosystem. Theoretically, DEMATEL is designed to unravel configurations of problems that are mutually entangled (intertwined problem groups). Its main advantage lies in this algorithm's capacity to visualise the structure of causality through relational matrices and graphs, while simultaneously accommodating asymmetric feedback loops (Si et al., 2018).

Despite its strengths, the classic DEMATEL formulation has one inherent limitation. This method uses crisp numerical representations that do not explicitly accommodate linguistic ambiguity in expert assessments. However, evaluation metrics from expert informants in the investigation of business ecosystems and policy governance are almost always marked by ambiguity, information asymmetry, and subjective uncertainty. To neutralise this measurement bias, this study injects fuzzy set theory (Zadeh, 1978). This mathematical hybridisation gave rise to fuzzy-DEMATEL (, an algorithmic extension capable of quantifying ambiguous "linguistic variable" inputs. Instead of reducing experts' hesitancy to useless statistical noise, the fuzzy-based approach embraces this uncertainty as valid data. This mechanism allows for a more flexible representation of uncertainty in expert judgments than the conventional crisp approach, such that the probability of causality in the real world can be represented proportionally (Wu & Lee, 2006).

Ultimately, the conversion of these qualitative assessments facilitates the identification of the main driving factors (cause group) within the entrepreneurial ecosystem. Primary data were collected through in-depth interviews and a pairwise comparison matrix questionnaire. Experts were presented with linguistically formatted elicitation questions such as: "How much direct influence does criterion *i* have on criterion *j*?" Linguistic responses ranging from No Influence on Very High Influence

were then converted into a TFN semantic rating scale with lower, middle, and upper probability parameters (l, m, u). The transformation of linguistic data produces systematically quantified estimates of cause–and–effect relationship structures through a series of rigorous matrix algebra operations, as represented in the algorithm stages in Figure 3.

Phase 1. Construction of the Direct-Relation Matrix (Fuzzy Direct-Relation Matrix): After the experts' linguistic assessments are converted into the TFN scale, the first step is aggregation. Considering that the panel of experts consists of multiple actors, the experts' matrix assessments are aggregated using fuzzy arithmetic mean to form the Initial Direct-Relation Matrix ($\tilde{Z}$). This matrix maps the collective perception of the raw influence between criteria.

Phase 2. Normalised Fuzzy Direct-Relation Matrix: To ensure that the matrix can be calculated within asymptotic limitations, $\tilde{Z}$ denormalized into a matrix $\tilde{X}$. This normalisation process is carried out by dividing each element of the matrix by the maximum upper bound probability value (u) from the sum of the rows or columns. This ensures that all elements of the matrix have values between 0 and 1.

Figure 3. Step of Fuzzy-DEMATEL Method

Source: Adapted from Lin & Wu, 2008; Luthra et al., 2017; Opricovic & Tzeng, 2003

Phase 3. Fuzzy Total-Relation Matrix: This is the core of the DEMATEL manoeuvre. The influence among criteria does not only occur directly (like the initial domino effect), but also continuously propagates through intermediary variables (indirect effects). The Total-Relation Matrix ($\tilde{T}$) is calculated using a Markovian series with the formula $\tilde{T} = \tilde{X}(I - \tilde{X})^{-1}$, where I, is the identity matrix. This matrix ($\tilde{T}$)captures the accumulation of all direct and indirect shocks within the ecosystem.

Phase 4. Defuzzification (Resolving Ambiguity): Since it is still in the form of a TFN interval, it must be brought back to absolute values (crisp values) to allow for

comparison. The defuzzification process in this study is performed using the Converting Fuzzy Data into Crisp Scores (CFCS) method, also known as the Centre of Area (CoA). This algorithm formulates the centroid of the fuzzy probability slice, producing the most representative absolute matrix score (T).

Phase 5. Extraction of Prominence and Relation (Ontological Separation): From the absolute matrix T, the total of each row (c, representing the total influence a variable exerts on the system) and the total of each column (r, representing the total influence a variable receives from the system) are calculated. Prominence ($c + r$) indicates the degree of centrality or the significance of a variable's role in orchestrating the overall ecosystem. Meanwhile, Relation ($c - r$) serves as the decisive scalpel for policymaking. If $c - r > 0$ the criterion is declared as Net-Cause (Trigger/Root Cause). However, if $c - r < 0$ the criterion is determined as Net-Effect (Effect/Symptom).

Phase 6. Network Relationship Map (NRM) Mapping: As the final step, the average value from the matrix is set as the threshold value (α). Values that exceed this threshold are visualised as arrows indicating causal flow in a Cartesian diagram, resulting in a Network Relationship Map (NRM). This map will later be overlaid with the IPMA matrix for the next stage.

1.6.3 Hybrid IPMA and Fuzzy-DEMATEL for Policy Positioning Matrix

The novelty of this research lies in integrating a methodology that synergistically combines the results of IPMA and fuzzy-DEMATEL to position factors for future bioeconomy policymaking. In parallel, fuzzy-DEMATEL analysis, particularly in assessing the influence and relational structure of entrepreneurial ecosystem factors, provides an analytical basis for identifying key drivers relevant to policy feasibility and readiness considerations (Si et al., 2018). Traditional policy evaluation tools are often too simplistic. They fail to capture complex interdependencies between ecosystem factors. The use of importance-performance map analysis (IPMA) based on partial least squares structural equation modelling (PLS-SEM) has been widely adopted as a tool for mapping strategic priorities in the context of PLS-SEM. IPMA offers precise spatial navigation by juxtaposing actual performance (X-axis) against structural urgency (Y-axis), resulting in intervention priority quadrants (Ringle & Sarstedt, 2016).

However, IPMA does not explicitly map reciprocal relationships between factors; therefore, its interpretation must be complemented by a systemic approach. In the asymmetrical reality of the entrepreneurial ecosystem, the assumption of independence can potentially lead policymakers into a diagnostic fallacy, i.e., treating indicators that appear critical in Quadrant I, even though they are merely "symptoms" of deeper structural issues elsewhere in the system. Aware of this ontological weakness, this study conducts a methodological hybridisation manoeuvre by combining the spatial coordinates of IPMA with the causal topology of the fuzzy-decision-making trial and evaluation laboratory (Fuzzy-DEMATEL). The fusion of these two instruments is inspired by trends in the MCDM literature, which have developed hybrid models to deepen analysis (Büyüközkan & Güleryüz, 2016; Kumar, 2025). Through this hybridisation, the IPMA quadrant, which is static in mapping the relative position of factors without modelling reciprocal interdependence, transforms into a dynamic multidimensional matrix.

While IPMA is tasked with detecting where the system is 'bleeding', Fuzzy-DEMATEL dissects the anatomy of why and how this 'bleeding' occurs through the separation of net-cause and net-effect variables. This hybrid architecture increases the chances of formulating more targeted and evidence-based policies. The main strength of this hybrid instrument also lies in the richness of its data architecture, which is extracted from two different epistemological poles. This fusion does not use a single data source but instead combines outputs from two computational engines. Spatial Coordinate Data (IPMA) are rooted in quantitative empiricism (large-N). This data is drawn from the results of PLS-SEM algorithm calculations. Performance values are extracted from rescaled latent variable scores (scale 0-100), whereas importance values are extracted from the unstandardised total effects between predictor latent variables and the target variable (bioeconomy transformation intentions). IPMA operates by extracting two absolute values: performance (empirical/actual performance from rescaled latent variable scores) represented on the abscissa (x-axis), and importance (structural weight/total predictive effect) on the ordinate (y-axis). The intersection of the mean values of both axes (x, y) creates a spatial demarcation that divides into four discrete quadrants (see Figure 4).

Through conceptual elaboration, the analysis does not stop at merely interpreting statistical parameters. This dissertation presents its final output in the form of a hybrid IPMA–DEMATEL, which is analytically reconstructed in a multi-dimensional matrix framework. This framework serves as a governance architecture resulting from the

measurable intersection between the resource-based view paradigm (Barney, 1991; Wernerfelt, 1984) and the foundation of classical operational efficiency (Slack, 1994). While the RBV is typically positioned as an instrument for allocating strategic assets at the micro-corporate level, this study deliberately adapts RBV logic for the context of resource allocation at the public policy level. This shift in scope transforms the mechanical interpretation of the matrix into a public regulatory navigation tool, useful as an aid in guiding public regulatory priorities. Through this hybrid perspective, the quadrant standards for evaluation are sharply redefined into four intervention priorities: quadrant I acts as the emergency locus and performance deficit (concentrate here), followed by quadrant II, which maps anchors of resilience and competitive advantage (keep up the good work). On the lower side, quadrant III isolates the stagnation zone and latent issues (low priority), culminating in quadrant IV, which functions to detect the redundancy zone and allocative inefficiency (possible overkill).

Figure 4. Framework of Hybrid IPMA-DEMATEL for Policy Positioning Matrix

Source: Adapted from (Barney, 1991; Slack, 1994; Wernerfelt, 1984)

Quadrant I: Concentrate Here (Zone of Urgency & Performance Deficit)

This quadrant represents the highest crisis zone within a policy. Indicators that fall into this area have immense importance as drivers of policy success yet realise highly inferior performance. In the discourse of institutional economics, the accumulation of variables in this zone confirms the occurrence of a "bottleneck" or structural pathology that blocks the flow of added value (Slack, 1994). Conceptually, Quadrant I demands appropriate managerial attention and intervention to prevent serious disruptions to a policy. Failure to address the performance deficits of these critical variables within Quadrant I will lead to long-term structural instability, undermining the fundamental viability of the bioeconomy transition

Quadrant II: Keep Up the Good Work (Anchor of Resilience & Competitive Advantage)

Located at the most ideal point of equilibrium, the variables residing in this quadrant demonstrate a high degree of influence (importance) and are simultaneously supported by excellent empirical performance (performance). The variables in this quadrant form a stable foundation that should be maintained to ensure the performance and sustainability of policy (Sarstedt et al., 2016). The policy prescription is protective and conservative, meaning that the country or policymakers do not need to undertake radical overhauls. The focus of governance in this zone is simply to maintain the investment trajectory and preserve momentum so that these instruments do not deteriorate and fall into Quadrant I.

Quadrant III: Low Priority (Stagnation Zone & Latent Issues)

Variables in this quadrant are characterised by a low level of structural importance and weak performance in the field. Although their performance is concerning, the weakness of indicators in this zone does not inflict significant damage on the ecosystem. Considering that the rationality of public policy is always limited by fiscal scarcity, interventions targeting variables in quadrant III should be carefully considered, given limited resources (Sever, 2014). Methodologically, indicators in this zone can be sufficiently demoted to latent issues that only require monitoring, without the need to allocate recovery resources in short-term work programs.

Quadrant IV: Possible Overkill (Redundancy & Allocative Inefficiency Zone)

This quadrant reveals the most ironic anomalies in governance, which often escape the notice of conventional technocrats. Indicators in this zone display outstanding performance, even though their structural weight or contribution (importance) to the target variable is very marginal. The presence of variables in quadrant IV indicates that the resources allocated to these variables should be re-evaluated to ensure allocation efficiency in policy (Martilla & James, 1977). The recommended actions for this zone are asymmetrical and radical. One option is to implement a divestment policy. Resources (whether time, effort, or funds) that are excessively channelled into quadrant IV must be decisively cut and reallocated to inject support into the instruments that are struggling in quadrant I.

This hybrid analysis procedure begins by plotting all evaluated factors and indicators, both at the structural level and at the indicator level, onto a Cartesian diagram. The Performance values from PLS-SEM are plotted on the X-axis (abscissa), while the Importance values are plotted on the Y-axis (ordinate). The intersection of the average values of both axes (x, y) is used to divide the space into four quadrants (Q1: Concentrate Here, Q2: Keep Up, Q3: Low Priority, Q4: Possible Overkill). Specifically for the Entrepreneurial Ecosystem (EES) indicator, which serves as the core during the transition period, this indicator is injected with two new lifelines based on the results of the Fuzzy-DEMATEL calculation. The Causality Relation Data (Fuzzy-DEMATEL) is rooted in qualitative-heuristic elicitation from the panellists. This data consists of the Prominence ($c + r$) and Relation ($c - r$) values generated from the defuzzification matrix (T), which represents the flow of power and the dominance of influence among the indicators.

After the spatial coordinate points are established, these indicators are injected with two new values derived from the fuzzy DEMATEL calculation. The size of each coordinate point is calibrated proportionally based on the prominence value ($c+r$). The larger the point, the more dominant the variable is in orchestrating the ecosystem. The coordinate points are coloured according to the relation value ($c-r$). If $c-r>0$, the point is coloured red to indicate its status as a net cause (root cause/trigger). Conversely, if $c-r<0$, the point is coloured blue to signify it as a net effect (symptom/receiver of consequence).

In this final stage, the results synthesised from both analytical techniques are integrated into the calibrated spatial architecture. These results are then overlaid with the Network Relationship Map (NRM) to uncover the routes of causal transmission that have been operating behind the scenes of the ecosystem. By evaluating the absolute relation

matrix (T) against the threshold value (α), inter-variable interactions that exceed statistical limitations are projected in the form of directional arrows that consistently originate from the Net-Cause indicator and land on the Net-Effect indicator. This constellation of causal relationships then leads the model to the stage of formulating asymmetric policies through the execution of cross-examination. The hybrid matrix rigidly dictates that policy makers are instructed to prioritise pure interventions on indicators located in Quadrant I (or control variables in other quadrants) that have Net-Cause status (Red) and emit bold NRM arrows.

1.7 Quality of the Research

To minimise the potential for statistical artefacts and subjective distortion, the testing architecture is governed by a series of layered quality protocols (research rigour). Given that this study is based on a hybrid methodological framework, the quality parameters are not merely reduced to positivistic metrics, but rather, the validity framework is broadened to capture the model's resilience to conceptual and interpretive biases.

In the quantitative trajectory (Partial least squares structural equation modelling), the latent threat of common method bias (CMB), a pathology in which variance is triggered more by the measurement instrument than by its theoretical construct, is preventively mitigated (Podsakoff et al., 2012). Procedurally, the survey instruments are designed to conceal causal links between variables from respondents and to ensure absolute anonymity to suppress social desirability bias among teak and bamboo business actors (Podsakoff et al., 2003). Furthermore, statistically, structural integrity is evaluated using the heterotrait-monotrait ratio (HTMT) matrix (Henseler et al., 2015) and the variance inflation factor (VIF) to ensure that the model is free from overlapping multicollinearity (Hair et al., 2019), which could mislead parameter estimation if left unchecked.

Meanwhile, in the trajectory of deconstructing the entrepreneurial ecosystem (fuzzy-DEMATEL), quality parameters have shifted to cognitive robustness. Because this instrument relies on expert justification, the greatest threat is subjective bias and the dominance of a single opinion. This risk is neutralised through two layers of protection. First, epistemically, the panel is limited only to knowledge gatekeepers (associations and heads of community groups) who possess the lowest information asymmetry regarding field realities. Second, mathematically, the injection of fuzzy logic serves as a shock

absorber; it absorbs human linguistic ambiguity and helps dampen the potential distortion from the extreme judgment of a single expert, resulting in a more stable equilibrium in the relational matrix (Si et al., 2018; Wu & Lee, 2007).

As the culmination of this rigour, the study employs a hybrid design as a form of methodological triangulation (Creswell & Plano Clark, 2017) so that the estimations from SEM and the fuzzy-DEMATEL interdependence map validate one another. This convergence strengthens confidence in the findings of the policy positioning matrix and supports interpretations that are academically accountable.

2 THEORETICAL FOUNDATIONS AND CONCEPTUAL FRAMEWORK OF FOREST-BASED BIOECONOMY TRANSITION

2.1 Scientific landscape for the forest-based bioeconomy in rural areas

This research began with the development of a comprehensive conceptual framework regarding the transition to a forest bioeconomy through a synthesis of global literature. In this initial phase, the study focused on evaluating three main, interrelated pillars: entrepreneurship, technological innovation, and the resilience of socio-ecological systems. This theoretical exploration was specifically designed to validate the extent to which the fundamental premises of these three pillars hold when confronted with empirical conditions in rural areas. To build this literature foundation, a systematic search was conducted. The search focused on databases by applying the following query: TITLE-ABS-KEY ((forest OR forestry OR forest-based) AND (bioeconomy OR bioeconomics) AND (rural)) AND PUBYEAR > 2012 AND PUBYEAR < 2026. Using these parameters, 84 scientific publications from various types of documents published between 2013 and 2025 were identified in Scopus.

The development pattern of these publications shows that the forest-based bioeconomy is emerging as a global research field with an increasingly strong scientific foundation and broad disciplinary scope. The trend of increasing publications and cross-country engagement indicates a paradigm shift toward sustainable rural development based on biological resources, while also opening opportunities for international collaboration and the exploration of local contexts in developing countries.

As shown in Figure 5, there has been a significant increase in research publication trends on forest-based bioeconomy in rural areas over the past decade. The annual graph displays a sharp rise in the number of documents starting in 2018, reaching its peak in 2023 with more than 15 publications. This increase suggests that the topic of bioeconomy, especially related to forest resources and rural development, is receiving greater attention from academics and policymakers as the urgency of sustainability issues and the transition toward a green economy grows.

The distribution of publications by journal source shows that articles on this topic are spread across several leading journals, such as Forests, Land, Energies, Forest Policy and Economics, and European Biomass Conference and Exhibition Proceedings. The dominance of these journals illustrates that research on forest-based bioeconomy is interdisciplinary, involving the fields of renewable energy, forest policy, and natural

resource economics. This further reinforces the interdisciplinary nature of bioeconomy, which not only focuses on the production aspect of biomass but also on resource governance and public policy.

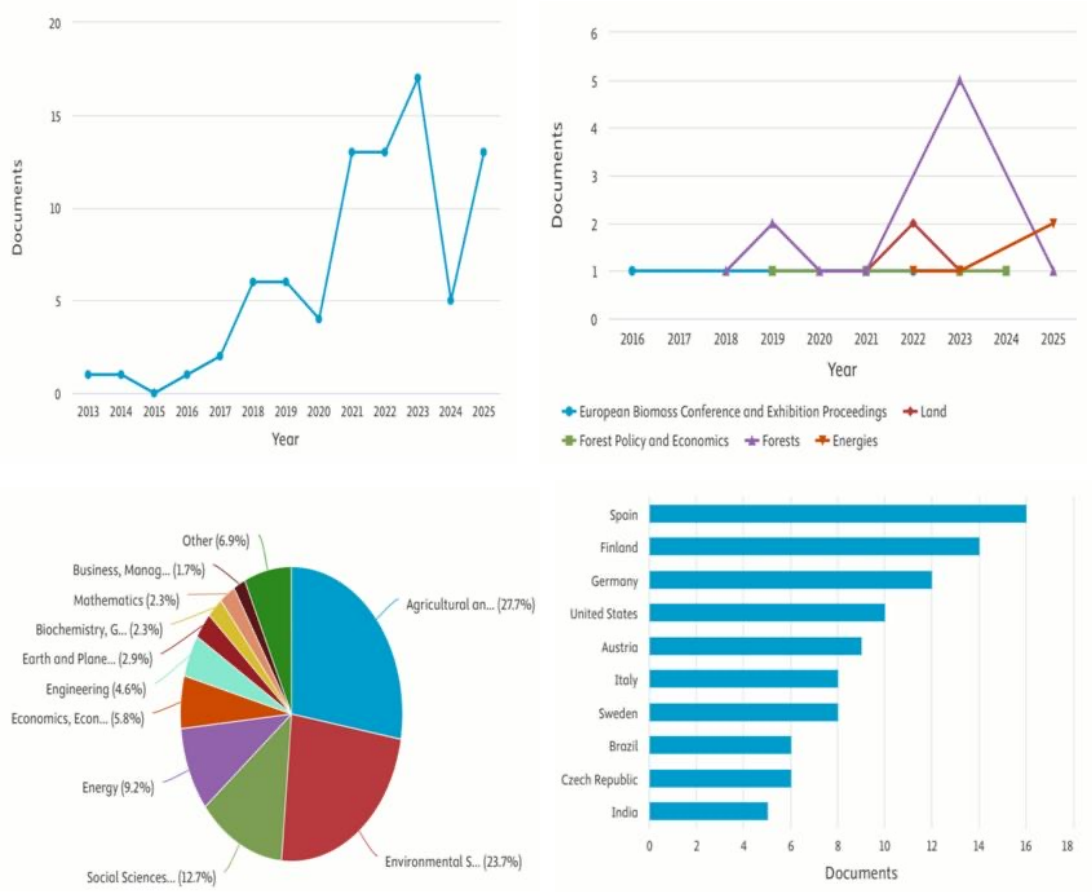


Figure 5. Mapping the Research Landscape of Forest-Based Bioeconomy in Rural Areas

Source: Scopus Analysis

Analysing the circular diagram from a scientific discipline perspective reveals that research predominantly focuses on agriculture and life sciences (27,7%) and environmental sciences (23,7%). These are followed by contributions from the social sciences (12,7%) and the energy sector (9,2%). This distribution confirms that the forestry-based bioeconomy is developing as a research area that integrates ecological, technological, and social approaches. The involvement of economics, engineering, and policy sciences also indicates a shift in research from a purely biological focus to a systemic approach that considers value chains and their socio-ecological impacts.

Furthermore, the distribution of publications by country shows that Spain, Finland, and Germany are the top three countries contributing to scientific publications

on this topic, followed by the United States, Austria, and Italy. The dominance of European countries reflects the progress in implementing bioeconomy policies in the region, where forest resource management strategies and bioindustry innovations have been integrated into rural development policies. The involvement of non-European countries, such as Brazil and India, demonstrates that interest in forestry-based bioeconomies is beginning to grow in tropical regions, although it is still at an early stage.

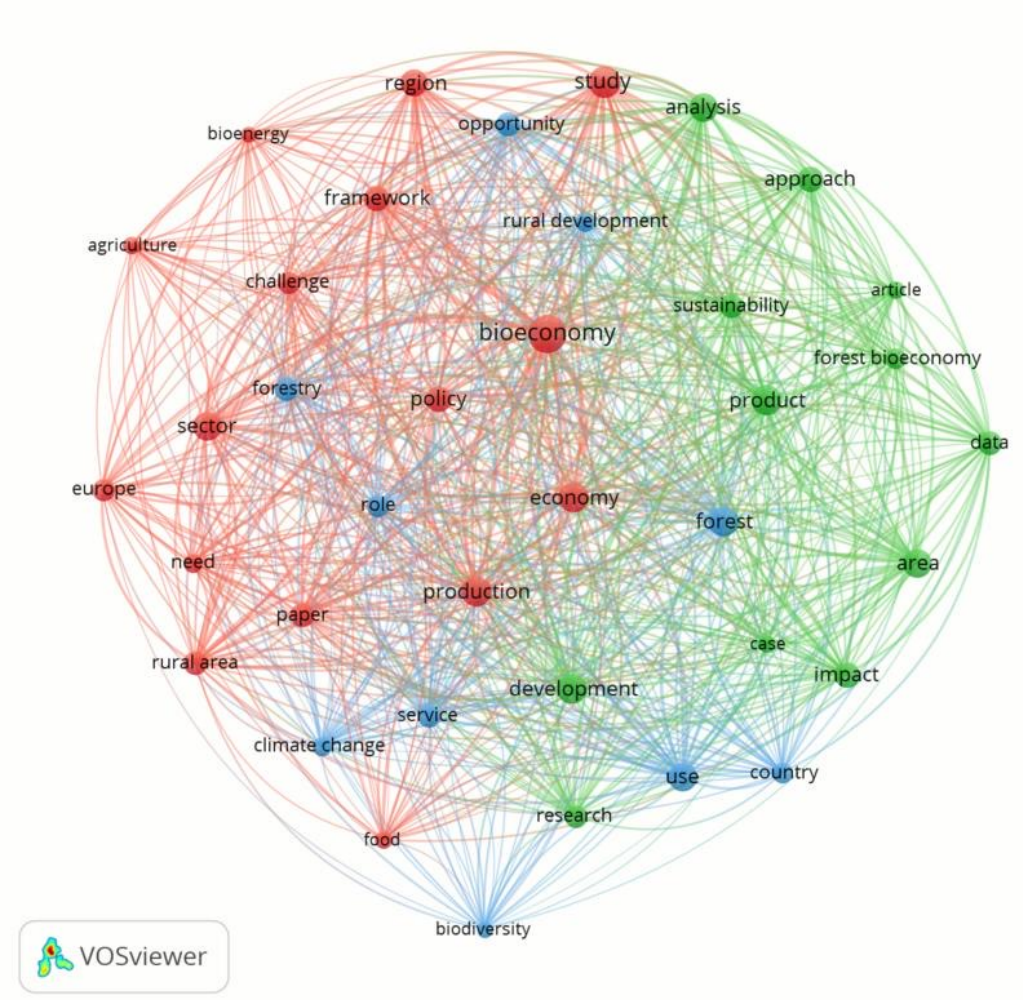


Figure 6. Co-occurrence Output by VOSviewer

Source: Own

Bibliometric analysis using VOSviewer (Figure 6) produces a keyword co-occurrence map that illustrates the thematic landscape and interconnections between concepts in research on forest-based bioeconomy and rural development. This visualisation reveals three main clusters, represented by red, green, and blue, which collectively indicate the multidimensional nature of the bioeconomy discourse. The red

cluster centres around keywords such as bioeconomy, policy, rural development, agriculture, and forestry, reflecting a focus on public policy and regional economic transformation. Studies in this cluster highlight how national and regional policies, particularly in Europe, drive rural economic diversification through the development of bio-based sectors and identify various institutional challenges and governance mechanisms needed to support a sustainable bioeconomy transition.

Meanwhile, the green cluster, comprising keywords such as sustainability, forest bioeconomy, product, impact, and approach, emphasises the technological and environmental innovation dimensions of the forest-based bioeconomy. This cluster demonstrates growing attention toward the sustainable use of forest resources, the application of circular economy principles, and the development of high-value forest-based products. This focus aligns with the dimensions of technology management and innovation within the conceptual framework of the research.

In contrast, although the blue cluster is smaller, it focuses on keywords such as biodiversity, climate change, and ecosystem services, which reflect the ecological foundations of the bioeconomy and its relationship to environmental conservation, climate adaptation, and socio-ecological resilience. The keyword bioeconomy occupies a central position, connecting these three clusters and signalling its role as an integrative concept bridging economic, technological, and ecological dimensions. These cross-cluster linkages affirm that the forest-based bioeconomy is interdisciplinary, and its success requires the alignment of policy innovation, technological advancement, and ecosystem sustainability.

Overall, the results of this bibliometric visualisation show that research on the forest-based bioeconomy has evolved toward a more integrated understanding of how policy, innovation, and ecology collectively contribute to sustainable rural transformation. However, the dominance of policy and economic themes also indicates that social aspects and local governance remain relatively underexplored, thus opening opportunities for further research to examine the roles of rural entrepreneurship and social capital in operationalising the concept of forest-based bioeconomy at the community level.

2.2 Rural economic development in the context of bioeconomy transition

Historically, rural economic development has relied heavily on extracting primary natural resources. This extraction primarily involves agriculture, forestry, fisheries, and

small-scale mining. In classical economics, this dependence often triggers overexploitation that threatens the rural ecology. The Natural Resource-Based View (NRBV) theory by Hart (1995) shifts this traditional paradigm. This theory asserts that long-term economic success depends on preserving the natural environment.

In practice, rural economies can apply NRBV principles by integrating into the bioeconomy sector (D'Amato et al., 2017). The bioeconomy provides practical tools to prevent pollution, maintain product stewardship, and develop villages sustainably. For example, villages can re-engineer biomass waste into circular raw materials with renewed utility. They can also create high-value bio-based products as sustainable substitutes (Maciejczak, 2015).

The bioeconomic transition aims to replace fossil-based resources with renewable biological materials for food, feed, energy, chemicals, and materials, which inherently involves rural areas as sources of biomass and sites where processing takes place (Golberg et al., 2016). This transition offers new economic opportunities for rural regions by fostering innovation, creating jobs, and developing more sustainable production systems in line with development goals (McClay & Sellare, 2025). However, the shift toward a bioeconomy can also present challenges for rural development. The dominance of large agribusiness companies may limit the benefits to smallholders and local biodiversity, as seen in Brazil, where bioeconomic policies have exacerbated existing social and environmental inequalities, even though the transition is framed as an effort to promote local development (Bastos Lima, 2021). In addition, a lack of stakeholder engagement and normative understanding of bioeconomy policy risks undermines the broader economic benefits for rural areas (Bogner & Dahlke, 2022). This transition requires investment in energy-efficient biotechnology and collaborative networks, particularly in rural bioclusters, which can drive regional innovation and job creation in line with the principles of a sustainable bioeconomy (Golberg et al., 2016; Hermans, 2018).

Local biological resources provide fundamental assets for bio-based industries in rural areas. The use of these natural biological resources can enhance sustainability, employment opportunities, output, and household income at the regional level, demonstrating the benefits of tailoring bioeconomy development strategies to local potential (Jurga et al., 2021). In the context of a forest-based bioeconomy, forests and non-timber forest products (NTFPs) in rural areas not only offer biodiversity and ecological benefits but also provide substantial income and employment sources for local communities when well-managed and properly integrated into bioeconomy value chains

(Peerzada et al., 2021). Research in Indonesia has demonstrated that utilising local biological resources can increase community income, empower women, develop entrepreneurship, and promote economic sustainability and independence (Nurlila et al., 2022). When effectively identified, optimised, and managed with community involvement and stakeholder collaboration, local resources are fundamental to driving sustainable rural economic development (Dhewanto et al., 2020).

However, the transition to a bioeconomy is not merely a technical or resource issue; social capital also plays a determining role. The importance of social capital in rural economic development during the bioeconomy transition can facilitate inclusive governance models and public–community partnerships (Hagemann et al., 2016). This social structure enables greater participation in bioresource value chains, enhances the sharing of benefits, and addresses governance barriers that may hinder rural development (Peerzada et al., 2021). Moreover, transitioning to a bioeconomy by merely replacing fossil-based resources with bioresources is inadequate and may even result in ecological degradation or social inequality if local contexts and social dimensions are ignored (Gawel et al., 2019; Nifatova et al., 2024). A regional bioeconomy that integrates local resources and leverages social capital can achieve more sustainable and inclusive outcomes by adapting innovations to local needs, promoting cross-sectoral collaboration, and embedding circular processes (Albrecht et al., 2021; De Besi & Mccormick, 2015).

During the bioeconomy transition, consideration of social capital is a crucial foundation for rural economic development by strengthening cooperation, improving quality of life, creating new economic opportunities, and facilitating collective and sustainable management of resources (Prayitno et al., 2023). The close interconnection between land access and strong social capital can increase active community participation; social networks and trust can facilitate better negotiation, collective action, and informal governance related to land access issues, thereby reducing the erosion of social trust and cooperation among residents (Supari & Anton, 2022). The importance of social capital also serves as a key driver that strengthens innovation and business performance in the MSME sector, which in turn supports the sustainable development of the rural economy during the transition to a bioeconomy (Utomo & Wartini, 2023). Therefore, policies and initiatives should prioritise strengthening social capital to enhance participation, ensure fair benefit sharing, and drive innovation within rural bioeconomy systems, supporting a sustainable and resilient rural economy.

The synthesis of social capital reaches its culmination through the concept of embeddedness, as proposed by Mark Granovetter (1985). This theory postulates that economic actions taken by individuals or groups never occur in a completely rational vacuum but are always strongly attached to the surrounding structure of social relations (Granovetter, 1985). Further studies on governing the commons have demonstrated that grassroots communities can achieve effective governance without relying exclusively on state or market mechanisms, provided they are supported by a strong foundation of thick social capital (Ostrom, 1990).

2.3 Grand theory: socio-technical transitions

The discourse on the shift from extractive industry paradigms to a circular bioeconomy is inadequate if approached solely through the lens of neoclassical economics, which typically reduces innovation to an exogenous shock that reduces the cost curve. Rejecting such myopic technological determinism, this line of thought situates the sociotechnical transition perspective, particularly the multilevel perspective (MLP) framework, as its grand theory (Geels, 2002, 2011). This approach postulates that fundamental transformations in economic structures are not a linear replacement of mechanical production instruments, but rather an asymmetric coevolutionary process among institutional arrangements, societal culture, actor constellations, and technological artefacts (Markard et al., 2012; Smith et al., 2005). For developing countries, this theory provides a crucial epistemological foundation for analysing why capital injections and modern machinery often result in operational dissonance when they are not accompanied by the cultivation of resilient social institutions.

Ontologically, the MLP framework dissects transition dynamics into three analytical hierarchies that continuously collide and penetrate each other: the macro landscape (socio-technical landscape), the meso regime (socio-technical regime), and the micro-niche (niche innovations) (Schot & Kanger, 2018). In resource-based sectors, the regime represents the incumbent industrial structure that tends to be rigid and resistant to change, characterised by path dependency pathologies and the carbon lock-in effect, which traps businesses in the comfort of past extractive practices (Unruh, 2000). Systemic transitions toward a new bioeconomy can be accelerated when massive destabilisation pressures emerge from the macro landscape, such as the global climate crisis, demographic transitions, or tightening resource regulations, which then fracture the protective barriers of the regime. These fractures open a "window of opportunity" for

innovations at the niche level to break through and restructure the prevailing market hegemony (Geels, 2019).

The comparative advantage of this transition theory for institutional economic studies lies in its ability to unpack the "black box" of green infrastructure adoption failure. Referring to the expansion of recent sustainability theories (D'Amato et al., 2017; Köhler et al., 2019), technocratic innovation has proven unable to catalyse strategic transformation if it is not organically embedded within the socio-ecological mindset of the actors involved. Fundamentally, this thesis provides a theoretical rationale for empirical anomalies and the phenomenon of decoupling that often dictates the communal sector, where technological interventions are reduced merely to functional tools without triggering the crystallisation of a sustainability vision (Kivimaa & Kern, 2015). Thus, the MLP framework justifies an essential shift in analysing transitions, moving from merely calculating output efficiency to exploring the causal architecture that weaves together institutional cohesion, ethical commitment, and machine capabilities. Ultimately, Socio-Technical Transition Theory offers a robust theoretical foundation to adjudicate the divergent trajectories between industrial structures with massive capitalisation on one hand, and subsistence economic entities governed by communal networks on the other. Transition pathways are not a universal blueprint (Loorbach et al., 2017); capital-intensive regimes tend to respond to pressure through radical technological acquisitions to preserve profit margins, whereas subsistence entities require a reconfiguration of cultural values and communal mentality as the primary determinants of their existence.

The Multi-Level Perspective offers a critical lens through which to conceptualise institutional hysteresis, positing it as an inherent manifestation of the inertia characteristic of dominant industrial regimes. Within the orthodoxy of institutional economics, business actors' reluctance to switch to circular economy practices is often not caused by irrationality or a lack of managerial literacy, but rather by the grip of a rigid techno-institutional complex (Unruh, 2002). Incumbent regimes are frequently constrained by the accumulation of sunk costs in legacy mechanical infrastructure and in linear, exploitative supply chain networks. In an order locked in by this path dependency, rigid quota regulations often reinforce the protective demarcation walls of the old regime (Geels et al., 2016). Through the lens of the MLP, the scarcity of physical resources and regulatory pressures operate as proxies for landscape pressure that disrupts the status quo. When such scarcity triggers a profitability crisis, the conventional industrial regime may

be compelled to open itself to adoption, not out of altruistic awareness, but as a pragmatic rationale for survival (scarcity-induced disruption).

Moreover, although the MLP framework is often criticised for its structuralist bias, which seems to reduce the role of individual agency (Smith et al., 2005), sharpening this theory within the micro-communal economic landscape revitalises the strategic position of local actors. Rural economic transition is not a mechanical equilibrium that moves on autopilot as capital enters, but rather a teleological (goal-oriented) manoeuvre that demands the orchestration of strategic agency by its actors (Farla et al., 2012). At this crossroads, the accumulation of social capital has the most essential epistemological relevance. Mechanical solidarity, reciprocity, and trust at the grassroots community level are not merely sociological residues of rural life, but act as the fundamental glue that translates macro pressures into collective action. Transition theory posits that the fusion of new technological artefacts and sustainability visions is more likely to crystallise when local agency proactively renegotiates old norms. In other words, the intent for transformation is not simply an algorithmic derivative of the existing business ecosystem, but rather a proclamation of the cognitive sovereignty of business actors to redesign their own socio-technical configurations.

The application of MLP in the context of developing countries (the Global South) necessitates the adoption of spatial dimensions, which are often absent in classic Western transition narratives. The discourse on the geography of sustainability transitions (Coenen et al., 2012; Truffer et al., 2015) postulates that innovation at the niche level is highly sensitive to spatial embeddedness or territorial attachment. Consequently, the divergence of transition trajectories among commodity entities frequently observed in the field is an empirical reflection of the postulate that bioeconomy transitions are highly contextual in spatial terms (spatially bounded). The architecture of this sociotechnical transition theory elegantly seals the argument that there is no single panacea or universal blueprint in policy architecture. Each industrial entity raises its own transition recipe that must be calibrated according to the anatomy of its regime and local cultural resilience.

Contextualising the MLP framework within the bioeconomy discourse reveals the complexity of transitions that go beyond mere material substitution. The shift toward a circular bio-based economy is not a matter of replacing production inputs on the same assembly line, but rather a radical deconstruction of the techno-economic architecture that has long supported the extractive regime. Recent literature on bioeconomy transitions (Bugge et al., 2016; Vivien et al., 2019) postulates that niche innovations in this sector

must contend with the hegemony of the fossil regime and linear economy, both of which have become deeply entrenched in market infrastructure, consumer preferences, and state regulations. Therefore, from the perspective of sociotechnical transitions, the bioeconomy is positioned not as a single, standalone technology, but rather as a constellation of emerging regimes that demand a re-engineering of value chain architecture, spanning from upstream biomass supply to downstream consumption of sustainable products.

The anatomy of the bioeconomy has highly essential spatial implications, which methodologically compel the MLP theory to recalibrate its locus of analysis toward peripheral or rural regions. Unlike renewable energy transitions or digitalisation, which often concentrate in urban areas. The gravitational centre of the bioeconomy is inherently rooted in rural landscapes as the primary providers of biological resources. However, without adequate niche shielding, this transition is vulnerable to slipping into the pathology of neo-extractivism, where rural actors are merely reduced to suppliers of raw biomass for large-scale downstream industrial regimes (Bauer, 2018). Through the lens of socio-technical transitions, a just bioeconomy requires the comprehensive strengthening of grassroots capacities, enabling local entities to restructure supply chain hierarchies and retain value capture within their territorial regions. This crucial process demands the emergence of innovations that are not only technology-instrumental in nature but also encompass the hybridisation of institutional governance and business rationalities in harmony with ecosystem carrying capacities.

At a more macro level of abstraction, the transformation toward a bioeconomy escalates the MLP framework from a single-regime transition model to an analysis of multi-regime interactions. The commodification of biological resources, which emphasises sustainability principles, inevitably leads to both friction and convergence among the forestry, agriculture, energy, and manufacturing regimes, which have historically operated within separate sectoral silos. Interactions between subsystems in sociotechnical transitions generate nonlinear dynamics that cannot be reduced to simple cause-and-effect relationships (Papachristos et al., 2013). Meanwhile, the expansion of the bioeconomy remains constrained by biophysical and metabolic limits (Giampietro, 2019); therefore, the narrative of multi-regime interaction cannot be separated from the material boundaries of ecological systems. In this overlapping institutional landscape, niche innovation is faced with the imperative to possess resilience to navigate the complex pressures from various regimes simultaneously. This conceptualisation elegantly asserts that the obstacles are often not solely due to weaknesses in biological technology but

more frequently stem from systemic inertia, particularly when various incumbent regimes fail to synchronise their institutional orientations. This layered theoretical understanding provides the foundation to justify why orchestration among technological capabilities, social capital, and institutional resilience is an indispensable prerequisite for breaking the deadlock in the bioeconomy trajectory.

2.4 Entrepreneurial ecosystems

The crystallisation of the interaction between macro-institutional structures and micro-level social capital networks materialises in what is conceptualised by contemporary strategic management literature as the entrepreneurial ecosystem (Isenberg, 2010; Stam, 2015). This concept emerged as a further elaboration of industry cluster theory (Porter, 1990). Whereas classic cluster theory focuses on the configuration of industry structures and the role of public policy in shaping economic agglomeration, the entrepreneurial ecosystem approach broadens the analytical ontology by placing entrepreneurial actors, social networks, and knowledge dynamics at the centre of regional economic value creation. Reversing that analytical ontology, the entrepreneurial ecosystem paradigm positions entrepreneurial agents at the centre of equilibrium, while institutions and social capital serve as its supporting architecture. In this framework, the ecosystem is no longer understood merely as a geographic agglomeration of static material supply chains, but rather as a dynamic biotic-economic community that facilitates the discovery, exploitation, and commercialisation of innovation.

Morphologically, (Spigel, 2017) and (Stam, 2015) dissect the anatomy of entrepreneurial ecosystems into interlocking relational attributes. A functional ecosystem relies on the precise coexistence between foundational framework conditions, such as formal regulations, physical infrastructure, and local traditions, as well as systemic conditions, including knowledge networks, financial support, and leadership. The theoretical significance of this analysis lies in the postulate of interdependence: the availability of one foundational element, such as an injection of capital or technology from outside, will never be able to stimulate transformative business manoeuvres if other elements, like a culture of risk tolerance or a foundation of communal trust, are absent. Through this lens, the transitional performance of an industrial entity cannot be explained in isolation solely by its internal capabilities; rather, it is a direct function of the thickness and fluidity of interactions within the institutional ecosystem that encompasses it.

A deeper excavation of this ecosystem theory demands precise spatial calibration (Autio et al., 2018). In rural landscapes that depend on natural resources, business ecosystems do not operate like digital innovation hubs in boundless urban areas. On the contrary, this supporting architecture must be organically embedded within the structure of local social hierarchies and biophysical boundaries. This theory provides a sharp rational foundation for dissecting why top-down institutional interventions often fail to translate into strategic capabilities at the grassroots level if they do not evolve mutually alongside the embryo of local social capital.

The functionality of entrepreneurial ecosystems can be conceptualised as a series of interlinked actors and mechanisms, often characterised by collective action among various stakeholders such as entrepreneurs, investors, universities, governments, and support organisations. These ecosystems are organised not through top-down or purely bottom-up approaches but through horizontal networks aiming to provide entrepreneurs with critical resources and support as they advance their ventures (Hruskova, 2024).

In economic studies, EE emphasises the importance of regional context in supporting the stability and dynamics of entrepreneurial activities that impact local economic development. This concept adopts an analogy from forest ecosystems, where the focus is not only on entrepreneurs or individual companies, but also on changes and the stability of the overall regional socio-economic system, which becomes the main unit of analysis (O'Connor and Audretsch, 2022).

Placing bioeconomy discourse within the entrepreneurial ecosystem reveals that the transition toward biological circularity is not merely a matter of substituting technical materials but represents a paradigm shift in the rules of the game. Rooted in the understanding of the inevitability of the laws of entropy in economic processes (Georgescu-Roegen, 1971), the bioeconomy demands a radical overhaul of market incentive structures that have long devalued nature's regenerative capacity. For centuries, the linear fossil-based economy has created a techno-institutional lock-in—a pseudo-equilibrium in which regulations, subsidies, and market infrastructure asymmetrically favour conventional extractive practices. Therefore, the institutionalisation of the bioeconomy requires the deconstruction of property rights architecture, the standardisation of ecological value metrics, and the development of new incentive schemes to reduce the inherently high transaction costs of tracking sustainable supply chains (D'Amato et al., 2019). From this institutional perspective, the failure or slow adoption of bioeconomy practices often occurs not because of a technological deficit at

the industrial level, but due to the rigidity of formal institutions that are ill-prepared to respond to the complexities of biomass governance.

At the lowest point, unlike conventional industrial commodities, which are centralised, the bioeconomy value chain is highly decentralised and relies on community-scale landscape governance. The framework of polycentric governance affirms that the management of biological resources is highly vulnerable to the tragedy of the commons if it is not safeguarded by social capital manifested in deep-rooted sanctions and reciprocity (Ostrom, 2010). In the equilibrium of the bioeconomy transition, social capital operates as an invisible infrastructure. This relational infrastructure facilitates the transfer of vernacular knowledge, reduces monitoring costs over forest exploitation, and ensures collective compliance with the boundaries of natural regeneration without requiring coercive intervention from the state apparatus (Adler & Kwon, 2002; Pülzl et al., 2014).

However, this dissertation moves beyond the objective inventory of ecosystem components. Following the cognitive perspective in entrepreneurship (Spigel, 2017), it is argued that the functional impact of an ecosystem is primarily dictated by how it is experienced by the actors. Therefore, the Entrepreneurial Ecosystem (EES) in this study is operationalised as 'Perceived Ecosystem Conduciveness.' This approach captures the entrepreneurs' holistic evaluation of their support environment, aligning with the reflective measurement model used in the subsequent analysis, where various indicators from policy to culture are expected to co-vary as they reflect a single underlying perception of systemic support.

2.5 Theory of planned behaviour in sustainability

Completing the analytical architecture from the macrostructural level to micro-foundations, the discourse on economic transition cannot disregard the crucial role of agent cognition at the grassroots level. Challenging the orthodoxy of instrumental rationality in neoclassical thought, which positions business actors merely as utility-maximising calculation machines (*homo economicus*), the theory of planned behaviour (TPB) is introduced into the theoretical arena as the primary explanatory instrument (Ajzen, 1991). According to its postulates, TPB articulates those human actions, when deliberated, are generally mediated by behavioural intention, which, in the TPB framework, is viewed as the primary proximal predictor of actual behaviour. This intention is conceptualised as the aggregate function of three cognitive determinants: attitude toward the behaviour, subjective norms, and perceived behavioural control. The

epistemological adoption of TPB provides a solid foundation for explaining an empirical anomaly: why two industrial entities operating under the same regulatory pressures and possessing identical capital access often respond to environmental disruptions with decisively divergent decision trajectories.

When the TPB matrix is extrapolated into the landscape of sustainability and the circular economy, this theory undergoes significant enrichment of its dimensions (Kuckertz & Wagner, 2009; Muñoz & Dimov, 2014). The shift from extractive business practices to bioeconomic rationality is not merely a trivial operational adjustment but rather a strategic transformation that demands a reorientation of values. In this context, the "attitude" dimension transforms into a representation of entrepreneurs' internalisation of environmental ethics. By contrast, "subjective norms" reflect the isomorphic pressures of the institutional ecosystem and the cohesion of surrounding social capital—a pressure that dictates conventions about what business practices are considered communally acceptable or taboo. Furthermore, "perceived behavioural control" manifests as the entrepreneurs' subjective assessment of their technological capacity, availability of material resources, and financial feasibility (Greaves et al., 2013). The integration of these three determinants unveils the "black box" of decision-making, showing that material abundance and the availability of supporting infrastructure will never crystallise into green innovation manoeuvres if the actors involved experience a deficit of normative and ecological conviction.

The use of "intention" as the main proxy for structural transformation in the economic sphere often sparks debate regarding the anomaly of the intention–behaviour gap. However, recent literature on entrepreneurship asserts that for large-scale strategic manoeuvres requiring massive resource allocation for supply chain restructuring or the adoption of environmentally friendly machinery, various empirical studies demonstrate that intention is a significant and consistent predictor of entrepreneurial and environmental behaviour (Kaiser et al., 2005; Kautonen et al., 2015). The intention to transform in the business realm is not a momentary sentiment but rather a teleological inevitability that has considered the risks of material scarcity and the probability of ecosystem intervention.

A deeper excavation into the architecture of TPB necessitates an epistemological intersection with behavioural economics literature. For centuries, mainstream economic postulates have relied on the axiom of agents who process information perfectly and mechanically (Thaler, 2000). However, Simon's (1955) conceptual contribution on

bounded rationality offers a fundamental critique of the assumption of perfect rationality in neoclassical economics. Simon postulated that human cognitive capacity inherently fails to grasp the full complexity of market information; instead of absolute optimisation, economic agents tend to make merely satisfactory decisions (satisficing) through mental shortcuts (heuristics). Within this framework, TPB provides an architectural framework to quantify these 'limitations of rationality.' The decision to change business strategic direction is no longer seen merely as the result of mathematical calculations over cost curves, but rather as the product of cognitive negotiation shaped by psychological perceptions and intentions.

This relationship becomes even stronger when we examine anomalies in decision-making under conditions of uncertainty (decisions under risk). Referring to Prospect Theory (Kahneman & Tversky, 1979). Humans as an Individuals are psychologically proven to be asymmetric in assessing risk. The pain of loss is felt much more intensely than the satisfaction of gaining an equivalent amount (loss aversion). This phenomenon gives rise to the status-quo bias, an irrational tendency in which economic actors choose to stick with conventional practices, even though transitional options offer objectively superior long-term returns (Samuelson & Zeckhauser, 1988). Through the lens of TPB, this psychological resistance is precisely captured in the dimension of “perceived behavioural control.” The low perceived behavioural control experienced by business actors is, in essence, a manifestation of escalating risk perception when they are faced with technological disruptions and business models that have not yet been proven communally.

Moreover, the integration of TPB into behavioural economics radically deconstructs the myth of extreme individualism. Recent literature proves that an individual's utility is not determined exclusively by the accumulation of personal wealth but is strongly calibrated by social comparison, a sense of fairness, and reciprocity within the group (Fehr & Schmidt, 1999). This thesis injects a very strong analytical spirit into the dimension of "subjective norms." Normative pressures from the surrounding ecosystem, be it industry associations, supplier networks, or local communities, operate as a choice architecture that frames rationality. Decisions to adopt sustainable production standards are often not driven by price incentives but rather by psychological impulses to avoid social sanctions or attain moral legitimacy.

Contextualising this analytical synthesis within the framework of bioeconomic equilibrium reveals a new layer of complexity. The transition toward a circular

bioeconomy inherently constitutes a case shrouded in radical uncertainty regarding future regulations, the viability of green technologies, and market acceptance (Zilberman et al., 2013). In this landscape fraught with ambiguity, bounded rationality prevails, and business actors in the forestry sector lack the capacity to accurately predict the efficiency curve of converting waste into value-added products. Instead of performing perfect optimisation calculations, their agency is driven by adaptive heuristics mediated through 'attitudes'. Cognitive evaluations of the bioeconomy transition are no longer reduced to net present value (NPV) projections but are calibrated by the belief that circularity is the only logical trajectory to avoid ecological extinction and business bankruptcy in the future.

The pathologies of status-quo bias and loss aversion offer a clear theoretical explanation for the sluggish adoption of bioeconomy practices in conventional industries. Shifting business models from linear extraction to circularity requires writing off sunk costs associated with outdated machinery and dismantling the old supply networks that have underpinned comfortable profitability. The psychological dread of these losses often weighs heavily on managerial rationality, directly eroding perceived behavioural control within the TPB framework. Industry actors frequently perceive the bioeconomy transition as a leap into a risk abyss that exceeds the bounds of their technical control (Shogren & Taylor, 2008). This reluctance underscores that dissonance in bioeconomic transformation is not a mathematical market failure but rather a cognitive failure.

At the communal territorial level, behavioural economics reveals subjective norms as a key catalyst in biomass governance. Unlike atomistic digital innovation, the bioeconomy relies on the supply of biological resources managed through shared ownership regimes. Therefore, social preferences, such as intergenerational justice and the fear of communal sanctions, dictate the calculation of individual preference (Cohen, 2013). This theoretical synthesis shows that the intention to transform toward a bioeconomy is strongly influenced by a combination of cognitive, normative, and institutional factors that shape the choice architecture of economic actors. The intention to transform toward a bioeconomy will never arise from a vacuum of calculative rationality but must be incubated through the engineering of a choice architecture that is simultaneously capable of reducing cognitive fears and stimulating pro-environmental moral pressure at the communal level.

While the integration of MLP, Entrepreneurial ecosystems, and TPB provides a robust theoretical foundation, it is imperative to empirically validate how these

conceptual dimensions have been globally discussed. Therefore, the following section maps the contemporary scientific landscape through a bibliometric analysis to pinpoint the exact theoretical gaps that this dissertation aims to fulfil.

2.6 An integration of theory: the multi-level perspective, entrepreneurial ecosystem, and theory of planned behaviour

The transition toward a bioeconomy in rural areas cannot be fully understood by exclusively examining government policies or isolating individual intentions. Therefore, the three theoretical lenses applied in this study, the Multi-Level Perspective (MLP), Social Capital within the Entrepreneurial Ecosystem, and the Theory of Planned Behaviour (TPB) are not treated as fragmented concepts. Instead, they are integrated into a cohesive causal pathway that moves from macro-structural pressures down to micro-level decision-making. Conceptually, this theoretical integration operates as a sequential mechanism.

The process is delineated into three distinct stages: First stage, Landscape Pressures as the Initial Catalyst (MLP Lens). The bioeconomy transition does not emerge spontaneously from rural communities. It is triggered by macro-landscape pressures, such as national regulations on timber legality, shifting global market trends toward sustainable products, or the looming threat of raw material scarcity (Geels, 2011; Schot & Kanger, 2018). Within this integrative framework, the MLP is employed specifically to identify the origins of these external forces. It is this macro-level pressure that compels the underlying local industrial structures—both the teak and bamboo sectors—to adapt or face the risk of market obsolescence.

Second stage, The Local Ecosystem as a Filter and Facilitator (Social Capital Lens). When macro-landscape pressures cascade to the rural level, they do not immediately impact individual entrepreneurs. These pressures are first filtered through the local entrepreneurial ecosystem (Stam, 2015). In rural areas, where formal government institutions are often absent or weak, informal ties embedded in Social Capital assume the primary governing role (Zellweger et al., 2018). This is where the theoretical intersection occurs. The local ecosystem determines whether the community can buffer macro pressures and facilitate its members, or if it will fail to adapt. The level of trust, the strength of association networks (such as HIMKI or APKJ), and the reciprocity among bamboo entrepreneurs are tangible resources that dictate a community's readiness for the sustainability transition.

Third stage, Shaping Individual Cognition and Decisions (TPB Lens). The final stage of this integration addresses a critical question: how do ecosystem conditions influence the entrepreneurial mindset? External factors and resource availability do not automatically alter business models; a psychological bridge is required. At this juncture, the TPB (Ajzen, 1991) is introduced to complete the logical sequence of the model.

Ecosystem conditions directly shape two central cognitive variables within the TPB. Through Subjective Norms, communal pressures and shared values within the ecosystem (social capital) dictate what is perceived as acceptable behaviour by the individual (Zehra & Usmani, 2021). If an association or a farming group begins to adopt sustainable practices, the individual experiences direct social pressure to conform. Then, Perceived Behavioural Control, access to information, financial capital, and communal protection foster a sense of capability. It allows individuals to feel they have actual control over the risks associated with the transition.

Through this sequential mechanism, the research framework effectively avoids the pitfall of theoretical stacking. This dissertation posits that macro-landscape pressures (MLP) compel the local entrepreneurial ecosystem to react. The subsequent interactions and social capital support within that ecosystem permeate the individual entrepreneur's cognition (TPB). This shapes their intentions and determines whether they execute actual bioeconomy innovations in the field. This highly linear causal pathway establishes a robust operational foundation for the empirical testing presented in the subsequent section.

2.7 Conceptual framework and formulation of hypotheses

As identified in the previous scientific landscape analysis (Section 2.1), current forest-based bioeconomy literature predominantly focuses on macro-level policies and technological eco-innovations. Consequently, the micro-dynamics of rural entrepreneurship, local governance, and social capital remain significantly underexplored. To bridge this theoretical gap, this dissertation constructs a comprehensive conceptual framework that shifts the analytical focus toward these neglected socio-economic dimensions.

Transitioning toward a sustainable forest-based bioeconomy in rural areas extends beyond commercial objectives. Economic shifts driven solely by profit, without calibrating to ecological carrying capacities, risk perpetuating resource extraction under the guise of sustainability (D'Amato et al., 2017; Fisher et al., 2017). A structural

alignment across multiple institutional levels is therefore required. Rather than treating policy, technology, and social structures as isolated variables, this study synthesises them into a single, operational framework.

As illustrated in Figure 7 this conceptual framework maps the bioeconomy transition from foundational grassroots inputs to global transformation outcomes. The architecture of this framework integrates three core developmental pillars: entrepreneurship (as the engine for value creation), technological innovation (for production efficiency), and socio-ecological resilience (to establish environmental boundaries).

At the base of the framework, rural economic development relies on two primary catalysts: local bioresources and social capital. These foundational elements feed directly into the central mechanism of entrepreneurship. To capture the complexity of this transition, the entrepreneurial core operates across three interconnected, nested dimensions:

- At the macro level, state interventions and sustainability pressures dictate the broader institutional environment. Progressive regulations and targeted investment support do not just exist on paper; they ensure that local entrepreneurial maneuvers align with global climate targets (Chatzinikolaou & Vlados, 2024; Warchold et al., 2025).
- At the meso level, the entrepreneurial ecosystem functions as a structural filter and facilitator. Micro-businesses cannot scale eco-innovations in isolation. These actors depend heavily on local value chains and communal social capital to commercialise new technologies and strengthen community resilience (Donner & De Vries, 2023; Kuckertz et al., 2020).
- At the micro level, these ecosystem dynamics shape the individual actor. Personal motivations, cognitive mindsets, and behavioural intentions ignite the initial push to transform biological resources into responsible, value-added products (De Schutter et al., 2019; Wilde & Hermans, 2021).

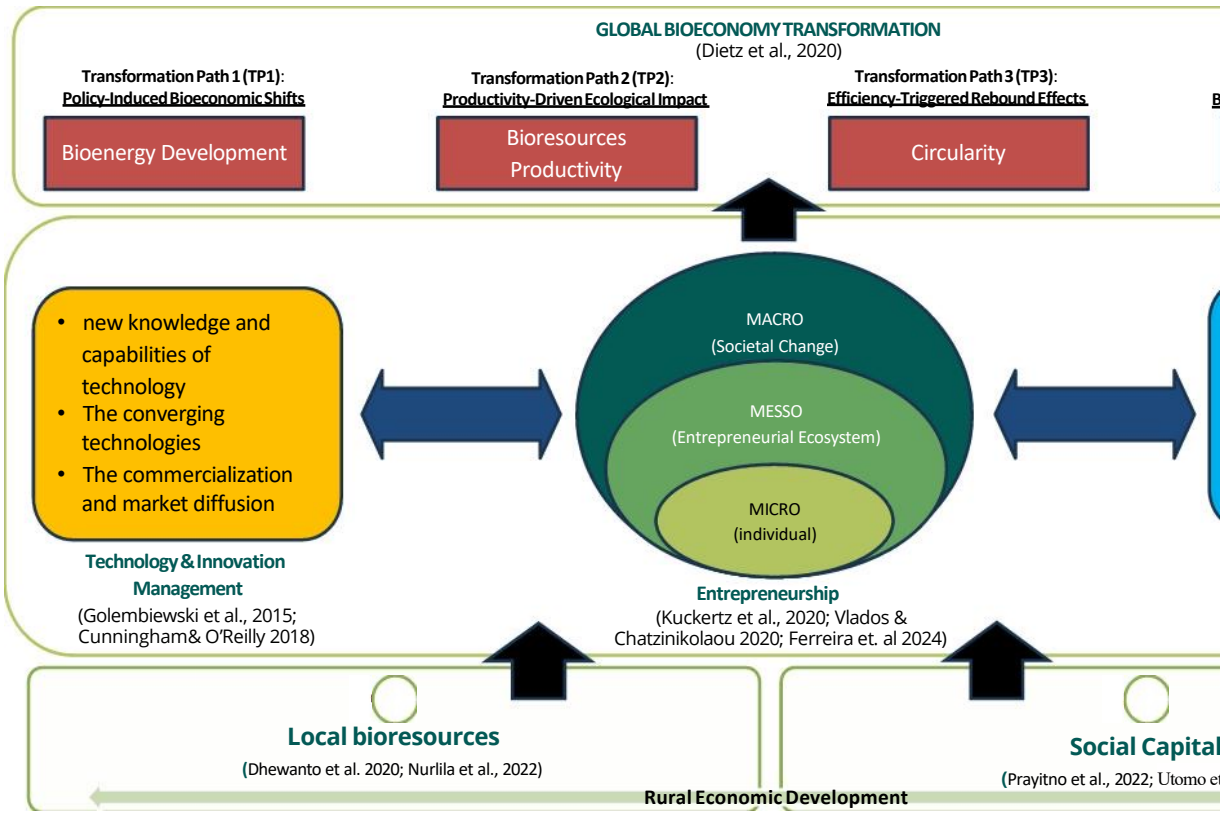


Figure 7. The Conceptual Framework

Source: own based on the sources cited.

Furthermore, this central entrepreneurial engine continuously interacts with two critical lateral pillars. On the operational side, Technology and Innovation Management supplies new knowledge and market diffusion. On the regulatory side, the Social-Ecological System enforces responsible production and governance boundaries.

As synthesised by Sebastian Hinderer and Andreas Kuckertz (2022), bioeconomy transitions involve multiple interconnected structural elements that shape the emergence of entrepreneurial opportunities. Rather than emerging from isolated policy or technological initiatives, these transformations tend to evolve through the interaction of institutional, technological, and resource-based dynamics. The combined development of these elements supports broader shifts toward bio-based economic systems. As depicted at the top of the framework, these transformations may unfold through several pathways (Dietz et al., 2018), including bioenergy development, bioresource productivity, circularity, and the development of advanced bio-based products.

To empirically test the structural dynamics within this conceptual framework, the study operationalises the model into seven specific hypotheses. The following subsections outline the theoretical rationale for each proposed relationship, systematically examining how technological adoption, social capital, and entrepreneurial intentions interact to drive the forest-based bioeconomy transition.

Operationalising the conceptual framework into an empirical model requires the integration of three main theories to map the bioeconomy transition pathways. Physical material availability constraints absolutely dictate the feasibility and production capacity of bioeconomy-based activities (O'Connor & Audretsch, 2022; Agnieray et al., 2021). Furthermore, community social cohesion crucially reduces structural barriers and transaction costs within rural environments (Grundel & Dahlström, 2016; Spigel & Harrison, 2017). Therefore, biomaterial sources and social capital are positioned as the fundamental exogenous variables forming the entrepreneurial ecosystem.

This structural model positions the entrepreneurial ecosystem as the central mediating mechanism based on the multi-level perspective (Geels, 2011; Schot & Kanger, 2018). Macro-structural pressures must be filtered by local ecosystems before they can influence individual actor decisions (Stam, 2015; Zellweger et al., 2018). Based on the theory of planned behaviour, these ecosystem conditions directly shape the cognitive and technical readiness of micro-entrepreneurs (Ajzen, 1991). The ecosystem facilitates sustainable technology adoption by partially lowering operational risk levels for rural businesses (Volkmann et al., 2019). Additionally, communal interactions instil

cultural legitimacy to gradually form a robust socio-ecological mentality among local actors (Zehra & Usmani, 2021). In this conceptual framework, the Entrepreneurial Ecosystem (EE) is operationalised as 'Perceived Ecosystem Conduciveness'. This reflects the entrepreneurs' holistic assessment of how supportive towards a sustainable bioeconomy.

The final testing phase isolates the predictive determinants triggering bioeconomic transformation intentions at the individual actor level. This model architecture systematically compares the practical effectiveness of two competing transformation strategies in the empirical field. The technocratic approach tests whether increased operational efficiency acts as a direct catalyst for behavioural change (Ha et al., 2023; Urmetzer et al., 2018). Conversely, the value-based approach asserts that genuine transformation requires a fundamental paradigm shift in cognitive awareness (Eversberg & Fritz, 2022; Segundo-Ortin, 2022). These two causal pathways ultimately determine how rural entrepreneurs commit to adopting absolute sustainability practices.

Translating the conceptual framework into an empirical model requires specific, directional causal pathways. Using Partial Least Squares Structural Equation Modelling (PLS-SEM), every conceptual block mapped in Figure 8 is operationalised as a measurable latent construct. Through this approach, the dynamics of the forest-based bioeconomy transition are distilled into seven operational hypotheses. The inner structural model positions the entrepreneurial ecosystem as the primary mediating mechanism. The hypothesis formulation unfolds across three analytical phases: anchoring the ecosystem in local endowments, tracing its technological and cognitive impacts, and comparing technological versus value-driven approaches to predict the entrepreneur's intention to transform.

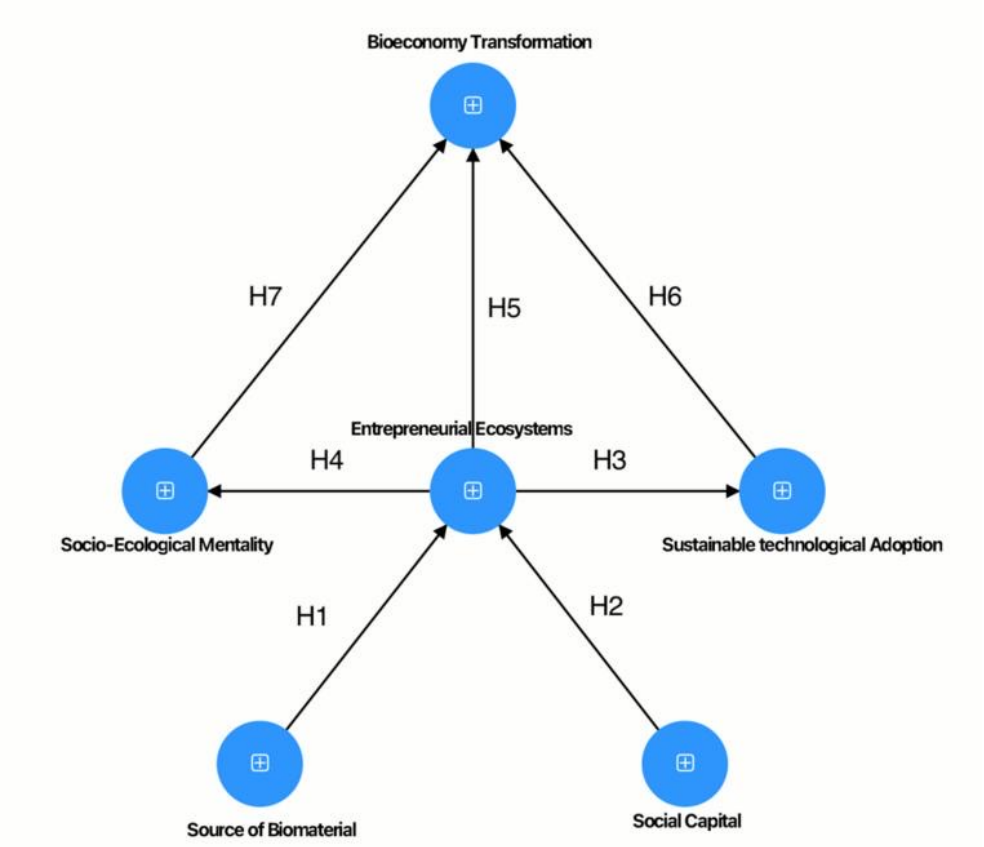


Figure 8. Forest-based Bioeconomy Transitions Model

Source: own.

Stage 1: Anchoring the ecosystem in local endowments. The initial phase tests a straightforward premise. Establishing a functional entrepreneurial ecosystem in rural settings, measured in this study through the entrepreneurs' holistic assessment of 'Perceived Ecosystem Conduciveness', relies heavily on physical limits and social cohesion.

H1: The Sources of biomaterial (SUB) positively influence the Entrepreneurial Ecosystem (EES). O'Connor and Audretsch (2022), alongside Agnieray et al. (2021) highlight a stark reality: stable natural resource supply dictates the absolute baseline of bio-based activities. The sheer source of biomaterials, be it teak or bamboo, defines the physical constraints of local production. This material baseline acts as the critical antecedent, allowing supplier networks and local craftsmen to emerge and function predictably. Consequently, this resource stability elevates the entrepreneurs' overall perception that their local business environment is highly supportive and conducive to growth.

H2: Social Capital (SCP) positive effect on the Entrepreneurial Ecosystem (EES). If biomaterials form the physical base, social capital provides the crucial relational glue. In rural environments where formal institutional backing remains notoriously weak, high levels of trust and social cohesion become mandatory. Drawing on Grundel and Dahlström (2016) and Spigel and Harrison (2017), community networks actively reduce transaction costs. This cohesion mobilises fragmented local resources, constructing a resilient ecosystem capable of collective action.

Stage 2: The bifurcated pathways of ecosystem impact. Once the ecosystem takes root and is perceived as highly conducive by its actors, the model projects its influence outward along two distinct institutional logics, while preserving a direct line to the entrepreneur's ultimate goals.

H3: The Entrepreneurial Ecosystem (EES) positively drives Sustainable Technology Adoption (TEA). This captures the technocratic pathway. A mature ecosystem **that is perceived as highly supportive** actively de-risks the adoption of novel, sustainable tools for micro-enterprises. Volkmann et al. (2019) suggest that ecosystems provide the collaborative frameworks and shared knowledge infrastructure necessary to make technological leaps financially and operationally viable.

H4: The Entrepreneurial Ecosystem (EES) positively affects the formation of Socio-Ecological Mentality (SOM). Representing the cognitive-normative pathway, the ecosystem operates as a profound socialising agent. It does much more than transfer technology. Based on Stam et al. (2025) and Hruskova (2024), continuous peer interaction instils ethical awareness and cultural legitimacy regarding sustainability. It systematically shifts the collective mindset, anchoring socio-ecological values deep within the entrepreneur's cognitive framework.

H5: The Entrepreneurial Ecosystem (EES) directly and positively impacts Bioeconomic Transformation Intentions (BOT). Aligning with Kuckertz et al. (2020) and Roundy (2021), the ecosystem directly forces behavioural intent. By showcasing viable business models, offering mentorship, and maintaining a supportive peer network, a business environment perceived as highly conducive directly compels business owners to abandon traditional production methods in favour of bioeconomic alternatives.

Stage 3: Driving the transformation (hard vs. soft approaches). The final stage of the structural model isolates the predictive determinants of bioeconomy transformation intentions. Here, the pathway systematically pits the "hard" technological approach against the "soft" value-driven approach to see what triggers behavioural change.

H6: Sustainable Technology Adoption (TEA) positively influences Bioeconomic Transformation Intentions (BOT). Testing the hard approach, this hypothesis draws on Ha et al. (2023) and Urmetzer et al. (2018) to spotlight technical efficiency. When entrepreneurs adopt green technologies and witness immediate economic or operational gains, their technical confidence surges. This practical, hands-on success acts as a direct catalyst, driving their intent to commit to a broader, systemic bioeconomic shift.

H7: Socio-Ecological Mentality (SOM) positively affects Bioeconomic Transformation Intentions (BOT). In contrast, the soft approach hinges on internal value paradigms. Rooted in the work of Eversberg and Fritz (2022) and (Segundo-Ortin & Heras-Escribano, 2023), this hypothesis argues that genuine transformation stems from a fundamental shift in values, not just tool interventions. When entrepreneurs harbour deep-seated socio-ecological awareness, this mentality serves as an internal compass. It translates directly into an uncompromising intention to align their enterprises with sustainable principles.

The architecture of this inner model goes far beyond testing simple linear relationships. It is specifically designed to systematically compare the efficacy of technological modernisation strategies highly relevant to the capital-intensive Teak sector, against the social value-strengthening strategies that characterise the community-based bamboo sector.

The main novelty of this dissertation stems from a discursive gap identified through bibliometric mapping of the forest-based bioeconomy literature over the past decade. The publication landscape analysis reveals an imbalance in the distribution of research focus within the global literature. Cluster visualisation using VOSviewer indicates that most studies are still concentrated on two main domains: macro-institutional policy engineering and technological innovation as well as material circularity efficiency. Meanwhile, social dimensions, communal governance, and the role of social capital at the community level tend to emerge as themes that are relatively under-integrated in the mainstream discourse on the forest-based bioeconomy. This situation

points to an analytical gap in the literature, where forest-based bioeconomy transition processes are often understood more from technological and material substitution perspectives, while the relational, institutional, and cognitive readiness of local economic actors has yet to receive balanced attention. By operationalising the entrepreneurial ecosystem not merely as a static inventory of physical endowments, but as 'Perceived Ecosystem Conduciveness', this dissertation directly captures the cognitive and relational realities of the entrepreneurs that dictate actual behavioural shifts.

In response to this gap, this dissertation develops a conceptual integration that connects four theoretical foundations that have so far been more commonly used separately in the study of transitions and innovation: the Multi-Level Perspective (MLP), the Natural-Resource-Based View (NRBV), social capital theory, and the Theory of Planned Behaviour (TPB). The main contribution of this research does not lie in testing each theory separately, but rather in the effort to construct an analytical framework that can bridge various levels of analysis—from system dynamics at the macro level, biophysical limitations of resources, relational structures within communities, to the cognitive dimensions of individual economic actors. Through this integration, barriers to the adoption of green innovation in rural areas can be understood not merely as a matter of technology diffusion, but also as the result of the interaction between pressures and stability in socio-technical regimes (MLP), limitations of natural resource carrying capacity (NRBV), the capacity of social networks to support collective coordination (social capital), as well as perception (specifically, perceived ecosystem conduciveness) and behavioural intention factors at the individual level (TPB).

Furthermore, this integrative framework provides an analytical basis for mapping bioeconomy transition pathways more contextually. Unlike some policy approaches that tend to be generic, the synthesis of these four theoretical perspectives demonstrates that the dynamics of bioeconomy transformations are strongly influenced by the specific material, social, and institutional conditions of each region. This conceptual framework used to analyse the differing characteristics between the capital-intensive teak production regime and the more community-based bamboo economic niche, this dissertation seeks to analytically contribute to understanding variations in bioeconomy transition pathways in rural contexts. The framework is expected to enrich the discourse on sociotechnical transitions in the literature on developing countries and, at the same time, provide a conceptual foundation that can help policymakers formulate bioeconomy governance approaches that are more sensitive to local social and ecological contexts.

3 CURRENT CONDITION OF FOREST-BASED BIOECONOMY IN INDONESIA

3.1 Bioeconomy policy

Bioeconomy policy functions as a framework to decouple economic growth from fossil fuel dependency (Holden et al., 2022). This agenda requires systemic innovation across forestry, agriculture, and biotechnology to internalise environmental costs while maintaining resource efficiency (Aguilar et al., 2019; Zilberman et al., 2013). Because these policies align with circular economy principles and the Sustainable Development Goals (SDGs), they provide a blueprint for long-term growth driven by biological resource management (Zhang et al., 2022; De Besi & McCormick, 2015).

The global adoption of bioeconomy strategies began with the 2012 European Union (EU) Bioeconomy Strategy, which established a model for knowledge-driven growth (Vogelpohl et al., 2021). While Germany adopted a knowledge-intensive approach (Bogner & Dahlke, 2022), other nations adapted the paradigm to their specific contexts. For instance, China integrated bioeconomic expansion into state planning through its 14th Five-Year Plan (Zhang et al., 2022), while North American policies focused on high-tech biomanufacturing (M'Barek & Wesseler, 2023). In contrast, emerging economies in the Global South utilised their extensive agricultural and forestry endowments to develop localised, circular production systems (Grilli et al., 2024).

However, the effectiveness of these strategies depends on their operational implementation. Success is determined more by regulatory clarity and stakeholder inclusion than by the ambition of official documents (Proestou et al., 2023). Resource conflicts, such as land-use rights and food security, can also impact the legitimacy of bioeconomy initiatives (Meyer, 2017). Furthermore, disparities in R&D funding and infrastructure suggest that uniform policy models are often ineffective when applied across different national contexts (Adamseged & Grundmann, 2020). Consequently, current scholarship advocates for adaptive governance frameworks that reflect the specific socioeconomic and ecological conditions of each region (Grilli et al., 2024).

Indonesia's bioeconomy policy is not contained within a single regulation but is integrated across several macro-development plans. The National Medium-Term Development Plan (RPJMN) 2025–2029 provides the primary framework, aligning climate commitments (NDC/Net Sink 2030) with domestic down streaming agendas. This blueprint prioritises agribusiness productivity and green infrastructure as drivers of

economic growth. To manage the environmental impact of resource utilisation, this framework is supported by the Indonesia Biodiversity Strategy & Action Plan (IBSAP) 2025–2045. The IBSAP serves as a governance instrument to ensure that bioproduct innovation and bioprospecting follow principles of fair access and benefit-sharing while preventing practices that threaten genetic conservation.

This policy framework is divided into maritime and terrestrial ecological axes. In the aquatic sector, the Indonesia Blue Economy Roadmap 2023–2045 shifts the focus from extractive fisheries to advanced value chains, such as marine nutraceuticals, bioplastics, and algal biorefineries. In the terrestrial sector, policy is focused on the management of forest biomass. The State of Indonesia's Forests (SoIFO) 2022 report identifies biomass potential within the constraints of the FOLU Net Sink 2030 targets. These interventions are designed to balance industrial biomaterial needs with the maintenance of ecosystem services and decarbonization goals. Finally, these sectoral policies are linked by a circular economy vision that emphasises the valorisation of organic residues into high-value industrial feedstocks.

3.2 The importance of Indonesia's forest-based economy

The forestry sector in Indonesia is an important part of the bioeconomy, supported by national policies and strategies. This is because forest resources have significant potential to contribute to Indonesia's economy. The forest area in Indonesia, including conservation areas, covers 120,27 million ha, or 64% of Indonesia's total land area. However, these forest areas include primary forests, secondary forests, open land, and even plantations (Indonesian Ministry of Forestry, 2024).

Functionally, these forest areas consist of conservation forests (27,54 million ha, 22,9%), protected forests (29,66 million ha, 24,7%), and production forests (63,07 million ha, 52,4%). In Indonesia, the utilisation of forests for products is carried out under regulations through the Business Permit for Forest Utilisation (PBPH), which saw an increase in forest land to 30,16 million ha in 2024. In addition, forests are utilised through social forestry regulations, where the government provides access and management approval for social forestry to communities, reaching 8,3 million ha, along with the establishment of 15,516 social forestry business groups.

3.2.1 Wood-based production

Empirically, Indonesia's forest landscape is supported by a massive foundation of material biodiversity. According to an analysis of comprehensive data from the Indonesian Ministry of Forestry (2024), there are at least 121 species of commercial timber, which are categorised into four primary groups: meranti, mixed hardwoods, ebony, and ornamental woods. In that year, the total volume of roundwood extracted amounted to 64,84 million cubic meters. However, the anatomy of this production is highly asymmetric. Instead of being evenly distributed among species, nearly half of the total national supply (32,03 million m^3) is overwhelmingly dominated by the mixed hardwood group. Acacia species follow closely in second place, securing a volume share of 42,52% (27,57 million m^3). This situation indicates a sharp shift: high-value species groups, such as meranti, ebony, and ornamental woods, have collectively shrunk and contribute less than 10% of the total extraction.

This structural imbalance is not only present in the material composition but is also replicated spatially. The centres of wood biomass production in Indonesia show an extremely high level of geographic concentration. Sumatra Island has definitively established itself as the main supply epicentre, controlling a total of 65,20% of the national production, leaving Kalimantan (20,29%) and Java (11,12%) in subordinate positions. This quantitative mapping reveals a crucial reality for the bioeconomy agenda: that any future policy interventions in forest governance and biomaterial innovation can no longer be built on assumptions of equal distribution but must adapt to the current reality of spatial concentration and the homogeneity of supply.

The use of roundwood as raw material for the large-scale forest product processing industry reached 33,32 million cubic meters in 2024. This roundwood is primarily utilised for sawn timber (3,84 million cubic meters), veneer (2,68 million cubic meters), and plywood and laminated veneer lumber (LVL; 4,62 million cubic meters). The resulting production contributed to the export of forestry industry products valued at US$12,59 billion in 2024, dominated by pulp, paper, and processed wood products (Table 3). These data indicate that Indonesia's forestry industry has a production structure dominated by bulk raw material-based commodities that are export-oriented, while value-added commodities show lower but stable export values.

Table 3. Export Value of Forestry Industry Products (USD)

No	Product	Export Value of Forestry Industry Products (USD)				
		2020	2021	2022	2023	2024
1	Panel/plywood	2,163,012,329	3,065,547,871	2,903,982,091	2,205,171,489	2,279,877,881
2	Paper	3,527,854,476	3,698,469,635	4,313,240,484	4,313,335,730	3,981,305,565
3	Pulp	2,530,024,570	3,242,940,925	3,717,872,440	3,451,207,765	3,558,126,318
4	Woodworking	1,075,495,368	1,185,054,333	963,972,615	900,774,028	847,768,694
5	Chip wood	50,450,382	99,032,121	98,439,013	164,940,790	179,420,889
6	Veneer	80,660,079	114,626,727	115,459,687	132,494,854	120,356,760
7	Wood Furniture	1,533,908,961	2,045,964,304	1,979,295,605	1,491,384,927	1,532,702,453
8	Prefabricated Buildings	2,030,294	2,075,374	2,847,181	2,775,930	4,490,617
9	Wood Crafts	86,487,455	109,015,201	110,012,840	93,550,222	87,751,808
Total Value		11,049,923,918	13,562,726,494	14,205,121,960	12,755,635,739	12,591,800,988

Source: Directorate General of Sustainable Forest Management, December 2024

According to the 2024 Statistics of the Ministry of Forestry, the forestry sector also absorbs a considerable workforce. In the Business Licensing for Forest Utilisation (PBPH) activities, specifically for the sub-activities of private forests (HHK-HA) and plantation forests (HHK-HT), a total of 88,579 workers were recorded in 2024 (Indonesian Ministry of Forestry, 2024). In addition, the large-scale forest product processing industry is also a significant source of employment, with the number of workers reaching 259,885 in the same year.

The fluctuating dynamics reflect the sensitivity of industries in developing countries to external factors, such as global demand, regulatory policies, and conditions of biomass-based supply chains, which are greatly influenced by logistics efficiency and the stability of raw material supply (Gebresenbet et al., 2018). These findings highlight that timber-producing countries in Southeast Asia tend to maintain a production orientation based on volume due to the availability of supply and large export markets (Erbaugh et al., 2016). Nonetheless, there is also a growing trend toward value-added commodities, such as veneer and woodworking, indicating that diversification toward sustainable wood processing products can enhance the industry's competitiveness and reduce ecological pressure (Toppinen et al., 2019). Therefore, this condition shows that the characteristics of Indonesia's forestry industry for timber products are still highly dependent on primary commodities with low added value.

3.2.2 Non-timber-based production

In Indonesia, non-timber forest products (NTFPs) have great potential to provide economic benefits while supporting forest sustainability. According to the 2024 forestry production statistics report, NTFPs include bamboo, rattan, forest latex, palm sugar, fruit, pine resin, honey, sago, clove essential oil, mushrooms, and other categories (Table 4). Overall, the table reflects the significant contribution of NTFPs in supplying raw materials for handicrafts, food, bioenergy industries, and other downstream products throughout 2024.

Table 4. Production of Non-Timber Forest Products by Type of Non-Timber Forest Products and Quarterly, 2024

Type of Non-Timber Forest Products	Unit of Measurement	Year 2024				Total
		1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	
Bamboo	stems	8,403,542.93	3,834,099.32	9,258,373.84	8,319,370.41	29,815,386.50
Rattan	stems	332,156.05	357,910.00	404,424.00	640,360.00	1,734,850.05
Rattan	tons	360.14	446.47	12,868.20	1,441.56	15,116.37
Rubber Sap	tons	9,755.03	170,567.14	355,588.24	59,482.27	595,392.68
Palm Sugar	litres	29,736.10	42,058.00	41,601.00	40,730.90	154,126.00
Palm Sugar	tons	27.24	26.72	33.00	40.45	127.41
Fruits	pieces	99,000.00	6,000.00	4,974.00	9,353.00	119,327.00
Fruits	tons	741.07	372.12	584.68	1 .194.08	2,891.95
Pine Sap	tons	24,116.11	26,925.21	30,981.66	26,377.88	108,400.86
Honey	litres	5,965.00	6,025.00	2,812.00	3,635.59	18,437.59
Honey	tons	134.39	151.61	195.99	106.58	588.57
Sago	tons	2,659.69	2,800.71	2,998.83	2,385.11	10,844.34
Clove Essential Oil	tons	1,221.71	7,188.91	2,167.71	17.31	10,595.64
Mushroom	tons	1,349.90	3,225.09	2,091.48	2,853.79	9,520.26
Others	tons	4,720.73	197,012.08	11,.237.18	7,105,12	220,075.11
Others	pieces			20,000.00	20,000.00	40,000.00
Others	litres		1,056.00		7,500.00	8,556.00

Source: Forestry Production Statistics Report 2024

Table 4 presents the empirical quarterly production data of Non-Timber Forest Products (NTFPs) throughout 2024. An analysis of this dataset reveals two distinctly contrasting production patterns within the forest-based bioeconomy. The first empirical pattern demonstrates strong structural production stability across several essential natural resource commodities. Products such as pine sap, sago, and palm sugar exhibit highly consistent output volumes year-round. This quantitative stability empirically confirms their function as a reliable economic foundation for rural households. Continuous

harvesting cycles allow these specific commodities to act as crucial income-smoothing mechanisms (Angelsen et al., 2014). Furthermore, stable NTFP extraction significantly reduces rural household vulnerability to sudden agricultural market shocks (Shackleton & Shackleton, 2004). These specific natural commodities remain relatively insulated from immediate seasonal disruptions or short-term climate anomalies.

Conversely, the second observed pattern highlights extreme seasonal production volatility in specific high-value agricultural commodities. Rubber sap production clearly illustrates this volatility with an aggressive spike during the third quarter. Clove essential oil demonstrates a similarly high sensitivity to seasonal shifts and external biophysical factors. Its total production peaked dramatically in the second quarter before collapsing completely during the fourth quarter. These extreme statistical fluctuations indicate a severe vulnerability to specific harvest cycles and environmental shocks. Highly seasonal production patterns often generate unpredictable financial income fluctuations for local rural communities (Dercon, 2002). Consequently, communities relying heavily on these volatile commodities face higher risks of temporary economic instability (Wunder et al., 2014).

Secondary biodiversity products, including local mushrooms and honey, maintain moderate but continuous quarterly production levels. These secondary commodities offer continuous raw materials suitable for local bio-manufacturing and consistent value addition. Developing bio-based derivative products from these resources can significantly enhance rural regional economic resilience (Gawel et al., 2019). Ultimately, regional policymakers must design differentiated economic strategies to manage these contrasting production characteristics effectively. Stable commodities require immediate supply chain optimisation to maximise their consistent circular economic potential (D'Amato et al., 2017). Conversely, highly volatile agricultural commodities demand advanced warehousing technologies and robust market price stabilisation mechanisms. Addressing both distinct patterns is a mandatory requirement for building a resilient rural bioeconomy architecture (McClay & Sellare, 2025).

3.3 Indonesia's small forest-based processing enterprises

Small-scale forest-based enterprises are pivotal to the forestry sector, as they transform raw materials into value-added finished products (Santika et al., 2019). These companies significantly influence rural development by generating local employment and strengthening financial systems in forest-dependent communities (Kaskoyo et al., 2017).

Beyond economic contributions, they facilitate improved forest management through community-led conservation and resource monitoring (Octavia et al., 2022; Qiao et al., 2024). Consequently, small-scale processing aligns with inclusive and sustainable economic goals by optimising local resource use.

Despite their potential, these enterprises face complex technical and non-technical barriers. Operational efficiency is often hindered by limited investment in research and development (R&D) and outdated equipment management (Krišťáková et al., 2021). Non-technical constraints include restricted access to working capital and difficulties in establishing business networks, which limit market expansion (Meinhold & Darr, 2019). Furthermore, legal frameworks and social dynamics can obstruct innovation and collaboration within the value chain (Denny-Smith & Loosemore, 2017). In the context of Industry 4,0, digital transformation is further slowed by a lack of IT competencies and security concerns (Arroyabe et al., 2023; Vuksanović Herceg et al., 2020). Addressing these challenges requires a holistic approach that integrates socio-economic and environmental contexts.

In Indonesia, small-scale forest-based processing is identified through two primary Standard Business Classifications (KBLI): **KBLI 16** (wood, cork, rattan, and bamboo products) and **KBLI 31** (furniture industry). Statistics Indonesia (BPS) further categorises these manufacturing entities based on workforce size: micro-industries employ 1–4 workers, while small industries employ 5–19 workers (Statistics Indonesia, 2025). These classifications are formally regulated under Law No. 2 of 2022 and Government Regulation No. 7 of 2021, which define enterprises based on capital and annual sales:

- **Micro-enterprises:** Maximum capital of IDR 1 billion (excluding land and buildings) and annual sales up to IDR 2 billion.
- **Small enterprises:** Capital between IDR 1 billion and IDR 5 billion, with annual sales between IDR 2 billion and IDR 15 billion.
- **Medium enterprises:** Capital between IDR 5 billion and IDR 10 billion, with annual sales between IDR 15 billion and IDR 50 billion.

3.3.1 Characteristics of small forest-based processing enterprises

An analysis of the demographic structure of small forest-based processing enterprises (SFBPEs) in Indonesia highlights a significant concentration of micro-scale and informal entities. Based on data from Statistics Indonesia (2024), the sector comprises

662,318 business units, the majority of which operate within the informal economy (Table 5).

Table 5. Number of micro and small forest-based processing enterprises

KBBI		16	31
Number of Workers Categories (person)	**1**	256,022	43,505
	2-4	251,738	80,819
	5-9	9,308	8,82
	10-14	1,186	1,611
	15-19	600	709
Form of enterprises (enterprise)	**Cooperative**	195	42
	Foundation	176	35
	Not incorporated	524,803	132,974
TOTAL		526,854	135,464

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

In the primary wood processing industry (KBLI 16), the landscape consists of 526,854 entities. Labour absorption in this cluster is characterised by extreme fragmentation, where business units are predominantly managed by individual owners (256,022 entities) or small family groups of 2–4 workers (251,738 entities). A similar pattern of scale is observed in the furniture and woodcraft manufacturing cluster (KBLI 31). Out of 135,464 operating units, the majority are classified as ultra-micro, driven either by a single worker (43,505 units) or small groups of 2–4 people (80,819 units).

The institutional profile of these enterprises reveals a lack of formal legal status. In the KBLI 16 cluster, 524,803 units operate without a legal entity status. This informal majority significantly outweighs formal communal structures, such as cooperatives (195 units) or foundations (176 units). This trend is consistent within the KBLI 31 cluster, which records 132,974 informal units compared to only 42 cooperatives.

These statistics indicate that the forest product processing industry in Indonesia is largely driven by subsistence economic units. The high level of informality and the limited workforce scale per unit present significant challenges for institutional integration and the implementation of bioeconomy policies at the grassroots level.

An analysis of micro and small enterprises reveals a significant demographic deficit regarding regeneration. This trend is evident across both the primary wood processing (KBLI 16) and furniture manufacturing (KBLI 31) clusters. Data from Table 6 and Table 7 demonstrate that older cohorts largely dominate the entrepreneurial landscape.

Table 6. Age Classification of entrepreneurs

KBLI	<20 years	20-24 years	25-44 years	45-64 years	>65 Years
16	531	4,489	149,970	294,309	77,555
31	48	807	44,685	82,310	26,920

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Business owners aged 45 to 64 constitute the largest segment within these industries. Specifically, this age group accounts for 294,309 individuals in KBLI 16 and 82,310 individuals in KBLI 31. Conversely, business participation among younger populations under 25 years old remains exceptionally low. This stark disparity indicates an ageing rural economy with a severe lack of intergenerational succession.

This demographic challenge is further compounded by a widespread deficit in formal human capital. Educational profiles in both industrial clusters skew heavily toward basic schooling levels. Most business owners hold only elementary or junior high school diplomas.

Table 7. Level of Education Attainment of entrepreneurs

Education Level	KBLI	
	16	31
Not Completed elementary school	127,57	10,295
Elementary school	223,481	39,192
Junior High School (SMP)	98,888	37,224
Senior High School (SMA)	53,794	32,491
Vocation High School (SMK)	16,763	9,624
Vocational Higher Education	1,335	1,717
University Higher Education (min. Bachelor)	5,022	4,922

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Meanwhile, university graduates remain marginal, numbering between 1,000 and 5,000 individuals per industrial cluster. Together, these metrics describe an ageing workforce operating with stagnant levels of formal education. This profile presents a substantial barrier to independent innovation and complex technological adoption. It severely limits their capacity to navigate the modern complexities of a bioeconomy supply chain. Therefore, grassroots transformation requires targeted state intervention through capacity building and vocational training.

An analysis of the macro-financial structure in these sectors reveals significant underlying inefficiencies. Aggregate turnover appears substantial, reaching Rp41 trillion for KBLI 16 and Rp38 trillion for KBLI 31. However, high labour absorption dilutes these gross figures, driving per capita productivity down to subsistence levels. Table 8 illustrates a stark disparity between total generated revenue and actual labour

compensation. In KBLI 16, only Rp4,7 trillion of the Rp41 trillion revenue is allocated to workers. Similarly, workers in KBLI 31 receive only Rp6,5 trillion from a Rp38 trillion revenue pool. This distribution limits the proportion of labour compensation to a narrow range of 11% to 17%.

Table 8. Number of workers, revenue, expenditure, and compensation of workers

KBLI	Workers (Person)	Revenue (000 Rp)	Expenditure (000 Rp)	Compensation of Workers (000 Rp)
16	943,248	41,089,093,041	21,491,774,645	4,788,021,708
31	363,868	38,309,396,279	19,218,083,832	6,553,877,791

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

For a labour-intensive industry, this low wage ratio clearly indicates an informality trap. Ultra-micro informal entities often offset their productivity inefficiencies through extreme wage compression (La Porta & Shleifer, 2014). Consequently, most small forest-based enterprises do not operate on a logic of capital accumulation. Instead, they function as survivalist entrepreneurs who keep their businesses afloat through wage repression. This business model systematically perpetuates ongoing economic vulnerability across rural areas (Berner et al., 2022).

3.3.2 Financial capital and structure

An analysis of the financial architecture in small forest-based enterprises reveals severe capital constraints. Table 9 indicates that this sector operates below adequate capital viability thresholds. Business activities are overwhelmingly confined to the ultra-micro scale. Most entities operate with a capital turnover of less than Rp1 billion. This includes 524,556 units in KBLI 16 and 134,063 units in KBLI 31. Furthermore, these businesses rely almost entirely on personal savings. Fully owned personal funds support 475,937 entities in KBLI 16 and 98,306 entities in KBLI 31. Conversely, the penetration of external capital from banks or investors remains exceptionally low.

This extreme reliance on internal funding does not indicate true financial independence for micro-scale business actors. Instead, this behavioural pattern serves as a clear manifestation of systemic financial exclusion in rural areas. This interpretation aligns directly with contemporary empirical evidence on micro-enterprise financial constraints by Wellalage and Fernandez (2019). Recent studies by Kersten et al. (2017) further confirm that businesses isolated from formal credit face inflated capital costs.

Consequently, this prolonged financial isolation severely restricts the long-term growth potential of rural forest processing enterprises.

Table 9. Financial Capital

KBLI		16	31
Financial Capital (billion rupiah)	**≤1**	524,556	134,063
	>1-5	129	513
	>5-10	-	-
	>10	-	-
	No Answer	2,169	888
Business capital ownership	**Fully Owned**	475,937	98,306
	Partially From Others	42,238	34,91
	Fully from Others	5,679	2,248

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Table *10* provides a detailed breakdown of external funding sources. The data exposes a significant imbalance within the rural financial market. Thousands of enterprises still sustain operations through informal non-bank networks or individual capital injections. This includes 14,664 units in KBLI 16 and 2,512 units in KBLI 31. While banking penetration exists, its distribution relies heavily on government subsidies. Formal credit only reaches the lowest enterprise layers through state-subsidised instruments. Pure commercial credit and cooperative institutions have proven largely ineffective in rural financial intermediation.

Table 10. Source of Capital

KBLI	16	31
Non-subsidised Bank	4,503	10,295
Subsidised Bank	24,713	39,192
Cooperative	3,506	1,356
non-bank financial Institution	2,96	598
Individual	14,664	2,512
Non-financial Institution	572	205

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

This statistical reality highlights a severe credit rationing phenomenon. It is primarily driven by information asymmetry within the banking market. The inability of formal institutions to distribute micro-credit systematically blocks business expansion (Beck et al., 2005). Furthermore, absolute reliance on personal funds severely limits sustainability initiatives. Financial constraints remain the most significant barrier to innovation adoption (Chien et al., 2021). Businesses lacking banking liquidity cannot acquire

environmentally friendly precision technology. Therefore, advancing bioeconomy standards requires dismantling these barriers to financial inclusion.

Tracking bank credit penetration reveals distinct sectoral inequalities. Table *11* demonstrates that liquidity distribution is highly asymmetrical. The furniture manufacturing cluster (KBLI 31) enjoys a relatively higher level of bankability.

Table 11. Utilisation of loans from banks

KBLI		16	31
Number of Lenders (entrepreneurs)		29,572	32,558
The Amount of Bank Loans (Millions)	**< Rp 20**	7,149	4,288
	> Rp 20-100	16,307	15,636
	> Rp 100-500	1,761	7,85
	> Rp 500	125	129

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Approximately 31,04% of this population (32,558 entities) successfully accesses credit facilities. In contrast, the basic wood processing cluster (KBLI 16) faces severe restrictions. Only 5,61% of these businesses (29,572 entities) secure formal banking access.

However, the primary limitation lies in the structure of the financing ceilings. Most disbursed loans are restricted to ultra-micro amounts. Credit limits predominantly fall below Rp20 million or within the Rp20–100 million range. Loans exceeding Rp500 million represent a rare statistical anomaly. This nominal restriction reflects the information opacity inherent in the informal sector. Banks lack precise metrics to evaluate micro-businesses without legal corporate status (Goldberg et al., 2002). Consequently, banks utilise strict credit-rationing mechanisms to mitigate default risks (Stiglitz & Weiss, 2009). These low credit ceilings restrict the capital absorptive capacity of rural entrepreneurs. Purchasing advanced bioeconomy machinery remains impossible while actors are constrained by subsistence-level credit.

A significant behavioural pattern emerges among actors who consciously avoid the banking system. Table *12* reveals substantial structural resistance toward formal credit. A massive population explicitly declares that bank credit is unattractive. This includes 14,347 entities in KBLI 16 and 3,128 entities in KBLI 31. Business owners cite complex administrative procedures and rigid collateral requirements as primary deterrents. They also perceive standard interest rates as overly burdensome for their subsistence margins.

Table 12. Loan Access to Banking

KBLI		16	31
Number of non-access loans to banking		21,245	4,6
Main Reason	**Not knowing Procedures**	495	124
	Difficulty in Procedures	2,376	316
	Not Having Collateral	1,493	403
	High Interest Rate	1,729	424
	Proposal Rejected	805	206
	Not Interested	14,347	3,128

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

This attitudinal anomaly aligns perfectly with the discouraged borrower syndrome. Following the postulates of Moro et al. (2017), this rejection is a rational economic calculation. It represents a deliberate voluntary exclusion by micro-entities. Business actors determine that transaction costs and collateral risks outweigh the utility of formal loans. Interpreting this resistance merely as poor financial literacy represents an analytical flaw. Resolving this issue requires more than distributing basic financial education. Policymakers must actively redesign financing instruments to accommodate grassroots business realities.

3.3.3 Technological capabilities

An analysis of technological capabilities within the forest product processing ecosystem reveals significant stagnation in production methods. Table *13* demonstrates a widespread and persistent reliance on traditional manual tools at the grassroots level.

Table 13. Process Technology Capability (can include several types of technology)

KBLI	Manual	Mechanic	Electronic	Digital
16	499,444	190,031	71,953	4,187
31	112,222	88,460	64,506	3,895

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Manual technology is currently utilised by 499,444 entities in the wood processing cluster (KBLI 16). Similarly, 112,222 entities in the furniture cluster (KBLI 31) operate using purely manual labour. This overwhelming dominance indicates a severe state of technological inertia. Production architectures remain firmly locked at the lowest levels of operational efficiency. Consequently, the penetration of electronic and digital automation remains exceptionally low across both sectors. This technological deficit stems directly from limited capital and insufficient managerial readiness.

In innovation literature, this low adoption rate reflects a fundamental lack of absorptive capacity. Businesses without basic technological literacy cannot assimilate or exploit sophisticated innovations (Limaj and Bernroider, 2019). These cognitive limitations present profound challenges for the implementation of bioeconomy policies. Mandating the integration of complex digital systems into this fragmented framework is highly unrealistic. Expecting premature technological leapfrogging toward advanced bioeconomy machinery represents a technocratic oversimplification (Ghobakhloo & Iranmanesh, 2021).

Indonesia currently ranks fourth globally in internet penetration, covering 74% to 77% of the national population (Statistics Indonesia, 2025a). However, this widespread connectivity does not extend to small forest-based processing enterprises. Table *14* reveals a severe digital asymmetry within this specific rural sector. A massive number of business units remain completely disconnected from the internet. Specifically, 361,315 entities in KBLI 16 operate without any internet access. Likewise, 45,629 entities in KBLI 31 report zero internet usage for their business operations.

Table 14. Internet Access, Usage, and Reasons for Non-Usage

KBLI		**16**	**31**
Number of Internet users		165,539	89,835
The Purposes of using internet	**Product Marketing**	123,414	76,757
	Order Raw Material	96,346	55,834
	Transaction Payments	21,986	27,043
	Fintech Loans	486	1,363
	Search of Information	22,307	21,377
Number of non-internet users		361,315	45,629
Reasons	**Not having a device**	101,421	6,357
	No Network	2,015	351
	Expensive internet cost	3,752	6,748
	Online Selling Problems	3,376	881
	Unable to Use	63,379	7,085
	Security Issues	12,268	1,137
	No Need	215,370	21,262

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

This widespread exclusion is driven by high hardware costs and pervasive technological illiteracy. Interpreting this phenomenon as a mere technical delay is an analytical mistake. It represents a structural digital divide that systematically isolates local actors from modern economic networks (Salemink et al., 2017). Establishing basic internet connectivity is an absolute prerequisite for future industry upgrading. Businesses must

secure this cognitive baseline before they can develop advanced digital capabilities (Eller et al., 2020).

An examination of cyber penetration in Table 15 reveals further structural limitations regarding marketing channels. While some enterprises adopt digital channels, their usage is heavily restricted to basic communication tools.

Table 15. Digital marketing channels

KBLI	Instant Messaging	Market Place	Social media	Email	Website	Government E-catalogue
16	157,349	7,320	34,055	3,204	952	476
31	85,227	5,711	37,711	3,402	1,370	799

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Instant messaging applications completely dominate the digital landscape for these micro-businesses. These basic applications are utilised by 157,349 entities in KBLI 16 and 85,227 entities in KBLI 31. In contrast, penetration into integrated marketplaces or independent websites remains remarkably marginal.

This extreme disparity reflects the most basic embryonic phase of business digitisation (Verhoef et al., 2019). Business actors merely utilise pragmatic communication to facilitate basic subsistence transactions. They are not executing strategic transformations of their supply chain or marketing models. This exclusive reliance on chat applications highlights a severe cyber literacy gap (Taiminen & Karjaluoto, 2015). Many micro-enterprises mistakenly equate simple messaging with comprehensive digital marketing capability. However, these practices remain entirely reactive and isolated from data-driven management processes.

3.3.4 Entrepreneurial ecosystem constraints and supply chain vulnerabilities

An entrepreneurial ecosystem functions as an institutional matrix that facilitates collaboration among actors. This network helps micro-entities survive market turbulence by addressing specific vulnerabilities (Bărbulescu et al., 2021; Fuerlinger et al., 2015). Ecosystem effectiveness depends on its ability to resolve frictions at the grassroots level (Filippelli et al., 2024). However, small forest-based processing enterprises in Indonesia face severe systemic constraints (Table *16*). In the primary wood processing cluster (KBLI 16), business actors experience significant operational stagnation. Capital scarcity restricts 182,245 entities, while marketing barriers paralyse 149,970 entities. Furthermore, raw material volatility threatens an additional 118,088 units. Blocked

financial and market access strips the ecosystem of its fundamental leverage. This isolation transforms potential entrepreneurs into isolated subsistence workers (Stam, 2015). Additional barriers involving public infrastructure and workforce deficits highlight the absence of comprehensive institutional support. Beyond physical and financial barriers, the core challenge for small forest-based processing enterprises in Indonesia lies in the low 'Perceived Conduciveness of the Entrepreneurial Ecosystem.' While policies may exist on paper, the entrepreneurs' perception of government fiscal support (EES1) and access to financial capital (EES2) remains significantly constrained. This lack of perceived support creates a psychological distance that hinders their willingness to engage in bioeconomic transitions. Thus, the ecosystem constraints identified in this section are not merely structural but are deeply embedded in the entrepreneurs' subjective assessment of their business environment.

Table 16. Problems Encountered

KBLI		16	31
Problems encountered (Number of Enterprises)	**Raw Material**	118,088	24,559
	Capital	182,245	65,9
	Marketing	149,97	40,446
	Fuel and Energy	7,324	2,963
	Public Infrastructure	17,424	2,672
	Workers	17,194	4,895

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

The advanced manufacturing furniture cluster (KBLI 31) exhibits a different structural resilience. This sector faces similar capital and marketing challenges, affecting 65,900 and 40,446 units, respectively. However, the intensity of its vulnerability remains significantly lower than that of the primary processing sector. Global value chain governance frameworks effectively explain this structural asymmetry (Kano et al., 2020). The furniture cluster operates further downstream within the supply chain. This position features consolidated structures and highly coordinated relational networks. Consequently, KBLI 31 actors generate greater value capture and build robust financial buffers. Conversely, upstream KBLI 16 craftsmen remain highly vulnerable to extreme raw material price volatility.

An analysis of geospatial supply chains reveals significant spatial embeddedness among these enterprises. Business units restrict their logistical networks to their immediate natural endowments. Table *17* indicates that intra-district supply dominates the wood processing cluster (KBLI 16).

Table 17. Source of Raw Material

KBLI	Inside district	Outside district	Outside province	Foreign	Import raw material content			
					<25%	<50%	<80%	≥80%
16	510,149	38,481	5,708	220	52	-	157	10
31	124,749	25,157	6,285	37	11	9	17	-

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

This localisation encompasses 510,149 business units across the sector. Procurement from outside the district or province remains exceedingly marginal. A similar pattern occurs in the furniture cluster (KBLI 31), encompassing 124,749 localised entities. Furthermore, exposure to global supply chains is virtually non-existent. Only 220 units in KBLI 16 and 37 units in KBLI 31 utilise imported materials.

This spatial concentration functions as a pillar of structural defence rather than a weakness. Geographic proximity generates collective efficiency and eliminates significant transaction costs (Spigel, 2017). This localisation builds robust interdependence between local entrepreneurs and raw material suppliers. Additionally, reliance on domestic resources provides high immunity to global macroeconomic shocks (Gong et al., 2020).

Market penetration strategies demonstrate acute spatial concentration downstream along the supply chain. Commercial activities remain tightly locked within domestic consumption boundaries. Table *18* illustrates the absolute dominance of intra-district circulation. This local market encompasses 509,777 units in KBLI 16 and 128,468 units in KBLI 31.

Table 18. Marketing Allocation

KBLI		16	31
Inside Regency/ Municipality		509,777	128,468
Outside Regency/ Municipality		63,149	39,116
Outside Province		11,595	9,798
Foreign market		2,742	1,645
Export	**<25%**	980	220
	<50%	243	126
	<80%	482	338
	≥80%	1,037	1,31

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Conversely, cross-border penetration and global export participation are statistically negligible. Exporting entities range between 980 and 1,037 units for KBLI 16. The KBLI 31 cluster records only 220 to 1,310 exporting units. Furthermore, export volumes for these participating entities rarely exceed a 25% market share.

This limited expansion signifies a structural liability of outsidership within international business models. Micro-enterprises face exclusion because they lack cognitive and relational connections to global networks (Vahlne & Johanson, 2017). Export barriers such as market intelligence deficits and regulatory complexities severely restrict micro-scale entities (Haddoud et al., 2019). Table *19* further reveals a highly asymmetric market structure within the domestic landscape. Small forest-based enterprises rely overwhelmingly on business-to-consumer (B2C) transactions. Household consumers dominate the market, supporting 248,770 entities in KBLI 16 and 109,665 in KBLI 31.

Distributors and conventional retailers function merely as secondary transactional channels. Penetration into institutional segments like business-to-business (B2B) and business-to-government (B2G) remains paralyzed. For instance, only 4,336 units in KBLI 16 successfully access government procurement chains. This exclusivity forces manufacturing SMEs into reactive marketing practices.

Table 19. Target market

Target Customers (*can include several markets*)	**KBLI**	**16**	**31**
	Households	248,77	109,665
	Retailer	110,816	21,114
	Distributors	226,208	22,499
	Other Businesses	23,151	10,251
	Government Institution	4,336	9,783
Key Customers	**KBLI**	16	31
	Households	211,102	98,834
	Retailer	82,326	8,343
	Distributors	215,224	18,839
	Other Businesses	17,177	6,794
	Government Institution	1,025	2,654

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Consequently, they lose opportunities to create value-added innovations typical of B2B contracts (Reijonen et al., 2015). Without targeted institutional bridges, SMEs remain excluded from complex public procurement systems (Flynn & Davis, 2015).

Table 20 details the structural landscape of strategic alliances across the ecosystem. The data reveals a distinct bifurcation of collaborative tactics between the two clusters. Basic wood processing (KBLI 16) relies heavily on extensive relational capital maneuvers.

Table 20. Partnerships and Collaborations

KBLI		16	31
Number of Having Partnership		54,023	9,74
Partnership Patterns	**Core-plasma**	4,274	536
	Sub-contract	3,618	1,936
	General Trading	30,382	4,199
	Profit Sharing	1,466	939
	Operational Cooperation	173,181	1,255
	Joint Venture	225	54
	Others	3,688	1,289

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Approximately 54,023 enterprises utilize partnerships to overcome business isolation. Joint ventures encompass 173,181 enterprises, while profit-sharing arrangements involve 30,382 entities. This configuration indicates that upstream clusters prioritize operational integration and capacity consolidation for survival.

In contrast, the furniture manufacturing cluster (KBLI 31) avoids deep institutional mergers. Only 9,740 entities engage in formal partnerships within this downstream sector. Most of these collaborations involve minor profit-sharing and limited joint ventures. This tactical disparity represents an adaptive response to distinct structural vulnerabilities. Upstream joint ventures function as a radical coopetition mechanism rather than standard expansion (Kraus et al., 2019). Competitors merge to secure volatile raw material supplies and ensure mutual survival. Conversely, downstream sectors prefer contract-based alliances to avoid escalating fixed costs (Bouncken et al., 2017). Therefore, strategic alliances operate as absolute survival mechanisms rather than supplementary ecosystem enhancements.

Table *21* outlines the architecture of institutional assistance within the entrepreneurial ecosystem. The data indicate a severe deficit in professional advisory networks. State agencies and financial institutions operate as monopolistic actors in providing business guidance. In KBLI 16, government interventions support 15,329 entities, followed by banking assistance for 7,725 units. However, advisory contributions from private companies and non-governmental organisations remain statistically marginal. An identical centralisation pattern occurs in the furniture cluster (KBLI 31). Banking and government pillars dominate advisory services for 5,964 and 4,210 units, respectively.

Table 21. Entrepreneurial Advisor

KBLI	Government	Private Company	Banking	Foundation and NGO	None
16	15,329	1,893	7,725	398	2,189
31	4,210	932	5,964	336	951

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

Furthermore, thousands of entities operate in absolute isolation without any professional advisors. This advisory gap poses an existential threat to long-term innovation capacity. Isolated business entities inevitably experience severe cognitive lock-in (Mole et al., 2016). Without external knowledge transfer, they cannot overhaul strategies or adopt new technologies. A robust entrepreneurial ecosystem requires professional mentors to bridge these critical information asymmetries (Brown & Mason, 2017).

Table 22 examines the structure of capacity-building interventions provided to these enterprises. Current guidance programs display significant operational limitations and policy disarticulation. Curricula focus almost entirely on technical skills and basic production engineering.

Table 22. Counselling, training, and coaching

KBLI	Number of receiving benefit	Type of Counselling, training and coaching			
		Managerial	Technical Skills and Engineering	Marketing	Environmental Impact Assessment
16	11,115	2,636	8,653	1,244	336
31	2,181	458	1,834	571	25

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

This technical focus absorbs 8,653 units in KBLI 16 and 1,834 units in KBLI 31. Conversely, strategic capabilities like managerial and marketing literacy receive minimal

attention. Environmental impact assessment modules are practically non-existent across both clusters. This discrepancy highlights a critical structural flaw within the ecosystem design. Enterprises receiving only technical training cannot achieve necessary leaps in added value (Saunila, 2016). Furthermore, the absence of green competency transfer undermines grassroots bioeconomy transitions (Cabral & Dhar, 2019).

Table 23 dissects the specific anatomy of innovation across the sectors. Innovation initiatives overwhelmingly favour incremental product development. This category dominates with 46,641 units in KBLI 16 and 36,185 units in KBLI 31. Process innovations targeting production technology and marketing modernisation lag significantly behind. This dominance of product innovation highlights a severe innovation bias among micro-enterprises (Hervas-Oliver et al., 2021). Businesses execute incremental product modifications because they require minimal capital expenditure. They systematically avoid process innovations due to prohibitive financial requirements. Additionally, thousands of entities rely entirely on external networks for innovation development. This reliance validates the concept of open innovation driven by necessity (Love & Roper, 2015). Lacking internal research facilities, entrepreneurs depend on downstream buyers to dictate product designs.

Table 23. Innovation and Development

KBLI		16	31
Doing Innovation		56,526	38,746
Form of Innovations	**Product Development**	46,641	36,185
	Marketing and Distribution	8,451	9,137
	Technology and Production Process	8,677	10,272
	Others	2,944	213
Development Process	**Internal**	476	799
	External	7,452	3,458

Source: Profile Micro and Small Industries of Indonesia (Statistics Indonesia, 2025a)

3.4 Structural constraints in the transition toward a forest-based bioeconomy in rural Indonesia - synthesis

An analysis of bioeconomy policies and enterprise profiles reveals significant structural barriers to sustainable rural development. This synthesis organises the

empirical findings across three distinct analytical levels of the rural economy. These three analytical levels encompass national policy structures, regional ecosystem dynamics, and individual entrepreneurial behaviour. This study focuses on rural micro-entrepreneurs to provide vital empirical contributions from a developing country context. The research contrasts the capital-intensive teak industry with the community-based bamboo sector to highlight divergent transition pathways.

Descriptive data indicate that three primary factors severely constrain the forest-based bioeconomy transition in Indonesia. These factors include massive policy implementation gaps, severe ecosystem fragmentation, and distinct behavioural barriers among rural entrepreneurs. These observed empirical realities effectively validate the four primary theoretical frameworks applied throughout this study.

First, a significant policy implementation gap severely limits sustainable progress at the national macroeconomic level. National strategies outline ambitious sustainability targets without providing the necessary operational support at the grassroots level. Through the Multi-Level Perspective (MLP), the teak industry represents a locked-in socio-technical regime facing severe resource stagnation (Geels, 2011). Conversely, the community-based bamboo sector currently operates strictly as a marginalised and informal niche innovation. This distinct sectoral disparity strongly supports the conceptual Natural-Resource-Based View (NRBV) proposed by Hart (1995). The physical sources of local biomaterials fundamentally dictates the competitive advantage and strategic options of these rural enterprises.

Second, the meso-level rural business environment suffers continuously from severe ecosystem fragmentation and institutional voids. The empirical data reveal pervasive enterprise informality, low financial inclusion, and a significant digital divide. These harsh structural conditions confirm the complete absence of effective formal institutional infrastructure in rural areas. In this restricted environment, Social Capital Theory adequately explains the underlying community survival mechanisms (Nahapiet & Ghoshal, 1998). Informal networks, mutual trust, and local reciprocity among entrepreneurs act as primary substitutes for formal institutional support. However, this reliance on informal social capital remains insufficient to scale up sustainable innovations independently.

Third, micro-level data highlight significant behavioural constraints and prevalent survivalist decision-making practices among rural entrepreneurs. The persistent reliance on manual technology does not simply reflect an irrational resistance to innovation.

Instead, the Theory of Planned Behaviour (TPB) explains this technological stagnation as a rational response to structural limitations (Ajzen, 1991). Micro-entrepreneurs experience extremely low perceived behavioural control due directly to material scarcity and severe financial constraints. Consequently, business owners naturally prioritise immediate economic survival over long-term ecological investments or technological upgrades. These massive institutional barriers actively prevent environmental awareness from translating into actual sustainable technology adoption.

The synthesis of these three levels confirms that generic, top-down policy approaches remain highly ineffective. National policies often fail because they ignore the specific institutional and material realities of different rural commodities. Policymakers must implement concrete, differentiated actions to permanently resolve these specific structural and coordination failures. The state must reform traditional financing instruments to successfully integrate informal micro-enterprises into the formal economy. Furthermore, local governments must actively strengthen rural entrepreneurial ecosystems through targeted capacity building and continuous mentoring. Policy instruments should explicitly support technological modernisation in the teak sector while facilitating market access in the bamboo sector.

To systematically design these precise interventions, the subsequent chapter employs an integrated multi-method analytical approach. Formulating a comprehensive governance model requires connecting individual entrepreneurial behaviour directly with systemic ecosystem dynamics. Therefore, the upcoming empirical analysis combines three advanced methodological tools to provide a highly comprehensive picture. Partial Least Squares Structural Equation Modelling (PLS-SEM) is utilised to test micro-level behavioural determinants empirically. This tool measures how socio-ecological mentality and ecosystem support drive the intention to adopt bioeconomy practices. Second, the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy-DEMATEL) maps complex cause-and-effect relationships within the meso-level ecosystem. This specific method explicitly distinguishes between the root causes and mere symptoms of regional transition barriers. Finally, Importance-Performance Map Analysis (IPMA) integrates with the DEMATEL findings to construct a definitive Policy Positioning Matrix. This matrix translates complex statistical data into concrete policy priorities, ensuring that future governance strategies remain highly actionable.

4 DIVERGENT PATHWAYS IN INDONESIA'S BIOECONOMY: A COMPARISON OF BAMBOO AND TEAK INDUSTRIES

5

5.1 Entrepreneurial profiles

The transition toward a forest-based bioeconomy in Indonesia does not follow a uniform developmental trajectory. This section compares two prominent forest product subsectors: bamboo handicrafts and teak wood furniture. The empirical analysis demonstrates that these industries operate under distinctly different entrepreneurial configurations. This divergence extends beyond the basic utilisation of different raw materials. It reflects significant variations in how these rural enterprises are structured and managed.

To systematically examine these differences, the entrepreneurial profiles of both sectors are evaluated across four key dimensions. These dimensions include demographic characteristics, primary business motivations, labour inclusivity levels, and initial capital mobilisation strategies. The comparative data reveal substantial variations between the two subsectors. Consequently, this chapter discusses how these specific strategic dimensions influence the adaptive capacity of each industry. The analysis focuses on empirical situations related to distinct entrepreneurial profiles that shape their respective responses to emerging sustainability demands within the forest-based bioeconomy.

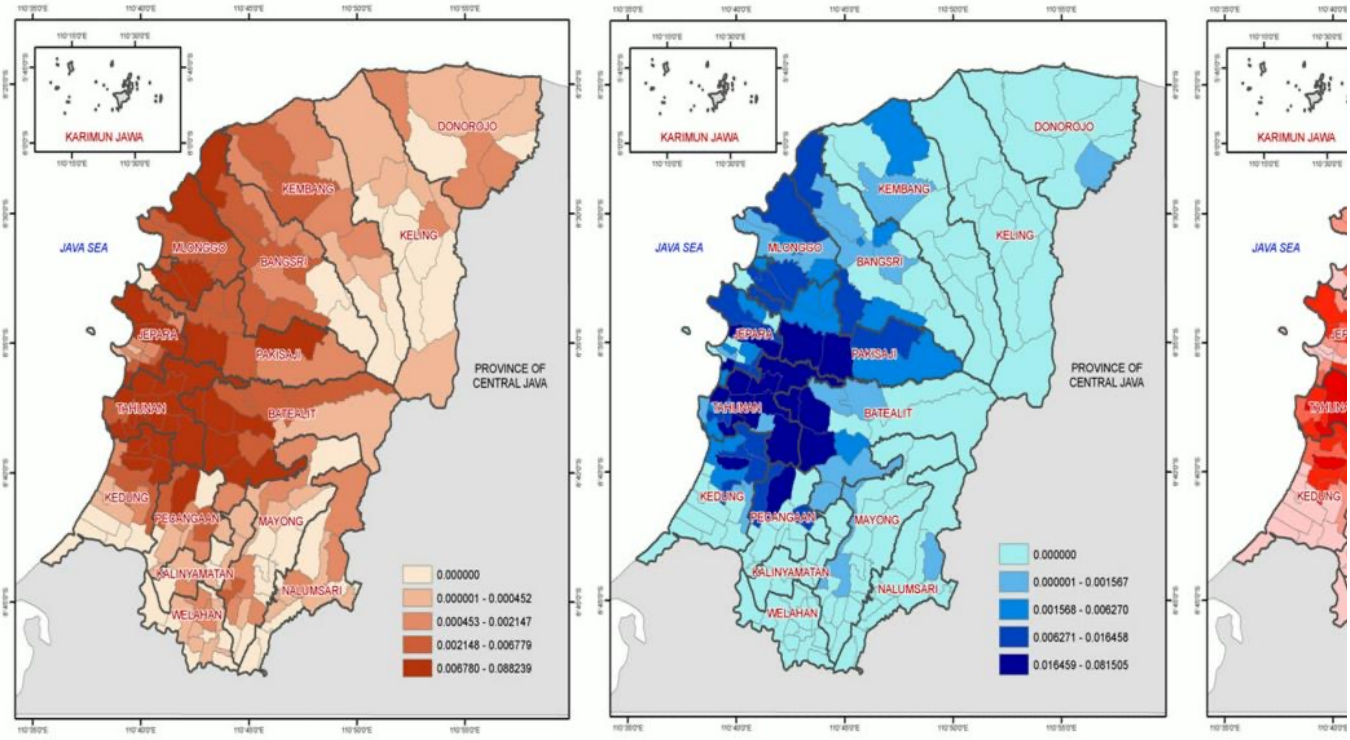
5.1.1 Comparing the Study Area

Jepara Regency is widely acknowledged as Indonesia's premier hub for furniture manufacturing and teak wood carving, occupying a pivotal position in both the regional and national economic landscapes (Purnomo et al., 2011). The sector exhibits a robust global footprint, maintaining a consistent export trajectory that penetrates over 90 international markets annually (Badan Pusat Statistik [BPS] Kabupaten Jepara, 2024). This international-scale output is heavily reliant on a massive mobilisation of local labour, absorbing between 70,000 and 85,000 workers. Such an employment figure accounts for more than half of the region's productive-age demographic currently engaged in the manufacturing sector. As a direct consequence, wood and furniture processing serves as the primary economic backbone, contributing the largest share to Jepara's Gross Regional Domestic Product (GRDP) (BPS Kabupaten Jepara, 2024; DPUPR Kabupaten Jepara, 2023).

From a structural perspective, the industrial landscape in Jepara is overwhelmingly dominated by Micro and Small Enterprises (MSEs). Recent statistical assessments reveal an active operational presence of roughly 5,500 to 5,993 furniture-related enterprises (BPS Kabupaten Jepara, 2024). More precisely, the wood-based commodity cluster alone encompasses over 4,074 highly active production units. This pronounced degree of business fragmentation reflects a profoundly decentralised production paradigm. Despite operating individually on a micro-scale, the overall resilience of the industry is communally sustained; it thrives by leveraging deeply integrated local supply chain networks and pervasive subcontracting practices among local entrepreneurs (Purnomo et al., 2011; Roda et al., 2007).

Figure 9 illustrates the distribution of furniture industry clusters in each village in Jepara, which are classified into: (a) production workshops, (b) wood raw material suppliers, and (c) retail outlets (Andriani et al., 2011). Cartographic representations utilising darker colour gradients denote heightened levels of industrial concentration, which are determined by the ratio of localised enterprises to the aggregate number of comparable businesses across Jepara. Spatially, nearly 70% of manufacturing workshops are heavily agglomerated within the Tahunan, Batealit, and Kedung sub-districts. Concurrently, the Tahunan, Jepara town, and Batealit areas host over 70% of the regional timber suppliers. Notably, this domestic timber provision satisfies a mere 24% of the industry's total material requirements, thereby necessitating substantial external sourcing to bridge the deficit. Within the downstream segment, retail operations exhibit severe clustering, with approximately 95% of vendors concentrated in the Tahunan, Jepara town, and Batealit vicinities. Collectively, these distribution metrics underscore the Tahunan sub-district as the paramount epicentre of the regional furniture ecosystem, accommodating 43% of the manufacturing workshops, 44% of raw material suppliers, and a striking 77% of retail outlets (Andriani et al., 2011).

Rather than being confined to a singular geographic location, furniture manufacturing activities across Jepara are dispersed into distinct industrial clusters, each systematically specialised according to specific craftsmanship domains (Roda et al., 2007). Functioning as the core commercial artery, Tahunan accommodates a broad spectrum of both indoor and outdoor furniture producers alongside large-scale commercial exhibition centres.



(a) Production workshop (b) Wood suppliers

Figure 9. Spatial Map of Furniture Industries in Jepara Regency

Source: Based on Andriani et al., 2011

In contrast, the Mulyoharjo enclave operates as a highly specialised hub dedicated to intricate relief carvings and premium wooden sculptures. Furthermore, peripheral buffer zones, such as the Kedung and Pecangaan sub-districts, primarily focus on supplying auxiliary components and performing critical finishing processes. Meanwhile, the Batealit sub-district is strategically positioned to facilitate medium- to large-scale export manufacturing facilities, a role enabled by its more expansive land availability (DPUPR Kabupaten Jepara, 2023; Roda et al., 2007). In the end, this spatial agglomeration coupled with functional clustering fosters a robustly synergistic industrial ecosystem, which remains instrumental in sustaining the global competitiveness of Jepara's furniture commodities (Purnomo et al., 2011).

Figure 10. Physical infrastructure and production processes of teak furniture Enterprises (MSMEs) in Jepara Regency, Central Java, Indonesia.

Source: Own.

As illustrated in Figure 10, the physical infrastructure of a typical teak furniture Enterprise in Jepara Regency encompasses a comprehensive, stage-by-stage production environment. The workspace is functionally divided into several key zones that support the complete manufacturing workflow within a single integrated facility. This includes outdoor and semi-open areas dedicated to raw material handling and primary machining, where large teak lumber and panels are initially processed. These zones transition seamlessly into covered assembly workshops to protect ongoing joinery and construction work. This spatial configuration demonstrates how these enterprises optimise constrained physical footprints to sustain a continuous production cycle, effectively bridging raw material logistics with the final stages of traditional woodworking and retail.

Tasikmalaya Regency is widely acknowledged as West Java's premier hub for creative manufacturing and traditional handicrafts, occupying a pivotal position in both the regional and national economic landscapes (Hendrayani et al., 2023). The sector exhibits a robust market footprint, maintaining a consistent trajectory that penetrates extensive domestic networks and international export markets (Prihardiputra, 2012). This large-scale output is heavily reliant on a massive mobilisation of local labour, absorbing tens of thousands of workers, primarily from rural demographics. Such an employment figure accounts for a substantial portion of the region's productive-age population currently engaged in the informal manufacturing sector. As a direct consequence, the handicraft and bamboo processing industries serve as a crucial economic backbone, contributing significantly to Tasikmalaya's Gross Regional Domestic Product (GRDP) and functioning as a vital poverty-alleviation mechanism (Badan Pusat Statistik [BPS] Kabupaten Tasikmalaya, 2024; Disperindag Kabupaten Tasikmalaya, 2018).

From a structural perspective, the industrial landscape in Tasikmalaya is overwhelmingly dominated by Micro, Small, and Medium Enterprises (MSMEs). Recent statistical assessments reveal an active operational presence of roughly 13,915 handicraft-related enterprises distributed across 405 communal nodes (Disperindag Kabupaten Tasikmalaya, 2018). More precisely, the woven commodity cluster encompassing bamboo, pandanus, and mendong grass accounts for a significant majority of these highly active production units. This pronounced degree of business fragmentation reflects a profoundly decentralised production paradigm. Despite operating individually on a micro-scale, the overall resilience of the industry is communally sustained; it thrives by leveraging deeply integrated local supply chain networks and pervasive subcontracting practices among rural entrepreneurs (Zuriyah et al., 2023).

Spatially, Figure 11 illustrates the highest concentration of commercial and manufacturing workshops is heavily agglomerated within the northern corridor, specifically the Rajapolah and Jamanis sub-districts. Before recent economic fluctuations, Rajapolah alone concentrated over 1,824 active MSMEs, maintaining absolute dominance in market absorption (BPS (Kabupaten Tasikmalaya, 2021). Rather than being confined to a singular geographic location, handicraft manufacturing activities across Tasikmalaya regency are dispersed into distinct industrial clusters, each systematically specialised according to specific material domains and craftsmanship expertise (Government of Tasikmalaya Regency, 2012).

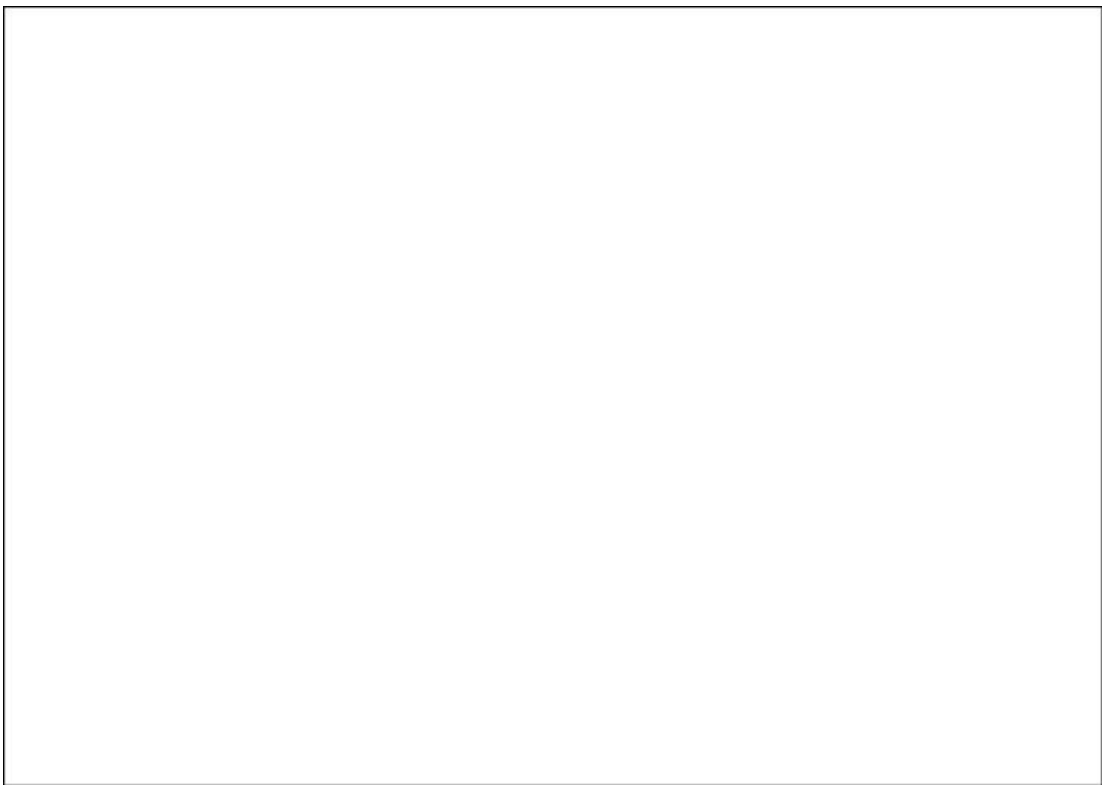


Figure 11. Spatial Map of Handicraft and Bamboo Industries in Tasikmalaya Regency

Source: Author's elaboration based on BPS Kabupaten Tasikmalaya, 2021.; Hendrayani et al., 2023; Zuriyah et al., 2023

Functioning as the core commercial artery, the Northern Zone (Rajapolah) accommodates a broad spectrum of woven goods producers alongside large-scale retail exhibition centres. In contrast, the Central and Eastern enclaves operate as highly specialised nodes; Leuwisari serves as the pioneering incubation hub for communal bamboo craftsmanship, while Manonjaya is dedicated to advanced mendong grass agro-industry and premium mat weaving (Hendrayani et al., 2023). Furthermore, peripheral buffer zones located in the Southern Zone, such as the Salopa and Pancatengah sub-districts, predominantly focus on supplying crucial raw materials, executing primary extraction, and conducting the preliminary processing of rough bamboo components (Government of Tasikmalaya Regency, 2012). Then, this spatial agglomeration coupled with functional clustering fosters a robustly synergistic industrial ecosystem, which remains instrumental in sustaining the economic resilience and competitiveness of Tasikmalaya's handicraft commodities (Zuriyah et al., 2023).

As illustrated in Figure 12 for the typical operational environment and physical infrastructure of a bamboo craft enterprise in Tasikmalaya Regency, the facilities are systematically segmented into several specific zones that facilitate the entire

manufacturing workflow, including a semi-outdoor storage area for raw bamboo materials, a mechanical workshop equipped with cutting and processing machinery, and a dedicated indoor space for material drying and preparation. Furthermore, the enterprise encompasses a semi-open assembly area where craftsmen weave the processed bamboo, alongside a designated inventory section equipped with shelving for storing and displaying finished products. This physical setup illustrates the functional spatial organisation of a traditional Enterprise, highlighting how available space is optimised to manage the complete production cycle from raw material handling to final marketable goods despite potential infrastructure limitations.

Figure 12. Production facilities and workspace environment of a bamboo craft in Tasikmalaya Regency, West Java, Indonesia

Source: Own

5.1.2 Comparative Profiling of Entrepreneurial Attributes in Teak Wood and Bamboo Enterprises

The entrepreneurial characteristics of business owners in bamboo handicrafts and teak wood furniture differ significantly across four strategic dimensions. These dimensions include demographic maturity (age distribution), primary entrepreneurial motivation, workforce inclusivity (gender composition), and initial capital structure (financial mobilisation).

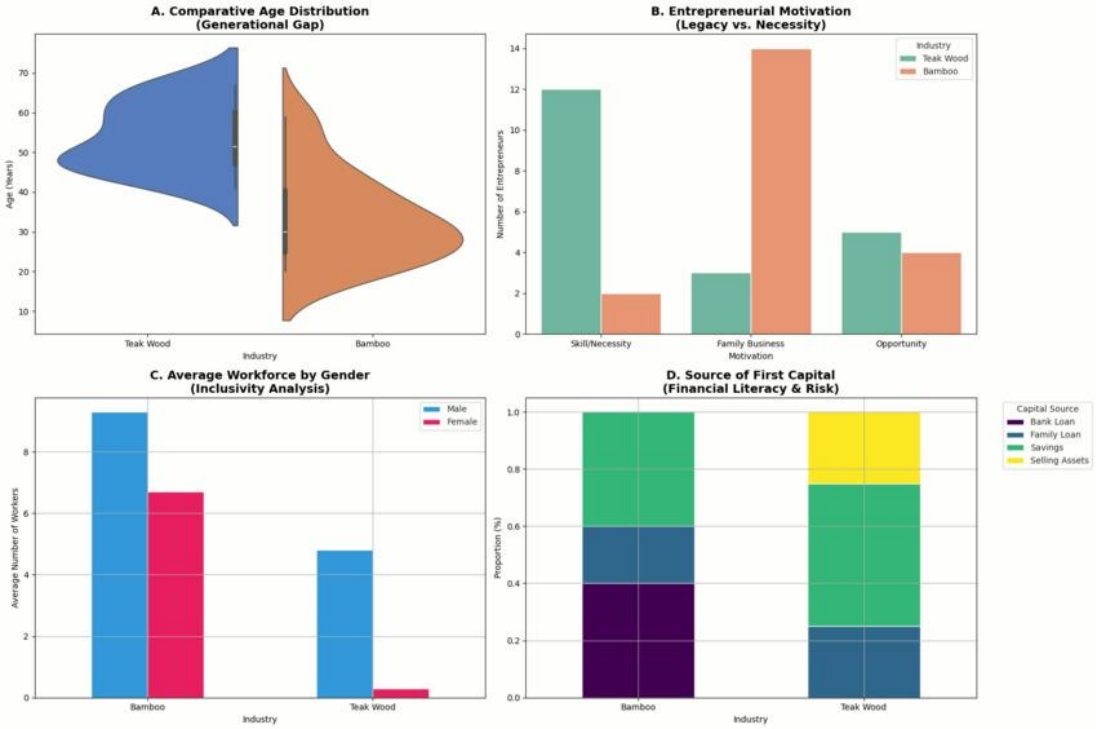


Figure 13. Profiling of Entrepreneurial Attributes in Teak Wood versus Bamboo entrepreneur

Source: own.

Figure 13 illustrates a clear structural dichotomy between actors in these two rural industries. The data indicate two distinct entrepreneurial configurations operating within the same regional bioeconomy. The teak sector largely represents a traditional business model based on specialised technical expertise and male-dominated labour. Conversely, the bamboo sector exhibits a more inclusive demographic profile integrated with better access to formal finance.

Panel A: Demographic Maturity and Generational Transition

The age distribution of entrepreneurs presented in Panel A (Figure 13) reveals a stark demographic contrast between the two sectors. The teak wood furniture sector shows a markedly older demographic structure. Most entrepreneurs in this cluster are aged between 50 and 77 years. In contrast, the bamboo handicraft cluster exhibits significant participation from younger demographics, primarily individuals in their 20s and 30s.

This generational imbalance may reflect the difficulty of transferring tacit skills within traditional woodworking industries. Expertise in teak carving is typically acquired through long-term practice and apprenticeship (Woodfield & Husted, 2017). The prevailing older demographic profile within the teak cluster suggests a potential

generational transition challenge. Furthermore, an ageing workforce may limit the sector's overall capacity to adopt new digital technologies or production innovations.

Conversely, the growing involvement of younger demographics within the bamboo cluster provides a distinct operational advantage. Lower technical entry barriers and material flexibility make bamboo highly accessible for new entrepreneurs. The prominence of younger cohorts aligns with recent sustainable entrepreneurship literature. Vuorio et al. (2017) indicate that younger demographics often demonstrate stronger orientations toward sustainability values and green business models. Consequently, this younger demographic profile may facilitate the future adoption of digital marketing tools and circular economy principles within the bamboo sector.

Panel B: Entrepreneurial Motivation and Institutional Continuity

Panel B (Figure 13) highlights fundamental differences in the primary motivations driving business formation in both clusters. The teak wood furniture cluster largely represents necessity-driven entrepreneurship. For many actors in this sector, starting a business serves as a proactive survival strategy, utilising existing woodworking skills. However, businesses born primarily out of economic necessity often face structural growth limitations. Dencker et al. (2019) suggest that necessity-driven enterprises frequently adopt conservative governance models focused strictly on self-sufficiency. This reliance on the physical presence and individual skill of the founder can restrict the enterprise's capacity to scale into a larger industrial entity.

This motivational profile contrasts sharply with the bamboo craft cluster. In this sector, business formation is heavily influenced by family succession and intergenerational transfer. The high frequency of inherited businesses indicates that the bamboo ecosystem has successfully managed institutional transitions across generations. This successful regeneration suggests an effective transfer of socio-emotional wealth (SEW). Zellweger et al. (2018) note that intergenerational succession facilitates the vital transmission of tacit knowledge and established relational capital. Consequently, successors in the bamboo cluster benefit from a shorter learning curve compared to new entrants in the teak sector.

Panel C: Workforce Inclusivity and Socioeconomic Resilience

An analysis of employment demographics in Panel C (Figure 13) reveals significant occupational stratification based on gender. The data indicate that the teak

wood furniture ecosystem operates predominantly with male labour. Female labour participation in this specific sector remains statistically marginal. This male dominance likely stems from the physical demands and ergonomic barriers associated with processing heavy hardwood. Historically, these physical requirements have created entry barriers that limit female participation in traditional logging and heavy carpentry.

In contrast, the bamboo handicraft industry displays a significantly more egalitarian employment profile. The physical characteristics of bamboo, specifically its lightweight and flexible fibres, fundamentally alter the production process. Bamboo processing accommodates tasks requiring precision rather than extreme physical strength, such as weaving and detailed assembly (Amjad, 2024; Depuydt et al., 2019). This material characteristic creates substantial opportunities for female workers to participate directly in the production base.

From a socioeconomic resilience perspective, these structural differences carry important implications. Ravera et al. (2016) note that sectors unable to absorb diverse labour may experience limited resilience to localised economic shocks. Conversely, the technical flexibility of bamboo production may enhance the overall economic resilience of rural households. Integrating women into the core production base supports a dual-income livelihood structure. This inclusivity aligns with broader bioeconomy goals that emphasise both product value-added and equitable development (Ramcilovic-Suominen, 2022).

Panel D: Initial Capital Structure and Financial Mobilisation

The initial capital structure detailed in Panel D (Figure 13) exposes a sharp financial asymmetry between the two sectors. The teak wood furniture cluster relies almost exclusively on internal funding and personal bootstrapping. The absence of formal bank credit indicates significant administrative barriers or a reluctance to engage with formal financial institutions. To maintain operations, these actors frequently liquidate household assets or sell personal vehicles. Relying entirely on internal capital restricts fiscal flexibility and exposes households to substantial financial risk (Blank et al., 2007; Zhu & Zhang, 2009). In such circumstances, a significant market shock could directly impact personal household assets, potentially constraining future investments in innovation.

In contrast, the financial profile of the bamboo craft cluster indicates a higher degree of interaction with formal banking institutions. The presence of bank credit

facilities suggests that these entities successfully navigate institutional lending requirements. Wellalage and Fernandez (2019) observe that access to external capital often correlates with the ability of entrepreneurs to present measurable business prospects to creditors. Access to formal institutional capital provides a clear comparative advantage. It allows bamboo enterprises to finance operational scalability and adopt new technologies without depleting personal household wealth.

5.1.3 Comparative Analysis of Operational Dynamics

Upstream supply chain efficiency represents a critical determinant of industrial competitiveness and resilience. The differing material characteristics of hardwood and bamboo necessitate distinct procurement mechanisms. Figure 14 presents a comparative visualisation of operational dynamics across these two commodities. The analysis evaluates two strategic dimensions: primary sourcing channels and specific resource constraints. The empirical data reveal significant structural differences between the two rural sectors. The teak industry relies heavily on complex intermediary networks to maintain quality standards. Conversely, the bamboo industry utilises a hybrid procurement pattern but faces physical accessibility challenges.

The architecture of raw material procurement highlights a significant asymmetry in upstream control. The teak wood furniture cluster demonstrates a high dependency on third-party intermediaries. Distributors unilaterally control approximately 95% of the raw material supply in this sector. This high degree of intermediation creates severe structural limitations for rural micro-enterprises. Complex forestry regulations and high logistical costs systematically restrict direct commercial access to forests (Purnomo et al., 2020). Consequently, teak craftsmen operate primarily as price-takers at the end of the supply chain. This position exposes their profit margins to accumulated transaction costs from multiple intermediary layers.

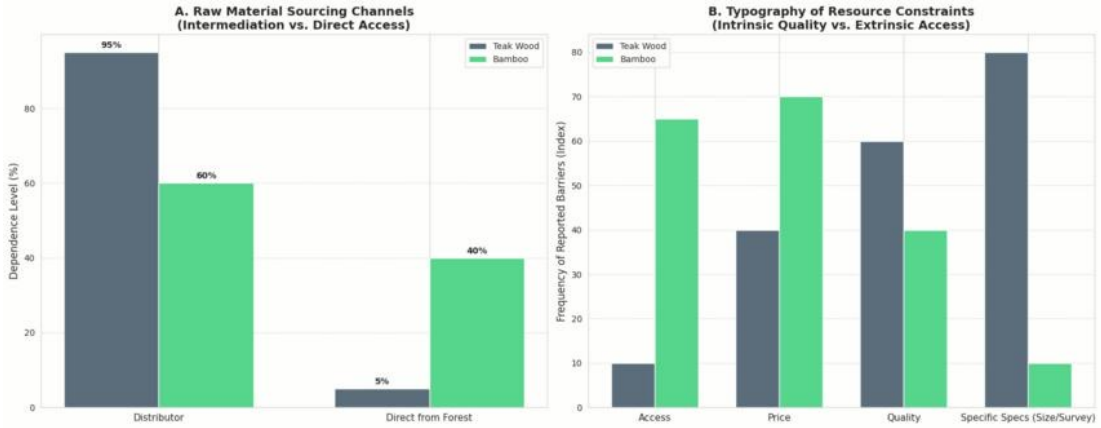


Figure 14. Comparison of sourcing channels and resource constraints

Source: own.

In contrast, the bamboo craft cluster exhibits a higher degree of strategic flexibility. Bamboo enterprises implement a dual-sourcing strategy for their raw material procurement. Distributors still supply approximately 60 percent of their required materials. However, these enterprises successfully secure the remaining 40 percent directly from forests or local farmers. The spatial proximity and regulatory elasticity of bamboo facilitate this partial vertical integration. Eliminating intermediary distribution channels directly supports the theoretical advantages of short supply chains (Paciarotti & Torregiani, 2020). This direct procurement significantly reduces input cost structures for bamboo entrepreneurs. Furthermore, reducing reliance on external stock availability enhances the overall operational resilience of these rural enterprises.

The visualisation of supply barrier typologies reveals distinct frictions across the two commodities. In the teak furniture cluster, procurement barriers centre primarily on intrinsic qualitative dimensions. The data indicate sharp increases in constraints related to specific material specifications and quality standards. The primary challenge involves information asymmetry regarding the structural integrity of the wood. Craftsmen require precise diameters, specific wood maturity, and particular grain patterns for export markets. The absence of a transparent upstream standardisation system generates significant transaction costs (Agi & Nishant, 2016). An entrepreneur must invest substantial time and capital in direct visual inspections to mitigate material defect risks.

The procurement barriers in the bamboo cluster differ substantially from those in the teak sector. Constraints for bamboo shift sharply toward extrinsic logistical challenges, specifically physical access and transportation prices. This phenomenon

reflects the inherent logistical challenges of managing low-density agricultural materials. Bamboo grows rapidly and abundantly, but it possesses a disproportionately low volumetric density. Biomass logistics frameworks indicate that low-density materials consume enormous spatial volume during transportation (Malladi & Sowlati, 2018). Consequently, transport costs escalate disproportionately and frequently surpass the intrinsic value of the raw material. This spatial friction is compounded by bamboo habitats typically located on steep topography with inadequate rural road infrastructure.

This divergence in supply chain constraints requires two distinct directions for policy intervention. The challenges in the teak sector primarily involve information asymmetry and quality verification. This sector requires institutional engineering through precise grading and standardised quality certification systems. Conversely, the bamboo sector faces a severe connectivity and logistical challenge. This sector requires infrastructural engineering through the decentralisation of primary processing units. Establishing preservation or splitting centres directly at the forest edge would significantly reduce spatial inefficiencies and transportation costs.

5.1.4 Market Orientation & Commercial Barriers

The downstream commercialisation of final bioeconomy products represents a critical phase for rural enterprises. A company's market penetration capability determines its long-term economic sustainability.

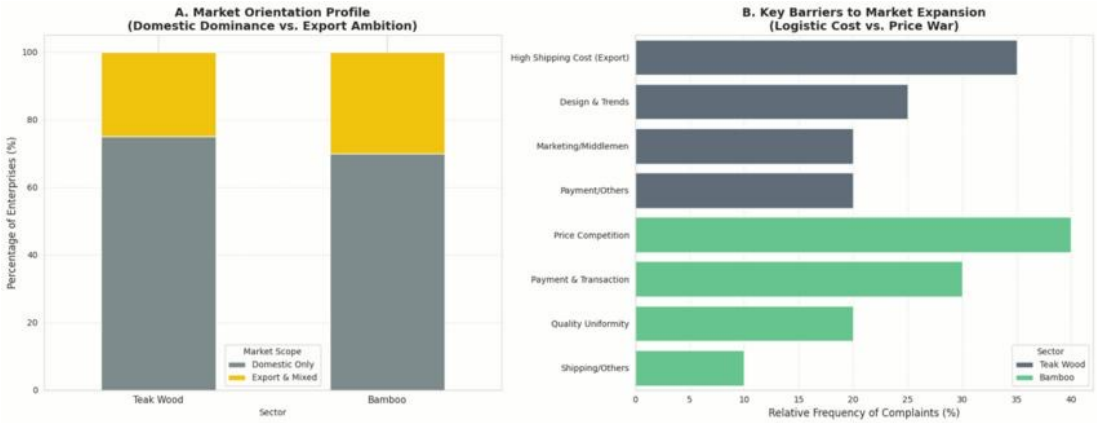


Figure 15. Comparison of market orientation and key barriers to market expansion

Source: own.

Figure 15 presents a comparative analysis of the commercial landscape across the two sectors. The data dissects the market orientation of business actors and their specific

barriers to expansion. The visualisation reveals a heavy dependence on domestic consumption across both industries. This reliance is primarily driven by uncertainties and structural constraints within the global market.

Panel A of Figure 15 illustrates a strong home-market bias in both clusters. Domestic demand overwhelmingly dictates business continuity for both teak furniture and bamboo craft enterprises. This phenomenon represents a pragmatic liquidity strategy rather than a simple lack of ambition. Local markets offer significantly faster cash-flow cycles and reduced cross-border transaction risks (Paul et al., 2017). Consequently, entrepreneurs prioritise domestic markets to secure their daily operational subsistence buffer. They accept this domestic focus despite a generally low consumer willingness-to-pay for ecological value-added products.

However, data regarding the export and mixed segments reveal a divergence in international competitiveness. The bamboo cluster demonstrates a slightly more progressive export penetration compared to the teak sector. Products with strong sustainability narratives often exhibit superior eco-credential elasticity in international markets. This characteristic allows bamboo products to align effectively with growing global eco-lifestyle trends (Hojnik et al., 2017). Conversely, teak furniture remains constrained within a slow-moving and expensive premium niche. This specific sector faces significant operational burdens from stringent international hardwood regulations. These industries utilise the domestic market as a foundational resilience strategy while gradually exploring export niches.

Panel B of Figure 15 identifies distinct commercial barriers affecting global market penetration. The teak wood furniture cluster faces severe physical and structural logistical constraints. High shipping costs represent the most prominent barrier for this specific sector. The disproportionate weight-to-commercial-value ratio of heavy hardwood creates significant logistical friction. These high transportation costs frequently erode the profit margins of exported teak products. Furthermore, the teak sector experiences substantial friction regarding design and trend adaptation (Kahiya, 2018). Producers struggle to translate contemporary global market preferences into their traditional product lines. This design inertia places teak products at risk of aesthetic obsolescence in international markets.

In contrast, the bamboo craft cluster faces fundamentally different market challenges. Frequent complaints regarding price competition indicate that bamboo

entrepreneurs operate in a highly saturated market. Low entry barriers in the woven goods industry generate an oversupply of generic products. This oversupply transforms bamboo crafts from specialised entrepreneurial goods into highly price-elastic mass commodities. Consequently, business actors must accept narrow subsistence margins that severely restrict their capacity for innovation.

Additionally, the bamboo cluster reports significant constraints related to international payments and transactions. This constraint highlights a severe exclusion from modern digital financial infrastructure (Li et al., 2017). Global demand for bamboo products frequently fails to materialise due to inaccessible cross-border payment gateways. This divergence in commercial barriers necessitates highly specific policy interventions. The teak cluster primarily requires hardware interventions, including more efficient physical distribution and logistics support. Conversely, the bamboo cluster urgently requires software and institutional injections. Policymakers must modernise digital financial architectures and support product differentiation to help bamboo entrepreneurs escape severe commoditization.

5.1.5 Strategic Trajectory and Institutional Support

Panel A of Figure 16 illustrates the distinct strategic roadmaps of both entrepreneurial ecosystems. The data indicates that these two entities operate at different stages of industrial maturity. Within the teak wood furniture cluster, strategic priorities centre entirely on deepening endogenous production capabilities. The prominence of product development indicators highlights a collective awareness among local entrepreneurs. They recognise that raw material quality alone cannot compensate for outdated production technologies. Consequently, the teak sector plans a structural transition from manual crafting to semi-mechanical manufacturing. Additionally, initiatives to adopt augmented reality (AR) for digital showrooms indicate targeted technological upgrading (Frank et al., 2019). This manoeuvre represents a deliberate effort to redefine their value proposition for premium global markets.

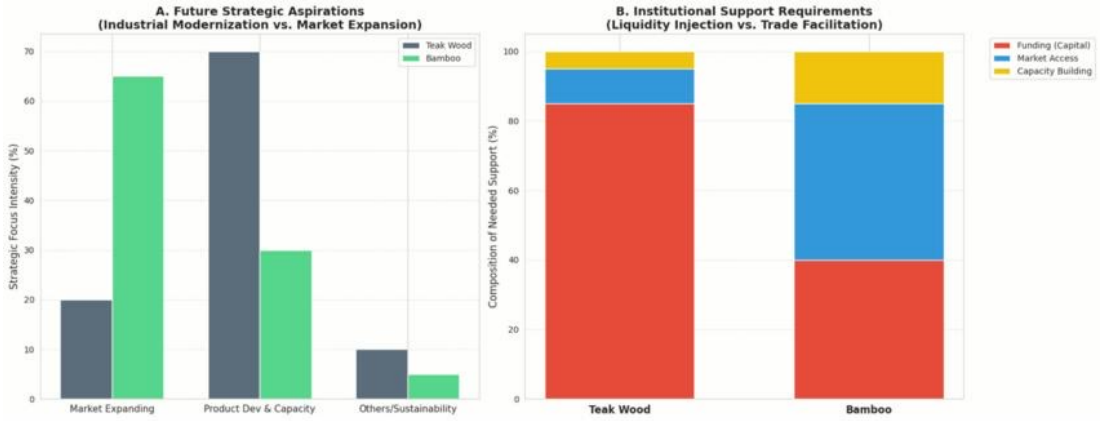


Figure 16. Comparison of Strategic Planning & Support Needs

Source: own.

In contrast, the future architecture of the bamboo industry relies heavily on spatial market expansion. The teak sector primarily faces physical capacity and precision constraints on the supply side. However, the bamboo sector experiences severe operational limitations strictly on the demand side. Bamboo weaving production capacity is highly elastic and can be rapidly scaled by local entrepreneurs. Therefore, acquiring new machinery yields minimal economic benefits without proportional market absorption channels. This dynamic aligns directly with empirical frameworks regarding MSME competitiveness in emerging markets (Oura et al., 2015). When industries face domestic saturation, creating new distribution routes becomes significantly more critical than product modification. Consequently, bamboo entrepreneurs focus their strategic rationale entirely on expanding demographic and geographic market reach. The teak sector requires technological capital injections to maintain its manufacturing relevance. Meanwhile, the bamboo sector requires accelerated inventory turnover across new geographic markets to ensure economic viability.

Panel B of Figure 16 outlines the specific institutional support mandated by these ecosystems. The data reveal a fundamental difference in the policy interventions expected by each sector. The teak wood furniture cluster demonstrates an exceptionally high reliance on direct capital funding. This urgent need for liquidity reflects structural constraints in long-term investment financing rather than operational mismanagement. Transitioning toward capital-intensive technological modernisation cannot rely solely on internal bootstrapping methodologies. This condition highlights the absolute necessity of restructuring traditional manufacturing MSMEs through external mechanisms (Hervas-

Oliver et al., 2020). Without targeted fiscal interventions, such as machinery subsidies or low-interest credit, this sector faces continuous liquidity constraints.

Conversely, the bamboo cluster exhibits a highly heterogeneous profile regarding its institutional needs. These entrepreneurs emphasise market access facilitation and specialised capacity-building programs. The data confirms that production capital scarcity does not represent their primary operational pathology. Instead, bamboo entrepreneurs struggle primarily with persistent information asymmetry and international market isolation. For globally oriented entities, export promotion programs provide significantly more effective interventions than generic financial injections (Malca et al., 2019). Distributing cash capital without opening new markets severely risks triggering localised oversupply issues. Therefore, bamboo enterprises specifically demand structured investments in soft infrastructure. They require active trade diplomacy, global compliance standardisation, and robust market intelligence frameworks. These institutional bridges remain critical for connecting rural supply capacities with specialised international demand.

5.1.6 Divergent Pathways in the forest-based Bioeconomy - Discussions

The physical characteristics of natural resources determine the strategic trajectory of each industrial sector. This aligns with the Natural-Resource-Based View (NRBV) regarding material-dependent business strategies (Laakkonen et al., 2023). Teak wood possesses heavy physical mass and a very slow regeneration cycle. Conversely, bamboo represents a lightweight biomass with a rapid harvesting cycle. These distinct material realities directly create different logistical and operational barriers.

The operational dynamics of both commodities demonstrate contrasting positions within the Socio-Technical Transitions framework. The rural teak furniture industry currently operates as a locked-in socio-technical regime. Teak entrepreneurs rely heavily on traditional supply chain intermediaries who monopolise the local market. The bamboo craft sector functions instead as a highly dynamic niche innovation. Bamboo entrepreneurs prove highly responsive to global circular sustainability demands. Successful systemic transitions require simultaneous regime destabilisation and niche innovation acceleration (Köhler et al., 2019; Geels, 2019).

These structural differences stem from individual cognitive rationalities explained through the Theory of Planned Behaviour (TPB). Pragmatic motives and economic necessity completely drive the transformation decisions of teak craftsmen. Mastering

physical machinery technology directly increases perceived behavioural control for these teak entrepreneurs. Conversely, a shared socio-ecological mentality entirely drives the transformation motives of bamboo entrepreneurs. Communal norms and environmental preservation values form the primary foundation for their business decisions. This ecological value alignment serves as the main driver for rural green entrepreneurial intentions (Kuckertz et al., 2020; Hinderer et al., 2021).

This transformation pathway divergence confirms a fragmented architecture within local entrepreneurial ecosystems. Bamboo entrepreneurs utilise social capital and communal networks to overcome severe local institutional voids. Nevertheless, scaling up these businesses still requires specific infrastructural interventions from the broader ecosystem (Fischer et al., 2020). The teak sector urgently requires hardware interventions like targeted machinery upgrading subsidy programmes. Meanwhile, the bamboo sector demands soft infrastructure, including digital payment gateways and export access licensing. Forest-based bioeconomy development governance cannot be uniformly standardised and must be specifically tailored.

5.2 Structural Dynamics of the Forest-Based Bioeconomy: The Role of Entrepreneurial Ecosystems in Rural Transformation

The demographic and entrepreneurial mapping in the previous section reveals a clear structural polarisation between the teak and bamboo industries. The teak furniture industry represents a traditional business model characterised by exclusive practices and a labour-intensive structure. Conversely, the bamboo handicraft sector exhibits a highly flexible business architecture with a more inclusive demographic composition. Furthermore, this non-timber sector demonstrates greater adaptability in adopting formal financial instruments compared to the traditional timber regime. However, descriptive structural characteristics alone cannot fully explain the fundamental drivers of entrepreneurial intentions toward the bioeconomy transition.

To better understand these underlying dynamics, the analysis must shift from structural observations to cognitive and behavioural determinants. Consequently, this chapter analyses the determinants of bioeconomic transformation intention using the Theory of Planned Behaviour (TPB). This foundational framework is systematically integrated with entrepreneurial ecosystem variables to evaluate the decision-making processes of micro-enterprises. The Partial Least Squares Structural Equation Modelling (PLS-SEM) approach is employed to empirically test the significance of these causal

relationships. Ultimately, this empirical analysis provides an objective foundation for designing targeted policy interventions across different forest-based industrial ecosystems.

5.2.1 Outer Model Evaluation (Measurement Model)

The measurement model specification begins by defining the exogenous variables representing fundamental rural development modalities. These fundamental modalities systematically consist of regional material resources and local social capital networks. To ensure analytical clarity and prevent descriptive redundancy, the operationalisation of all variables is systematically tabulated. Table *24* explicitly details the constructs, their designated measurement indicators, and the corresponding theoretical sources. Furthermore, the table specifies whether each latent variable functions as a formative or reflective construct. This precise specification is critical because PLS-SEM requires fundamentally different statistical evaluation criteria for each type. Formative indicators are rigorously evaluated using convergent validity, outer weights, and variance inflation factor statistics. Conversely, reflective measurement models are systematically assessed through internal consistency reliability and discriminant validity parameters.

Following standard PLS-SEM reporting protocols, this study systematically evaluates the measurement model before hypothesis testing. This preliminary evaluation remains essential to eliminate the statistical risk of measurement specification bias. The procedure ensures that all extracted questionnaire indicators accurately and consistently represent their respective latent variables. Consequently, the assessment focuses strictly on internal consistency reliability, convergent validity, and discriminant validity parameters.

Table 24. Operationalisation of Variables, Construct Types, and Measurement Indicators

Latent Variables	Construct Type	Code	Measurement Indicators	Main References	Status
Source of Biomaterial (SUB)	Formative	SUB1	Biomaterial stock stability	Johnson et al. (2022)	Adapted
		SUB2	Price affordability	Johnson et al. (2022)	Adapted
		SUB3	Procurement legality and ethics	Otto et al. (2021); Dobrynin et al. (2021)	Adapted
Social Capital (SCP)	Formative	SCP1	Family entrepreneurial traditions	Hinderer & Kuckertz (2022)	Adapted

Latent Variables	Construct Type	Code	Measurement Indicators	Main References	Status
		SCP2	Local community support	Daskalopoulou et al. (2023)	Adapted
		SCP3	Entrepreneurial network participation	Chen et al. (2021)	Adapted
Entrepreneurial Ecosystem (EES)	Reflective	EES1	Government policy/fiscal support	Scarlat et al. (2015)	Adapted
		EES2	Presence of financial capital providers	Stam & Van De Ven (2019)	Adapted
		EES3	Geographical embeddedness and proximity	Spigel & Harrison (2017)	Adapted
		EES4	Local public support and consumer trends	Kuckertz (2020)	Adapted
		EES5	The role of culture in norms and behavior	Spigel & Harrison (2017)	Adapted
		EES6	Human resource competencies	O'Connor & Audretsch (2022)	Adapted
		EES7	Cross-sectoral coordination	O'Connor & Audretsch (2022)	Adapted
		EES8	Collaboration with research institutions	Stam & Van De Ven (2019)	Adapted
Sustainable Technological Adoption (TEA)	Formative	TEA1	Ease of system integration	Scarlat et al. (2015)	Adapted
		TEA2	Biomass utilisation efficiency (cascading use)	D'Amato et al. (2017)	Adapted
		TEA3	Compatibility with regulations and standards	McCormick & Kautto (2013)	Adapted
		TEA4	Availability of local and regional knowledge	McCormick & Kautto (2013)	Adapted
		TEA5	Mitigation of negative ecosystem impacts	D'Amato et al. (2017)	Adapted
		TEA6	Cost feasibility and competitiveness	Scarlat et al. (2015)	Adapted
Socio-Ecological Mentality (SOM)	Formative	SOM1	Education on environmental issues	Pülzl et al. (2014)	Adapted
		SOM2	Recognition of resource limits (climate crisis)	Pfau et al. (2014)	Adapted
		SOM3	Alignment of economic activities with natural cycles	Pfau et al. (2014)	Adapted
		SOM4	Prioritisation of long-term	McCormick & Kautto (2013)	Adapted

Latent Variables	Construct Type	Code	Measurement Indicators	Main References	Status
			environmental policies		
		SOM5	Demands for supply security and transparency	McCormick & Kautto (2013)	Adapted
		SOM6	Promotion of environmental ethics	Pülzl et al. (2014)	Adapted
Bioeconomic Transformations Intentions (BOT)	Reflective	BOT1	Support for bioenergy development	Dietz et al. (2018)	Adopted
		BOT2	Commitment to circular economy principles	Dietz et al. (2018)	Adopted
		BOT3	Support for bio-based product innovation	Dietz et al. (2018)	Adopted

Source: Own based on the sources cited.

Table 25 presents the statistical resilience of these measurement instruments across two distinct bioeconomy landscapes. These compared industrial landscapes specifically comprise communal bamboo craft entities and capital-oriented teak furniture industries. The statistical extraction results confirm that both survey instruments successfully surpassed contemporary PLS-SEM reliability thresholds. Furthermore, both the formative and reflective indicators demonstrated highly acceptable statistical robustness during the evaluation process. Passing this rigorous evaluation provides a solid analytical foundation for the subsequent structural path analysis. Any subsequent causal differences detected between commodities accurately reflect institutional field realities rather than methodological flaws.

Table 25. Outer Model Evaluation Result

Diagnostic Metrics & Thresholds	Empirical Realities: Bamboo Craft	Empirical Realities: Teak Wood Furniture
Indicator Reliability (Outer Loadings λ>0,708) ***Ensuring measurement precision.***	**Robust Convergence.** The indicators for EES and SOM exhibited high precision (λ = 0,726–0,890). The instrument effectively captured field realities.	**Exceptional Stability**. EES items demonstrate superior homogeneity (λ:0,869−0,925). The measurement tool was highly reliable for the formal sector.
Internal Consistency (Cronbach's α & ρc >0,70)	**Strong Cohesion.** (α=0,905; ρc =0,927). Entrepreneur responses reflected a highly	**Supreme Reliability**. (α=0,949; ρc =0,959). Yields absolute internal

Diagnostic Metrics & Thresholds	Empirical Realities: Bamboo Craft	Empirical Realities: Teak Wood Furniture
This confirms the instrument coherence.	unified understanding of the constructs.	consistency in the teak industrial sample.
Convergent Validity (AVE >0,50) ***Verification of variance extraction.***	**Substantial Validity**. (AVE = 0,680). Explains >68% of the information variance and successfully minimises error terms.	**High Dimensionality.** (AVE = 0,798). Captures nearly 80% of the latent variance, reflecting a highly concentrated construct structure.
Lateral Collinearity (Outer VIF <5,0) **This prevents data redundancy.**	**Safe Margin.** VIF spans 2,10−3,67. The formative dimensions are uniquely distinct without overlapping biases.	**Safe Margin**. VIF spans 1,204−4,673. Assures structural independence across Raw Material and Technology indicators.
Formative Significance (Weight p<0,05 or λ≥0,50) ***Evaluation of absolute relevance.***	**Selective Drivers.** TEA1, TEA3, TEA6, and SOM1, SOM4, and SOM5 were statistically significant. Non-significant items with strong absolute loadings (λ≥0,641).	**Key Determinants.** SUB1, SUB3, TEA2, and TEA5 act as the main operational pillars. Statistically weak weights were retained seamlessly because of robust loadings (λ≥0,635).
Redundancy Analysis (Correlation ≥0,70) ***Defines formative constructs.***	**Valid Construct Design**. The TEA validly encapsulates the spectrum of appropriate technology dimensions in rural settings.	**Valid Construct Design**. Formative composites (SUB, TEA) accurately encapsulate operational reality from upstream to downstream.

Source: Own

A. Teak wood model

The measurement model evaluation for the Teak wood cluster begins with the reflective Entrepreneurial Ecosystems (EES) construct. The EES construct, operationalised reflectively to capture the holistic perceived conduciveness, demonstrates strong convergent validity. These empirical outputs substantiate the theoretical assumption that the diverse pillars of the entrepreneurial ecosystem act as highly interdependent components that collectively reflect a unified conducive environment for the respondents. Figure 17 illustrates this reflective specification through outward-directed arrows from the latent variable to its indicators. The reliability analysis reveals a high level of internal consistency for this specific measurement model. The statistical

extraction recorded a Cronbach's alpha coefficient of 0,949 and a composite reliability of 0,960. Both parameters substantially exceed the acceptable threshold of 0,70 recommended in contemporary PLS-SEM literature (Hair et al., 2019). Furthermore, the evaluation assesses convergent validity to rigorously verify the accuracy of the measurement instrument. All EES indicators demonstrate significant variance contributions with outer loading values ranging from 0,869 to 0,925. These specific values significantly surpass the critical threshold of 0,708 required for satisfactory indicator reliability.

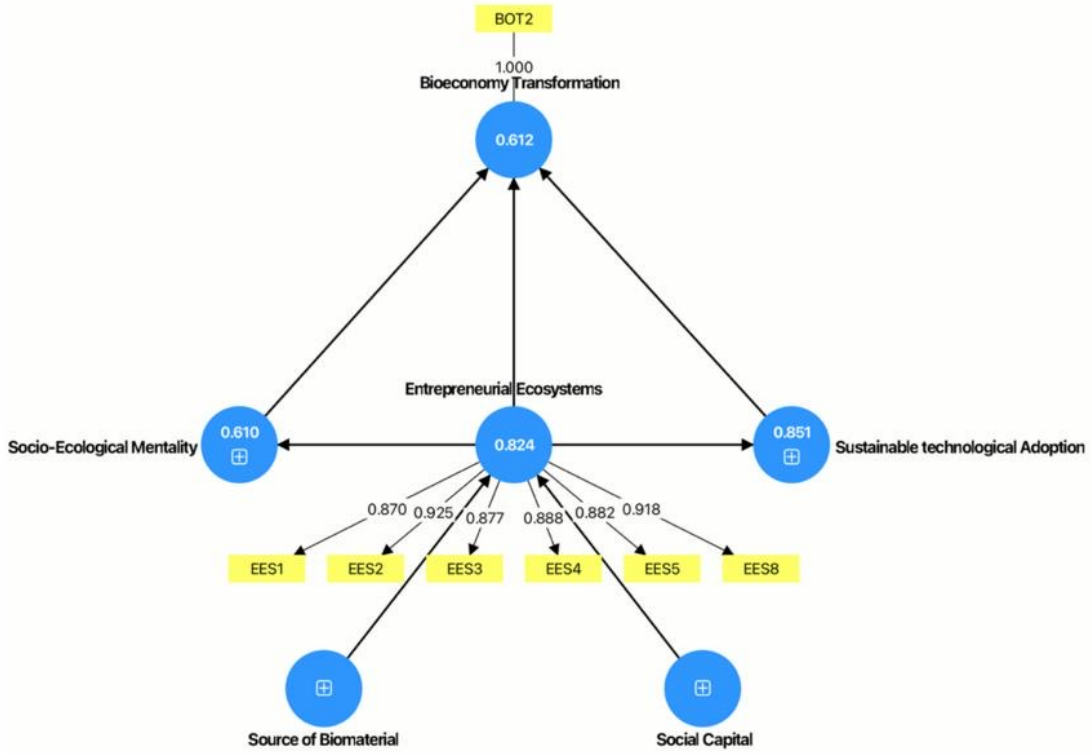


Figure 17. Reflective measurement model for teak wood

Source: Own.

The evaluation then proceeds to examine the specified formative constructs within the structural model framework. These specific constructs thoroughly include sustainable technological adoption (TEA) and the source of biomaterial (SUB). Figure 18 displays these formative specifications using inward-directed arrows from the indicators to the latent variables. The convergent validity of these formative constructs is initially confirmed through a standard redundancy analysis. The correlation between the formative composite and the global single item strongly exceeds the 0,70 threshold (Hair et al., 2022). The next diagnostic step thoroughly evaluates potential multicollinearity issues

among the tested formative measurement indicators. The statistical output confirms that all indicators record Variance Inflation Factor (VIF) values below the tolerance threshold of 5,0. The highest VIF value observed in this specific model is 4,67 for the TEA1 indicator. This result indicates that each indicator dimension provides unique informational value without severe statistical redundancy.

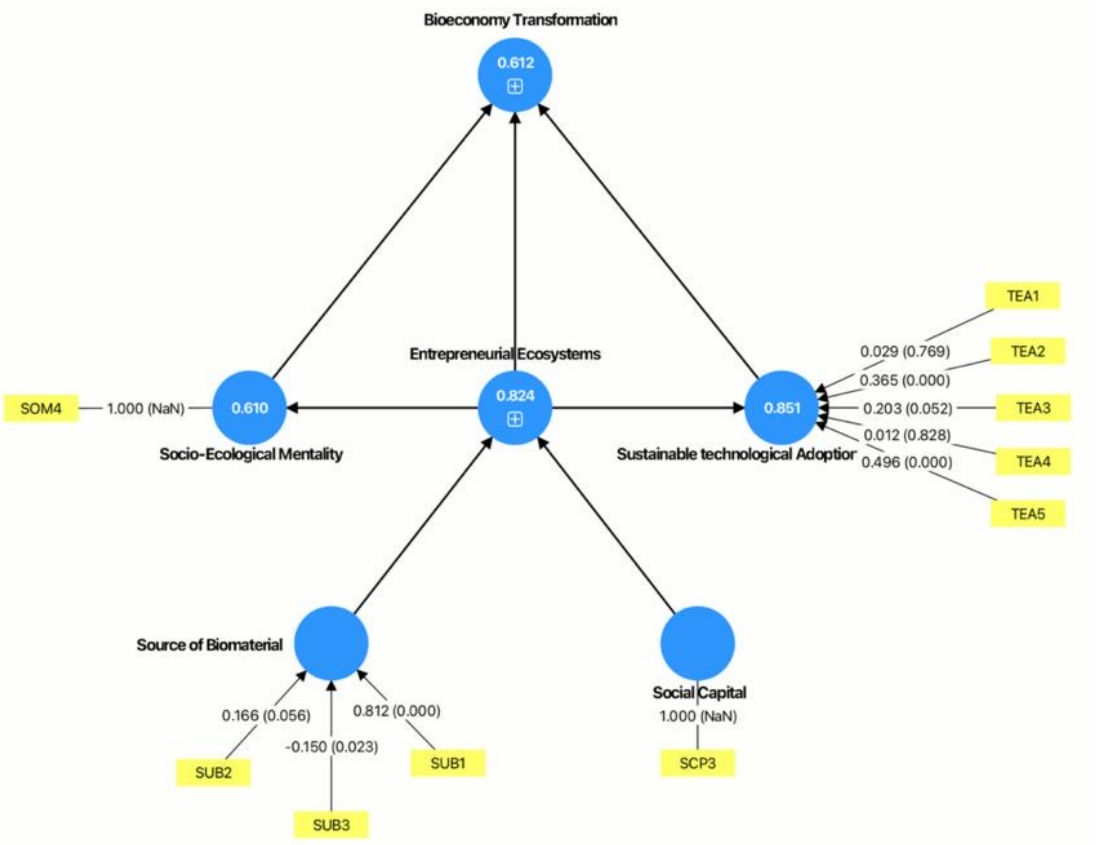


Figure 18. Formative measurement model for teak wood

Source: Own

Further examination utilises the standard bootstrapping procedure to strictly assess the significance of formative outer weights. Within the TEA variable, the production efficiency (TEA2) and pollution mitigation (TEA5) indicators demonstrate high statistical significance. Conversely, several other measurement indicators do not demonstrate significant relative weights at the 5% level. These specific indicators strictly include TEA1, TEA3, TEA4, and the SUB2 indicator for raw material availability. Nevertheless, a methodological decision was strictly made to retain these specific indicators in the final structural model. These non-significant indicators display absolute outer loading values that successfully exceed the recommended 0,50 threshold. Retaining

these specific indicators safely preserves the theoretical content validity of the measured constructs (Hair et al., 2022).

The statistical output also reveals a significant negative outer weight for the raw material legality indicator (SUB3). This negative coefficient (β = -0,150, $p < 0,05$) indicates an inverse relationship within the teak industry context. Strict legality regulations are statistically perceived as operational constraints that negatively correlate with raw material resource accessibility. This finding sharply contrasts with the stock availability indicator (SUB1) acting as the primary positive determinant. Finally, the measurement model deliberately includes several single-indicator constructs, namely SOM4, BOT2, and SCP3 variables. The measurement validity for these specific variables is methodologically assumed to be automatically fulfilled by default. These constructs are directly represented by a single item without any variance distortion from other indicators.

B. Bamboo Model

The measurement model evaluation for the Bamboo cluster begins with the assessment of the reflective Entrepreneurial Ecosystems (EES) variable. Figure 19illustrates this reflective measurement model through outward-directed arrows from the latent variable to its indicators. The internal consistency analysis indicates strong reliability across all measurement items within this construct. The statistical analysis yields a Cronbach's alpha coefficient of 0,905 and a composite reliability of 0,927. Both metrics substantially exceed the standard acceptable threshold of 0,70 recommended in contemporary PLS-SEM literature (Hair et al., 2019). Furthermore, the evaluation assesses convergent validity to verify the contribution of each indicator to its construct. The extraction results indicate that all EES indicators possess outer loadings ranging from 0,786 to 0,877. These loading values successfully surpass the critical threshold of 0,708 required for satisfactory indicator reliability. This statistical finding is further supported by an Average Variance Extracted (AVE) value of 0,680. This AVE result confirms adequate convergent validity by demonstrating that the construct explains sufficient indicator variance.

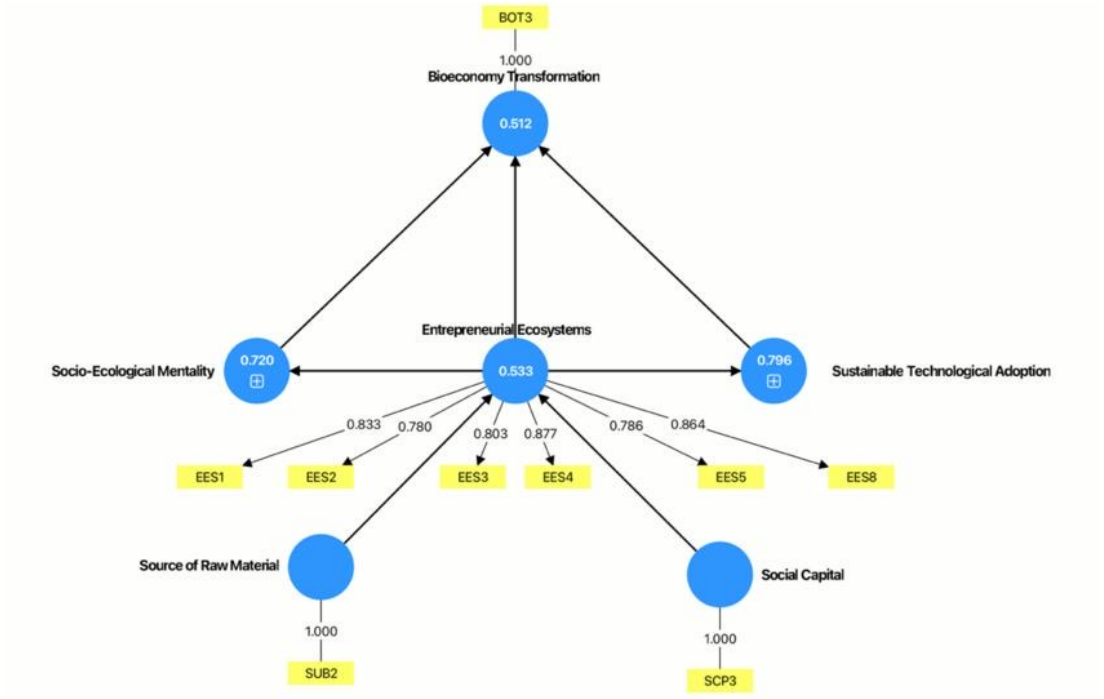


Figure 19. Reflective measurement model for Bamboo

Source: Own.

The evaluation subsequently shifts to the formative constructs, namely socio-ecological mentality, sustainable technological adoption, and biomaterial source. Figure 20 displays this formative architecture using inward-directed arrows from the measurement indicators to the latent variables. The convergent validity of these formative constructs is initially verified through a standard statistical redundancy analysis. The correlation between the formative composite and the global single item successfully exceeds the 0,70 threshold (Hair et al., 2022). The next analytical step evaluates potential collinearity issues among the formative indicators using the variance inflation factor (VIF). The statistical output confirms that all indicators record VIF values strictly below the tolerance threshold of 5,0. The highest VIF estimate observed in the measurement model is 4,88, indicating an absence of critical multicollinearity. This condition guarantees that each indicator provides a distinct informational contribution without causing regression estimation bias.

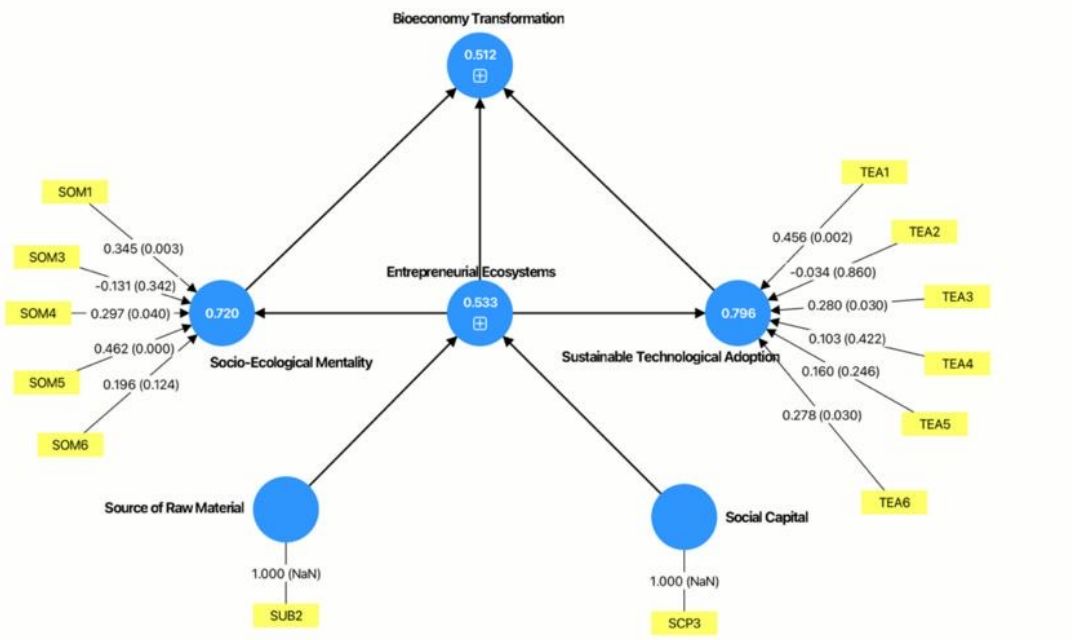


Figure 20. Formative measurement model for bamboo

Source: Own

Further examination utilises the bootstrapping procedure to determine the significance and relevance of the formative indicators. For the SUB variable, the purification process results in a single-item construct represented by raw material availability. Within the SOM and TEA constructs, several specific indicators demonstrate statistically significant outer weights at the 5% level. These significant indicators specifically include SOM1, SOM4, SOM5, TEA1, TEA3, and TEA6 based on their respective p-values. Conversely, the remaining indicators, namely SOM3, SOM6, TEA2, TEA4, and TEA5, do not achieve statistical significance. Despite their non-significant outer weights, a methodological decision was made to retain these indicators within the final model. This retention strategy strictly follows the established guidelines for formative measurement evaluation provided by Hair et al. (2022). All these non-significant indicators display substantial absolute outer loadings exceeding the recommended minimum threshold of 0,50. Removing these indicators based solely on weight significance would severely compromise the theoretical content validity of the constructs.

The final verification step assesses the discriminant validity of the reflective entrepreneurial ecosystems (EES) construct. This study adopts the Heterotrait-Monotrait (HTMT) ratio as the primary parameter for evaluating empirical distinction. The HTMT

criterion offers superior statistical sensitivity in detecting discriminant validity issues compared to the Fornell-Larcker method (Henseler et al., 2015). The matrix analysis confirms that all calculated correlation ratios remain securely below the conservative threshold of 0,85. The highest observed ratio occurs between the entrepreneurial ecosystems and social capital variables, recorded at exactly 0,739. Meanwhile, the correlation ratios with other latent variables, such as bioeconomic transformation intentions, demonstrate much lower values. These results provide robust statistical confirmation that respondents successfully distinguish between the theoretically correlated conceptual entities. Consequently, the measurement model demonstrates adequate discriminant accuracy, thereby justifying the progression to structural model testing

5.2.2 Inner Model Evaluation (Structural Model)

The structural model specification delineates the hypothesised causal relationships among the evaluated latent variables. To ensure analytical clarity and prevent narrative redundancy, these structural pathways are systematically tabulated. Table *26* explicitly outlines each formal hypothesis alongside its proposed directional effect.

Table 26. Structural Model Hypotheses and Theoretical Mechanism

Hypothesis	Structural Path	Expected Direction	Theoretical Mechanism	Adapted References
H1	Source of Biomaterial (SUB) → Entrepreneurial Ecosystem (EES)	Positive (+)	Stable natural resource supply dictates the physical baseline, allowing local supplier networks to predictably emerge and function.	O'Connor & Audretsch (2022); Agnieray et al. (2021)
H2	Social Capital (SCP) → Entrepreneurial Ecosystem (EES)	Positive (+)	High trust and community networks actively reduce transaction costs and mobilize fragmented local resources.	Grundel & Dahlström (2016); Spigel & Harrison (2017)
H3	Entrepreneurial Ecosystem (EES) → Sustainable Technological Adoption (TEA)	Positive (+)	Supportive ecosystems provide crucial access to knowledge and advanced technical infrastructure.	Volkmann et al. (2019)
H4	Entrepreneurial Ecosystem (EES) → Socio-Ecological Mentality (SOM)	Positive (+)	Ecosystems systematically transfer cultural legitimacy and essential environmental sustainability awareness.	Stam et al. (2025); Hruskova (2024)

Hypothesis	Structural Path	Expected Direction	Theoretical Mechanism	Adapted References
H5	Entrepreneurial Ecosystem (EES) → Bioeconomic Transformations (BOT)	Positive (+)	Comprehensive ecosystems directly stimulate strategic transformation intentions among rural micro-enterprises.	Kuckertz et al. (2020); Roundy (2021)
H6	Sustainable Technological Adoption (TEA) → Bioeconomic Transformations (BOT)	Positive (+)	Enhanced technical efficiency significantly drives the operational capability for bioeconomic transition.	Ha et al. (2023); Urmetzer et al. (2018)
H7	Socio-Ecological Mentality (SOM) → Bioeconomic Transformations (BOT)	Positive (+)	Shifting social value paradigms fundamentally motivates long-term sustainable business behavioural changes.	Eversberg & Fritz (2022); Segundo-Ortin (2022)

Sources: own based on the sources cited.

Furthermore, the table concisely describes the underlying theoretical mechanisms justifying these specific causal relationships. This structured tabular presentation effectively eliminates the need for excessively lengthy literature reviews. Consequently, it provides a highly efficient and objective framework for the subsequent empirical testing phase.

Table 27. Inner Model Evaluation Result

Diagnostic Metrics & Thresholds	Empirical Realities: Bamboo Craft Sector	Empirical Realities: Teak Wood Furniture Sector
Structural Paths (Significance threshold: p-values < 0,05)	Socio-ecological mentality significantly drives transformation intentions (p < 0,001). Conversely, sustainable technology adoption does not significantly influence transformation intentions (p = 0,963).	Sustainable technology adoption significantly drives transformation intentions (p < 0,001). Furthermore, the entrepreneurial ecosystem strongly dictates this technological adoption (p < 0,001).
Predictive Power (Explained Variance / R2)	High explanatory power observed across constructs. Key variances include TEA (79,6%), SOM (72,0%), and EES (53,3%). The model effectively explains internal transition drivers.	Strong predictive capacity observed across constructs. Key variances include TEA (85,0%), EES (82,4%), and BOT (61,1%). This indicates a high dependency on institutional infrastructure.
Practical Magnitudes (Effect Size / f^2)	Ecosystem-Driven Effects: • EES → TEA (f^2 = 3,910) • EES → SOM (f^2 = 2,576)	Technology-Driven Effects: • EES → TEA (f^2 = 5,706) • EES → SOM (f^2 = 1,564)

(Large ≥ 0,35; Medium ≥ 0,15)	• SCP → EES (f^2 = 0,931) Insignificant Effect: • TEA → BOT (f^2 = 0,000)	• TEA → BOT (f^2 = 0,425) Marginal Effect: • SOM → BOT (f^2 = 0,042)

source: own

The preceding measurement model successfully satisfied all rigorous prerequisites for indicator validity and construct reliability. Following this robust validation phase, the analytical focus shifts to evaluating the inner structural model.Table 27 presents a comprehensive comparative analysis of the core structural metrics across both sectors. These essential evaluation metrics include causal path significance (p-values), predictive explanatory power (R^2), and effect sizes (f^2). This structural assessment systematically examines the distinct bioeconomic transition mechanisms within these two contrasting industries. The study identifies specific structural variations between teak and bamboo enterprises.

The structural model analysis provides empirical support for the influence of the entrepreneurial ecosystem on the bioeconomy transition pathways, while critically revealing divergent trajectories between the teak and bamboo sectors. A comparative evaluation of the path coefficients highlights how Perceived Ecosystem Conduciveness (EES) triggers different dominant responses depending on the structural nature of the industry. The compilation of these structural parameters ensures that subsequent strategic conclusions rely on empirical predictive power. Beyond basic statistical justification, this structural mapping identifies distinct bioeconomic transition pathways for each sector. The empirical data indicate that the teak industry follows a highly capital-intensive and technocratic transition route. Conversely, the bamboo ecosystem relies predominantly on robust sociocultural values and local institutional networks for its operational resilience

A. Teak Wood Furniture Model

The structural evaluation begins with variance inflation factor (VIF) diagnostics to detect potential lateral collinearity among the predictors for bioeconomy transformation intentions (BOT) within the teak model. The results reveal that while the socio-ecological mentality (SOM) construct remains completely stable with a VIF of 2.68, the entrepreneurial ecosystems (EES) and sustainable technological adoption (TEA) constructs record elevated values of 7.29 and 7.02, respectively. Although exceeding the conservative threshold of 5.0 (Hair et al., 2022), this elevated collinearity is a precise statistical reflection of the 'ecological entanglement' and strong vertical embeddedness

typical of capital-intensive sectors like teak furniture (Autio et al., 2021). In these highly localised industries, technological capabilities (TEA) do not exist independently; they are fully absorbed and provided by the surrounding ecosystem networks (EES). Therefore, these elevated VIF values indicate strong institutional-technical integration rather than critical model specification errors (Wurth et al., 2021). Following advanced PLS-SEM guidelines, these predictors were retained because removing them would severely compromise the theoretical validity of the socio-technical transition framework. Finally, bootstrapping results confirmed that the path coefficients remained robust despite this variance overlap.

The analysis subsequently evaluates the coefficient of determination (R^2) to measure the model's predictive power. The structural model successfully explains 85,1% of the variance in sustainable technological adoption. According to standard PLS-SEM criteria, this specific coefficient represents a highly substantial explanatory capacity. This empirical finding implies that technological capability is heavily determined by established entrepreneurial ecosystem support. Furthermore, the model demonstrates strong predictive power for the primary endogenous variable, bioeconomy transformation intentions. The antecedent variables collectively explain 61,2% of the variance in this strategic transformation intention. This substantial explanatory power indicates a highly predictable and linear transformation pathway within the teak sector. The remaining 38,8% of unobserved variance is likely influenced by external macroeconomic factors or export regulations.

The structural evaluation proceeds with testing the significance of path coefficients via standard bootstrapping procedures. The path model visualises the specified causal relationships operating within the teak wood entrepreneurial ecosystem (Figure 21). Starting with upstream supply chain dynamics, Hypothesis 1 (H1) assesses how the Source of Biomaterial (SUB) influences Entrepreneurial Ecosystems (EES). The estimations yielded a strong, counterintuitive inverse relationship ($\beta = -0.655$, $p < 0.001$). This anomaly can be interpreted through the lens of regulatory pressure. Strict legal timber requirements and traceability mandates impose asymmetric compliance burdens on micro-scale furniture producers. Aligning with the theoretical framework of Sánchez-Medina et al. (2014), such rigid environmental governance tends to suppress the perceived behavioural control of local actors. Absolute resource scarcity, compounded by state regulations, functions as a structural bottleneck that fractures, rather than fosters, local institutional ties. In response to this institutional friction, Hypothesis 2 (H2) is

confirmed: Social Capital (SCP) significantly drives ecosystem formation ($\beta = 0.305$, $p < 0.001$). When raw material scarcity paralyses formal operations, grassroots trust networks and informal associations serve as vital substitute mechanisms to preserve ecosystem cohesion, a dynamic consistent with theories of entrepreneurship operating within institutional voids (Webb et al., 2020)

At the mid-stream level of capability diffusion, the model examines how the ecosystem equips its participants. The data unequivocally support Hypothesis 3 (H3), confirming that Entrepreneurial Ecosystems (EES) serve as a critical catalyst for Sustainable Technological Adoption (TEA) ($\beta = 0.922$, $p < 0.001$). Parallel to this technical upgrading, Hypothesis 4 (H4) is validated. Institutional embeddedness successfully diffuses ecological awareness, exerting a substantial positive effect on Entrpreneurs' Socio-Ecological Mentality (SOM) ($\beta = 0.781$, $p < 0.001$).

However, the true test of this transition framework lies in whether these newly acquired capabilities trigger strategic business shifts. To evaluate the direct downstream impact, Hypothesis 5 (H5) tests the unmediated link between EES and Bioeconomy Transformation Intentions (BOT). This direct path was statistically insignificant and slightly negative ($\beta = -0.162$, $p = 0.274$). Such an empirical reality proves that merely injecting institutional support or the absence of any technological or cognitive internalisation remains completely inoperative. This supports emerging critiques that ecosystem attributes must be actively mediated by internal firm capabilities to spark strategic intent (Spigel, 2017). Full mediation is essential to prompt real transformation.

This absolute necessity for mediation leads to Hypothesis 6 (H6), which isolates the role of technology adoption. The estimations indicate that Sustainable Technological Adoption (TEA) is the definitive determinant of strategic transformation intentions (BOT). This specific pathway is exceptionally strong ($\beta = 1.076$, $p < 0.001$), suggesting that technical upgrading is not merely an option but a fundamental prerequisite for bioeconomy transitions in this context. For a capital-intensive sector like teak, institutional support only translates into strategic change when it materialises into tangible machinery and operational efficiency, an observation that aligns firmly with socio-technical transition theories regarding legacy industries (Geels, 2019).

Conversely, the cognitive pathway fails to materialise in this case. Hypothesis 7 (H7), linking Socio-Ecological Mentality (SOM) to BOT, lacks a significant positive impact, instead showing a marginal negative tendency ($\beta = -0.209$, $p = 0.051$). The formal rejection of H7 exposes profound cognitive dissonance within the legacy timber industry.

While the ecosystem may successfully foster theoretical ecological awareness (as evidenced by H4), this mentality does not escalate into strategic intent. This highlights a deeply pragmatic reality: ecological ethics that fail to instantly deliver production efficiency are viewed as cost burdens to be avoided. This outcome reflects the persistent sustainability paradox, wherein actors in mature sectors prioritise immediate economic rationality over normative environmental values (Hahn et al., 2014). Consequently, the socio-ecological pathway is entirely ineffective as a mediator for transitioning this specific industrial regime.

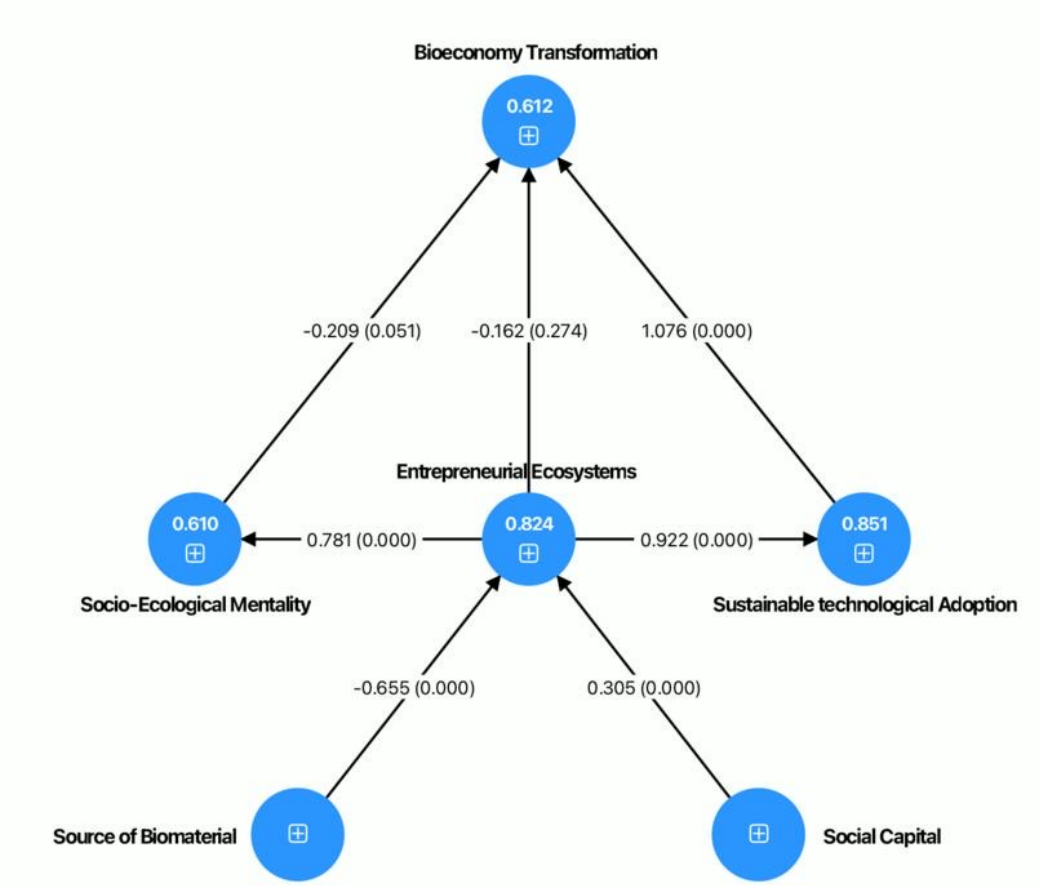


Figure 21. Structural model for teak wood

Source: Own

The structural architecture evaluation concludes with an effect size (f^2) analysis for all predictor variables. The calculated matrix mechanically confirms the dominant role of technological infrastructure within the teak cluster. The causal path from the entrepreneurial ecosystem to technological adoption demonstrates an exceptionally large

effect size. This specific relationship records an f^2 value of 5,706, far exceeding the standard large effect threshold. Furthermore, technological capability functions as the primary driver of transformation intentions with substantial leverage (f^2 = 0,425). In the upstream supply chain, biomaterial dynamics exert a very large structural effect on the ecosystem (f^2 = 1,043). This indicates that legal material access significantly dictates the operational stability of local institutional relationships. Conversely, socio-ecological mentality contributes only a marginal effect size toward transformation intentions (f^2 = 0,042). This specific finding suggests that ethical considerations alone remain insufficient to drive strategic capital-intensive business decisions.

B. Bamboo Craft Model

The structural model evaluation systematically begins with lateral collinearity diagnostics among the defined predictor constructs. The variance inflation factor (VIF) calculation reveals elevated values within the bioeconomy transformation intentions (BOT) predictors. Specifically, sustainable technological adoption (TEA) and socio-ecological mentality (SOM) display VIF values of 7,11 and 5,18. Furthermore, the entrepreneurial ecosystems (EES) construct records a VIF value of 5,28 in this structural configuration. These values technically exceed the conservative threshold of 5,0 recommended in recent PLS-SEM guidelines (Hair et al., 2022). However, elevated collinearity frequently occurs in structural models featuring highly correlated mediation pathways (Nitzl et al., 2016). This specific variance overlap is a methodological consequence of the entrepreneurial ecosystem dominating its subsequent mediator variables. Consequently, these VIF values are retained as they represent actual institutional transmission rather than critical specification errors.

The analysis subsequently evaluates the coefficient of determination (R^2) to assess the model's overall explanatory power. The structural estimation indicates that antecedent variables explain 79,6% of the variance in sustainable technological adoption. Similarly, the antecedent variables successfully explain 72,0% of the variance within the socio-ecological mentality construct. According to standard PLS-SEM criteria, these specific R^2 values indicate a substantial explanatory capacity (Hair et al., 2022). In contrast, the model predicts the primary endogenous variable, bioeconomy transformation intentions, at a moderate level. The R^2 value of 0,512 indicates that the framework maps approximately half of the transformation intention variance. This moderate explanatory

power suggests that unobserved exogenous variables also influence final strategic business transformation decisions.

The structural evaluation proceeds with testing the significance of path coefficients through the standard bootstrapping procedure. Figure 22 systematically visualises the specified structural relationships operating within the bamboo craft entrepreneurial ecosystem. At the upstream supply chain level, the model tests the baseline assumption that physical resource endowments dictate the viability of ecosystems. Hypothesis 1 (H1), which assesses the influence of the Source of Biomaterial (SUB) on Entrepreneurial Ecosystems (EES), yields a surprisingly weak relationship ($\beta = 0.172$), marginally significant only at the 90% confidence interval. Therefore, the abundance of physical resources is insufficient to spontaneously generate a functional ecosystem. Rather, the actual structural engine lies in the relational dynamics. Hypothesis 2 (H2) is firmly validated, showing that Social Capital (SCP) acts as the primary determinant of EES formation ($\beta = 0.675$, $p < 0.001$). Such an asymmetric upstream configuration highlights a critical reality for rural bamboo clusters: grassroots trust and communal reciprocity exert a substantially stronger structural pull than mere biophysical availability, validating theories of institutional voids in which informal relational mechanisms inherently substitute for formal resource infrastructure (Muralidharan & Pathak, 2016).

Shifting to the mid-stream diffusion of capabilities, the analysis evaluates the ecosystem's capacity to empower local entreprenuers. The data provide strong support for Hypothesis 3 (H3), confirming that Entrepreneurial Ecosystems (EES) serve as a highly effective conduit for Sustainable Technological Adoption (TEA) ($\beta = 0.892$, $p < 0.001$). Parallel to this technical provisioning, ecosystems also perform critical cognitive functions. Addressing Hypothesis 4 (H4), the results indicate that institutional embeddedness actively incubates value-based motivations, significantly reinforcing entrepreneurs' Socio-Ecological Mentality (SOM).

However, a central theoretical question remains: can this ecosystem support bypassing internal firm capabilities to directly trigger strategic shifts? Hypothesis 5 (H5) tests this by examining the unmediated pathway from EES to Bioeconomy Transformation Intentions (BOT). As anticipated in full mediation frameworks, this direct path failed to produce a statistically significant independent effect. Institutional support appears to be entirely inert unless it is effectively metabolised through the entrepreneurs' own cognitive or technological faculties. This aligns closely with contemporary

ecosystem literature, which emphasises that institutional attributes must be internally mediated by firm-level capabilities to initiate strategic entrepreneurial action (Spigel & Harrison, 2017).

This inherent institutional inertia forces a closer examination of downstream mediation channels. Hypothesis 6 (H6) assesses the technological route and tests whether the adopted tools translate into strategic intent. The findings reveal a stark empirical reality: the link from Sustainable Technological Adoption (TEA) to BOT is entirely negligible ($\beta = 0.013$, $p = 0.963$). This non-significant result captures the clear phenomenon of pathway decoupling. Although the ecosystem effectively supplies green technology (as evidenced by H3), hardware interventions alone are insufficient to catalyse strategic transformation. In highly labour-intensive contexts, new technologies are absorbed merely as utilitarian production aids, rather than as drivers of a broader bioeconomy vision. This empirical decoupling confirms critiques within socio-technical transition studies, asserting that hardware upgrading devoid of normative alignment inevitably fails to trigger deep sustainability transitions (Pansera & Fressoli, 2020)

The actual catalyst for transformation is finally isolated in hypothesis 7 (H7). The structural pathway connecting Socio-Ecological Mentality (SOM) to BOT is highly significant, capturing the most dominant positive effect within the entire model ($\beta = 0.889$, $p < 0.001$). The confirmation of H7 with such a massive coefficient leads to a definitive theoretical boundary condition. For community-based, highly elastic rural industries, internalised environmental ethics and normative values are not secondary considerations; they are the absolute, non-negotiable prerequisites for triggering a strategic bioeconomy transition. This establishes a fundamental axiom supported by the modern sustainable entrepreneurship literature: in grassroots, community-embedded sectors, profound value-based cognitive shifts are the true vanguard of ecological transformation (Muñoz & Cohen, 2017)

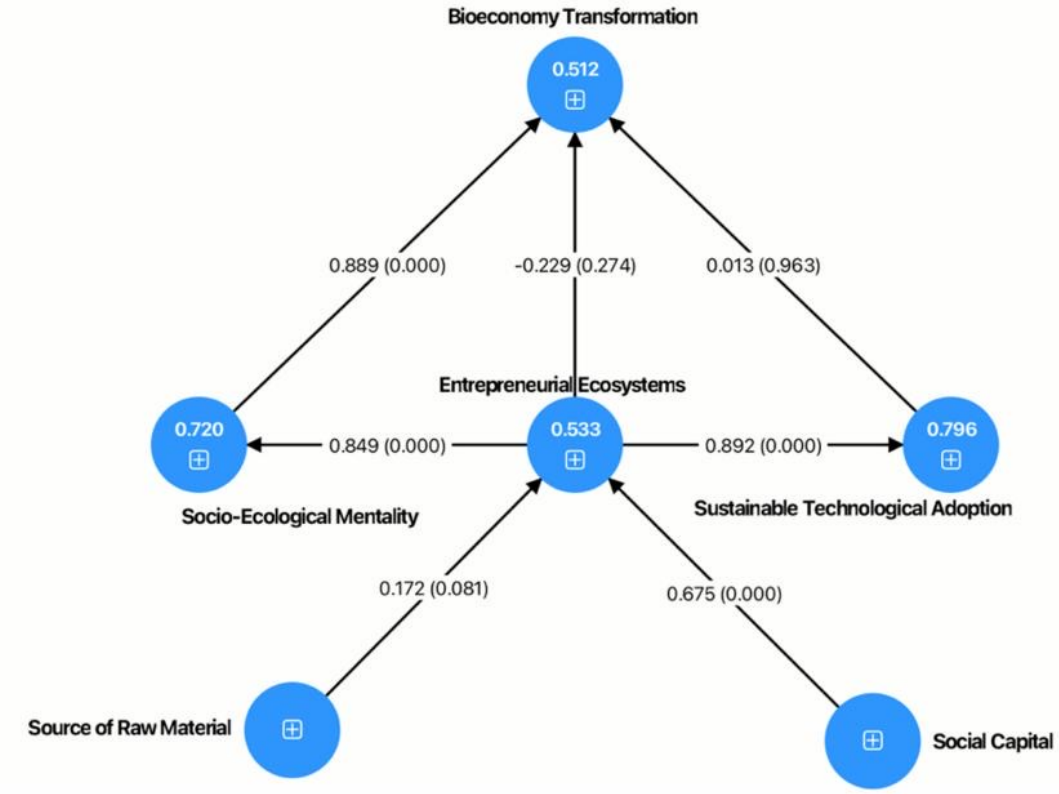


Figure 22. Structural model for bamboo

Source: Own

Complementing the path significance tests, the analysis evaluates the effect size (f^2) to measure substantive predictor contributions. The calculated f^2 matrix confirms the substantial leverage of social capital and ecosystem variables (Hair et al., 2022). The causal path from social capital to the entrepreneurial ecosystem demonstrates a very large effect size (f^2 = 0,931). Furthermore, the entrepreneurial ecosystem exerts massive effect sizes on both socio-ecological mentality (2,576) and technological adoption (3,910). Socio-ecological mentality provides a stable, moderate effect size (f^2 = 0,312) as a determinant of transformation intention. Consistent with the path significance results, technological adoption shows no practical effect on transformation intentions (f^2 = 0,000). Finally, Source biomaterial demonstrates only a small effect size (f^2 = 0,060) regarding the entrepreneurial ecosystem formation.

5.2.3 Indirect Effect (Mediation) Analysis

The structural model evaluation systematically proceeds with a rigorous analysis of the hypothesised indirect effects. This specific analytical stage strictly tests the specified mediation pathways operating within both industrial clusters. The statistical

analysis evaluates the mediating roles of sustainable technological adoption and socio-ecological mentality constructs. These specific variables systematically mediate the relationship between entrepreneurial ecosystems and strategic bioeconomic transformation intentions. Furthermore, the analysis rigorously investigates complex serial mediation pathways originating from fundamental supply chain predictors. Standard bootstrapping procedures are consistently employed to determine the exact statistical significance of these indirect effects. To ensure analytical clarity and prevent narrative redundancy, the comprehensive mediation results are systematically tabulated. Table *28*. Specific Indirect Effects and Serial Mediation Pathways explicitly outlines the specific indirect pathways, their respective statistical coefficients, and mediation types. This tabular presentation accurately identifies the dominant causal transmission mechanisms operating within each respective sector.

The statistical mediation analysis for the teak furniture cluster reveals a strictly technocratic transmission configuration. Sustainable technological adoption functions as a highly significant full mediator within this specific capital-intensive industry. This specific indirect pathway demonstrates a strong positive coefficient of 0,993 with a p-value below 0,001. This specific statistical finding indicates that institutional support must be converted into tangible technical capabilities. Without corresponding technological modernisation, standard entrepreneurial ecosystem interventions fail to stimulate strategic bioeconomic transformation intentions. Conversely, the alternative structural mediation pathway through socio-ecological mentality demonstrates a completely non-significant statistical impact. This specific cognitive pathway records a negative coefficient of -0,163 with a marginal p-value of 0,055. This empirical result suggests that environmental ethics currently provide a weak impetus for capital-intensive entrepreneurs.

Table 28. Specific Indirect Effects and Serial Mediation Pathways

Specific Indirect Path (Mediation)	Industrial Cluster	Path Coefficient (β)	P-value	Mediation Result
Entrepreneurial Ecosystem (EES) → Sustainable Technological Adoption (TEA) → Transformation Intentions (BOT)	Teak Wood	0,993	< 0,001	Full Mediation
Entrepreneurial Ecosystem (EES) → Socio-Ecological Mentality (SOM) → Transformation Intentions (BOT)	Teak Wood	-0,163	0,055	Non-Significant
Source of Biomaterial (SUB) → Entrepreneurial Ecosystem (EES) → Technological Adoption (TEA) → Transformation Intentions (BOT)	Teak Wood	-0,650	< 0,001	Negative Serial Mediation

Entrepreneurial Ecosystem (EES) → Socio-Ecological Mentality (SOM) → Transformation Intentions (BOT)	Bamboo	0,754	< 0,001	Full Mediation
Entrepreneurial Ecosystem (EES) → Sustainable Technological Adoption (TEA) → Transformation Intentions (BOT)	Bamboo	0,012	0,964	Non-Significant
Social Capital (SCP) → Entrepreneurial Ecosystem (EES) → Socio-Ecological Mentality (SOM) → Transformation Intentions (BOT)	Bamboo	0,509	< 0,001	Positive Serial Mediation

source: Own analysis

The serial mediation analysis uncovers a highly significant inverse relationship originating from resource availability. The specific serial pathway from resource availability through ecosystems and technology to transformation intentions is negative. This continuous serial mediation path records a substantial negative coefficient of -0,650 ($p < 0,001$). This inverse statistical relationship empirically validates the theoretical phenomenon of scarcity-induced technological innovation (Geels, 2019a). Severe legal raw material scarcity systematically forces teak furniture businesses to execute efficiency-driven technological adaptations.

The statistical mediation analysis for the bamboo cluster elucidates a fundamentally different sociological transmission mechanism. Socio-ecological mentality functions as a complete and highly significant mediator within this specific communal model. This specific cognitive mediation pathway records a substantial positive coefficient of 0,754 ($p < 0,001$). This specific empirical finding confirms that institutional support cannot automatically trigger strategic behavioural change alone. Ecosystem interventions strictly require the successful incubation of cognitive environmental values among local bamboo entrepreneurs. These internalised cognitive values function as a prerequisite for forming sustainable strategic business intentions. In stark contrast, sustainable technological adoption proves completely ineffective in fulfilling a structural mediation function. This specific technological pathway decoupling records a negligible coefficient of 0,012 with a p-value of 0,964. This specific result suggests that technological diffusion alone cannot sufficiently escalate the strategic vision of entrepreneurs.

Furthermore, the serial mediation analysis strictly validates a continuous sociological causal chain for this communal sector. The serial pathway from social capital through ecosystems and mentality to transformation intentions is highly significant. This specific continuous serial mediation chain records a strong positive coefficient of 0,509

($p < 0{,}001$). This causal sequence emphasises that transformation intentions strictly emerge from cohesive community networks and ethical awareness.

5.2.4 Comparative Subgroup Model Analysis

The comparative subgroup analysis reveals fundamental structural divergences between the teak and bamboo industrial sectors. These structural differences represent distinct socio-technical configurations rather than mere statistical measurement inconsistencies (Rigdon et al., 2017). The teak entrepreneurial ecosystem demonstrates extreme statistical homogeneity within its specific empirical measurement construct. This statistical uniformity logically reflects strict regulatory pressures operating at the macro-landscape transition level (Geels, 2019). Consequently, formal market standardisation systematically forces structural conformity among teak business actors. Conversely, the bamboo sector exhibits high data variability characteristic of organic community-based economic environments. The local entrepreneurial ecosystem functions primarily as a collaborative sociocultural support mechanism (Spigel, 2017). Grassroots economic groups rely heavily on these local social networks to drive sustainable business activities.

This ontological divergence significantly affects the biomaterial resource construct validation phase. The teak legality indicator retains a negative weight, reflecting tension between administrative compliance and operational realities. In contrast, the statistical exclusion of the bamboo legality indicator indicates informal common-pool resource governance. These distinct measurement patterns demonstrate that bioeconomy readiness heavily depends on specific material contexts (D'Amato et al., 2020). Evaluating these statistical divergences requires integrating the Theory of Planned Behavior (TPB) with the Multi-Level Perspective (MLP). The radically different transition trajectories directly manifest the underlying cognitive architectures framing entrepreneurial decision-making processes. Entrepreneurs in both sectors systematically process distinct entrepreneurial ecosystem inputs to form their strategic business intentions.

Within the teak cluster, the causal analysis empirically reveals a highly technocratic socio-technical regime. Sustainable technological adoption functions as an absolute statistical prerequisite for strategic transformation intentions ($\beta = 0{,}993$). Interpreted through the TPB framework, this near-perfect coefficient indicates that perceived behavioural control strictly dominates decision-making. Facing severe raw material scarcity, teak entrepreneurs perceive mechanical modernisation as their primary

adaptive capability. Consequently, the socio-ecological mentality fails to significantly influence transformation intentions in this specific subgroup. This specific phenomenon validates the MLP concept of technological lock-in within established industrial regimes (Geels, 2019). The entrepreneurial ecosystem exclusively channels its influence through physical technological provision rather than ethical incubation. Therefore, capital-intensive actors prioritise pure mechanical efficiency over environmental ethics to ensure immediate business survival.

In strict contrast, the bamboo sector operates as a grassroots niche driven by socio-ecological mentality ($\beta = 0{,}754$). The complete statistical failure of the technological pathway ($\beta = 0{,}012$) highlights a significant structural decoupling. Although technology is physically adopted, it empirically fails to trigger transformation intentions. Applying the TPB framework, this specific anomaly proves that subjective norms and attitudes dictate cognitive calculations. Bamboo entrepreneurs utilise deeply embedded environmental preservation values as their primary psychological drivers (Eversberg & Fritz, 2022). Furthermore, the local entrepreneurial ecosystem successfully incubates these relational bonds and collective ecological responsibilities (Spigel, 2017). Therefore, sustainability transitions in this niche community represent fundamental value shifts rather than mere mechanical upgrades. Technology functions strictly as a supplementary operational instrument rather than a strategic transformation driver.

Synthesising these subgroup findings confirms that bioeconomy transformation trajectories are not exclusively dictated by technical-economic optimisation. Transformation success remains highly contingent upon local socio-economic configurations and specific cognitive behavioural antecedents. These empirical conditions strictly demand a differentiated policy mix accommodating distinct socio-technical transition pathways. Regional bioeconomy acceleration requires untangling resource frictions for regime-locked industries while simultaneously strengthening niche communal norms.

5.2.5 Different Paths of Forest-based Bioeconomy Transformation - Discussion

The structural dynamics of the forest-based bioeconomy are fundamentally dictated by the physical materiality of local resources. Confirming the Natural-Resource-Based View (NRBV), local entrepreneurial ecosystems do not operate in a vacuum; their value-creation strategies are strictly bound by biophysical realities (Laakkonen et al., 2023). For instance, the severe scarcity of legal teak imposes immense operational

friction, mandating a transition driven almost entirely by high technical efficiency. In stark contrast, the rapid regeneration cycle of bamboo offers high logistical elasticity, circumventing the need for massive capital accumulation in the ecosystem.

Beyond physical boundaries, external market forces profoundly reconfigure traditional social orders within these ecosystems. In the teak sector, the aggressive penetration of financial capital visibly erodes relational proximity (EES3), substituting the communal trust that historically anchored the rural economy with formalised transactional efficiency (Spigel, 2022). Moreover, public regulations (EES1) function less as proactive industrial development tools and more as rigid export compliance instruments, effectively triggering market exclusion for micro-enterprises (Prasetyo et al., 2022). Consequently, the spatial autonomy of the teak ecosystem is systematically hollowed out by supra-local orchestration, validating the critique that integration into global value chains often strips governance power from local communities and transfers it to global lead firms (Kano et al., 2020).

This divergence in structural adaptation is deeply rooted in the contrasting cognitive rationalities operating within each cluster, as mapped through the Theory of Planned Behaviour (TPB). The strategic transformation of teak craftsmen hinges entirely on pragmatic mastery of physical production technology; their perceived behavioural control dictates their intent. Alternatively, bamboo entrepreneurs' green entrepreneurial intentions are cultivated almost exclusively through communal norms and socio-ecological mentalities. For grassroots actors, communal value alignment is not merely an ideological preference but a fundamental cognitive prerequisite for sustaining rural business operations (Yasir et al., 2023).

However, individual pro-environmental cognition, whether driven by technology or ecology, remains inert without tangible facilitation from the broader entrepreneurial ecosystem. Bioeconomy transitions cannot be successfully materialised through isolated, atomised business adaptations. While bamboo entrepreneurs leverage social capital to bypass formal financial constraints, permanently scaling these rural economies requires concrete structural interventions from public authorities. Governance instruments must be highly asymmetrical and explicitly calibrated to the unique material and social characteristics of each commodity network. This confirms that an adapted entrepreneurial ecosystem approach offers the most viable institutional framework for orchestrating sustainable rural transformation (Ricket et al., 2023).

While the PLS-SEM structural evaluation conclusively establishes the entrepreneurial ecosystem as the primary determinant of this transition, it inherently treats this complex architecture as an aggregated latent construct. For precise public policymaking, treating the ecosystem as a 'black box' is insufficient; there is a critical need to unearth the internal causal interactions among its specific elements. The analysis must systematically untangle which institutional indicators act as primary driving forces and which are merely passive receivers of change. Therefore, Chapter 4.3 specifically dissects the ecosystem causality anatomy using the Fuzzy Decision-Making Trial and Evaluation Laboratory algorithm.

5.3 Mapping the Cause-and-Effect Dynamics of Entrepreneurial Ecosystems in Forest-Based Bioeconomy Pathways

Investigating the structural architecture of entrepreneurial ecosystems necessitates shifting from aggregate perspectives toward detailed relational analysis. Contemporary economic literature increasingly conceptualises the entrepreneurial ecosystem as a highly dynamic institutional configuration (Stam & van de Ven, 2021). Various interrelated systemic elements must interact continuously to stimulate regional innovation and ensure long-term sustainable economic resilience. The previous structural equation modelling analysis systematically validated the local entrepreneurial ecosystem as a highly significant mediator. However, this variance-based statistical approach contains inherent methodological limitations regarding the mapping of complex internal systemic interactions. Structural modelling effectively evaluates aggregate impact magnitudes but may inadvertently obscure internal causal heterogeneity among distinct ecosystem pillars. Empirical evidence consistently suggests that foundational ecosystem components operate through highly asymmetric mechanisms and complex nonlinear structural dependencies.

Understanding these complex structural interdependencies requires supplementing macro-level pathway analysis with highly granular diagnostic methodological instruments. Consequently, this specific sub-chapter adopts the Decision-Making Trial and Evaluation Laboratory (DEMATEL) analytical framework for further investigation. This specific mathematical methodology systematically deconstructs the internal causal mechanics operating within the regional entrepreneurial ecosystem. Conventional structural regression models strictly assume predictor variable independence during standard statistical parameter estimation procedures. In contrast, the

DEMATEL approach specifically maps complex cause-and-effect topologies within highly interrelated systemic network components (Nicula & Constantinescu, 2023). This advanced analytical approach successfully isolates specific system variables to identify foundational structural drivers and derivative systemic effects.

Evaluating regional bioeconomy transition readiness frequently involves significant subjective linguistic ambiguity among surveyed local industry actors. Therefore, fuzzy set theory is systematically integrated into the standard DEMATEL computational matrix to enhance measurement precision (Šmidovnik & Grošelj, 2023). This specific methodological hybridisation effectively calibrates subjective cognitive biases to consistently produce highly reliable structural centrality computations.

This integrated computational framework facilitates a systematic structural comparison between two fundamentally distinct regional entrepreneurial ecosystems. The subsequent comparative analysis primarily focuses on fundamental structural disparities originating from underlying biomaterial resource characteristics. Previous structural modelling findings clearly indicated a significant institutional bifurcation between the two observed local industrial sectors. The capital-intensive teak furniture sector structurally diverges from the community-driven bamboo handicraft sector in operational logic. These fundamentally divergent ecosystem configurations demand highly precise internal causality evidence to accurately formulate targeted policy interventions. The primary analytical objective systematically extends beyond simply mapping descriptive statistical variable divergences between the two groups. This granular cross-sector comparison specifically aims to identify strategic policy leverage points within each distinct commodity regime. Identifying these specific structural leverage points may systematically support the evidence-based design of context-specific regional bioeconomy interventions.

5.3.1 Prominence Analysis ($c+r$): Ecosystem Centrality Degree

The Decision-Making Trial and Evaluation Laboratory methodology requires quantifying the absolute degree of systemic centrality. This structural magnitude is precisely calculated using the specific prominence metric designated as $c+r$. This specific index represents the mathematical aggregation of distributed influence emission and received influence absorption. This computational parameter effectively delineates the boundaries of an element's total involvement within the entrepreneurial ecosystem. Variables accumulating high prominence values typically operate as critical structural

nodes within the broader systemic network. These central structural nodes substantially influence the overall dynamic stability of the regional economic architecture.

Evaluating prominence indices within entrepreneurial ecosystem studies remains fundamentally rooted in efficient policy allocation logic. A specific variable may formally function as an institutional driver within the structural causal network. However, low centrality indices suggest that systemic stimuli will only transmit marginal regional economic impacts. Consequently, the prominence metric functions as a systematic filtration instrument isolating the core systemic structural element. This analytical precision ensures that bioeconomy transition interventions remain concentrated on highly resonant systemic leverage points. Targeting these specific high-prominence variables systematically prevents the inefficient dissipation of limited regional policy resources.

Table 29. Comparison of Prominence (*c*+*r*) Values

Criteria	*c*+*r* (Teak Wood EES)	*c*+*r* (Bamboo EES)
Government policy/fiscal support (EES1)	8.00969	17.01003
Presence of Financial capital providers (EES2)	8.45798	16.79667
Geographical embeddedness and proximity (EES3)	6.80087	16.67571
Local public support and consumer trends (EES4)	7.71466	15.97411
The role of culture in norms and behavior (EES5)	8.24299	18.03924
Collaboration with research institutions (EES8)	7.71814	16.15864

source: own analysis

The empirical centrality analysis revealed distinct entrepreneurial ecosystem configurations between the two observed bioresource regimes (Table 29). Within the teak furniture sector, the Presence of Financial capital providers (EES2) establishes the highest systemic structural prominence. This specific financial indicator recorded a calculated prominence value of 8.45 within the empirical matrix. This structural finding suggests that financial liquidity acts as the primary gravitational centre, heavily mediating operational activities in the capital-intensive forestry sector (Harrison & Herbohn, 2016). In contrast, the structural hierarchy of the bamboo ecosystem is predominantly anchored by the role of culture in norms and behaviour (EES5), which records a massive prominence score of 18.04. Rather than merely reflecting local traditions, this intense reliance on sociocultural capital often signals the presence of severe institutional voids in rural environments. Such voids—manifesting as significant gaps in formal banking or regulatory presence—force local bamboo entrepreneurs to mobilise communal trust and cultural norms to ensure continuous economic exchange without formal institutional backing (Sydow et al., 2020; Živojinović et al., 2019).

Examining the variables with the lowest systemic involvement (prominence) further exposes the fundamental structural divergence between the sectors. In the teak entrepreneurial ecosystem, the indicator for geographical embeddedness and proximity (EES3) occupies the lowest structural hierarchy, recording a marginal prominence value of 6.80. Conversely, within the local bamboo ecosystem, local public support and consumer trends (EES4) registered the lowest structural centrality. This marginal positioning implies that grassroots bamboo extraction activities are governed predominantly by subsistence economic logic. Consequently, local production adaptations are calibrated far more by cultural survival strategies than by global sustainability discourses or shifting green consumer demand (Phimmachanh et al., 2015).

These shifting centrality phenomena strongly align with the contemporary institutional economics literature on the physical materiality of resources. The structural architecture of an entrepreneurial ecosystem is not random; it is partially dictated by the biophysical characteristics of the extracted biomaterials. Within the hardwood regime, high capital intensity linked to the Presence of Financial capital providers (EES2) mirrors the economic rationality of slow-cycle harvests. These specific biophysical constraints naturally elevate sunk costs and create operational barriers within the teak industry (Rizanti et al., 2018; Roshetko et al., 2013; Shukla & Viswanath, 2014). Therefore, massive financial liquidity remains a fundamental prerequisite for maintaining equilibrium in the teak bioeconomy ecosystem. Conversely, the fast-yielding nature of bamboo commodities requires significantly less financial capital to stimulate productive activities (Emamverdian et al., 2020; Gupta and Kumar, 2008; Li and He, 2019). Notably, the fuzzy-DEMATEL computation also indicates that government policy/fiscal support (EES1) and local public support and consumer trends (EES4) operate as crucial institutional anchors for bamboo. Formal state presence and public backing can provide the necessary operational legitimacy to scale up grassroots subsistence networks into formalised entrepreneurial ventures (Nason & Bothello, 2022; Porras-Paez, 2023).

These comparative structural findings provide highly specific empirical justification for formulating a differentiated regional policy mix. The analytical results confirm that the Presence of Financial capital providers (EES2) play an absolute central role in the teak ecosystem, implying that policies targeting financial accessibility (such as subsidised credit or investment grants) will be vastly more effective than mere regulatory expansion. Conversely, for the bamboo sector, prematurely injecting substantial financial capital without prior orchestration of government policy/fiscal

support (EES1) and an integration of the role of culture in norms and behaviour (EES5) may lead to institutional misalignment. Effective regional bioeconomy transition strategies must be explicitly calibrated to accommodate these distinct ecosystem configurations.

5.3.2 Causality Polarisation: Identifying the Cause Group

The causal group analysis reveals a significant structural divergence between the two distinct regional bioeconomy regimes (Table *30*). This specific empirical finding systematically challenges the assumption of homogeneity within regional bioeconomic governance frameworks.

Table 30. Comparison of the Cause Group (Based on $c-r$ Values)

	Teak Wood EES		**Bamboo EES**	
Criteria	$c-r$	Role	$c-r$	Role
Local public support and consumer trends (EES4)	+1.79714	Cause	-1.01003	Effect
The role of culture in norms and behavior (EES5)	+0.03167	Cause	+0.38715	Cause
Government policy/fiscal support (EES1)	-0.04133	Effect	+0.69716	Cause
Collaboration with research institutions (EES8)	-0.1793	Effect	+0.80428	Cause

Source: Own analysis

Analysis of the teak wood entrepreneurial ecosystem indicates that local public support and consumer trends (EES4) act as the primary systemic driver, supported by a strong positive causal value ($c-r$ = +1.797). In contrast, the influence of cultural norms and behaviour (EES5) is marginal ($c-r$ = +0.031). Furthermore, government policy and fiscal support (EES1) fall into the effect group ($c-r$ = −0.041), suggesting that their role in this context is largely reactive. This configuration points to a demand-pull dynamic, where external market forces dictate local production systems. However, this does not render state governance irrelevant. Drawing on Global Value Chain (GVC) literature, public policy in export-oriented sectors typically adapts to international market requirements (Bartley, 2018). Rather than driving local innovation, regulations mostly serve as mechanisms to ensure compliance, maintain legitimacy, and secure market access within highly standardised global regimes (Maryudi et al., 2017; Ponte, 2020).

The bamboo entrepreneurial ecosystem, however, presents a markedly different structure. Due to the absence of strong market demand, EES4 shifts into the effect group ($c-r$ = −1.010), showing a high dependency on other variables. Under these conditions,

endogenous drivers take the lead. Cultural norms and behaviour (EES5) emerge as a key systemic driver ($c+r = 18.039$; $c-r = +0.387$), heavily shaping community engagement. At the same time, government policy (EES1) takes on a proactive role ($c-r = +0.697$), while collaboration with research institutions (EES8) demonstrates the strongest causal influence overall ($c-r = +0.804$). These findings support an institutional-push dynamic, where structural support compensates for weak market signals. As Schot and Steinmueller (2018) argue, market forces alone are rarely sufficient to initiate sustainability transitions in marginal sectors. Therefore, institutional intervention and knowledge support are essential for building capacity and enabling these sectors to gradually integrate into formal value chains (Reichert, 2019).

The stark contrast between these two ecosystems emphasises the need for context-specific bioeconomy governance. In the teak sector, global market pressures dominate, making EES4 the main driver and leaving EES1 in a reactive position. This aligns with institutional perspectives on export-oriented sectors, where regulation primarily facilitates participation in global markets rather than fostering domestic innovation (Horner & Nadvi, 2018; Ponte, 2020). Conversely, the bamboo ecosystem demonstrates how crucial institutional support is for emerging sectors. Interestingly, collaboration with research institutions (EES8), which acts merely as an outcome in the teak system ($c-r = -0.179$) becomes the primary driver in the bamboo ecosystem. This shift practically reflects the Multi-Level Perspective, which posits that niche innovations require early-stage protection and structural support to develop (Smith & Raven, 2012; Köhler et al., 2019).

5.3.3 Dependency Anatomy: Identifying the Effect Group

The effect group analysis reveals significant structural subordination disparities between the two distinct regional bioresource regimes (Table *31*). Within the bamboo entrepreneurial ecosystem, pro-environmental consumer trends exhibit the highest degree of systemic structural dependency.

Table 31. Comparison Table of the Effect Group (Based on c−r Values)

Criteria	Teak Wood EES		Bamboo EES	
	c−r	Role	c−r	Role
Presence of venture capital providers (EES2)	-0.19893	Effect	-0.75402	Effect
Geographical embeddedness and proximity (EES3)	-1.40925	Effect	-0.12454	Effect

Local public support and consumer trends (EES4)	+1.79714	Cause	-1.01003	Effect
Government policy/fiscal support (EES1)	-0.04133	Effect	+0.69716	Cause
Collaboration with research institutions (EES8)	-0.1793	Effect	+0.80428	Cause

Source: Own Analysis

The structural dependency configuration demonstrates fundamentally different systemic characteristics within the capital-intensive teak timber sector, where local socio-economic and institutional factors are entirely subordinated to external market forces. In this regime, "Geographical embeddedness and proximity (EES3)" experiences the most severe systemic subordination, recording the lowest net-influence value of $c-r = -1.409$. This substantial negative divergence potentially indicates a systematic reconfiguration of traditional rural communal social interactions. However, this structural dependency is not limited to social geography; it extends across the entire financial and institutional spectrum. The "Presence of venture capital providers (EES2)" functions merely as a dependent outcome ($c-r = -0.198$), suggesting that investment capital strictly follows established commercial viability rather than acting as a pioneering catalyst. Furthermore, institutional anchors such as "Collaboration with research institutions (EES8)" and "Government policy/fiscal support (EES1)" are similarly relegated to passive systemic effects, recording negative values of c−r=−0.179 and c−r=−0.041, respectively. Collectively, these empirical findings indicate that the dominant export market determinism necessitates the ongoing formalisation of all local networks. Consequently, informal communal relationships are increasingly transformed into formal contractual frameworks to enhance transactional efficiency, while state governance and academic research are primarily mobilised to ensure operational compliance and maintain transactional legitimacy within the rigorous requirements of highly integrated global market supply chains (Ponte, 2020; Overdevest & Zeitlin, 2018).

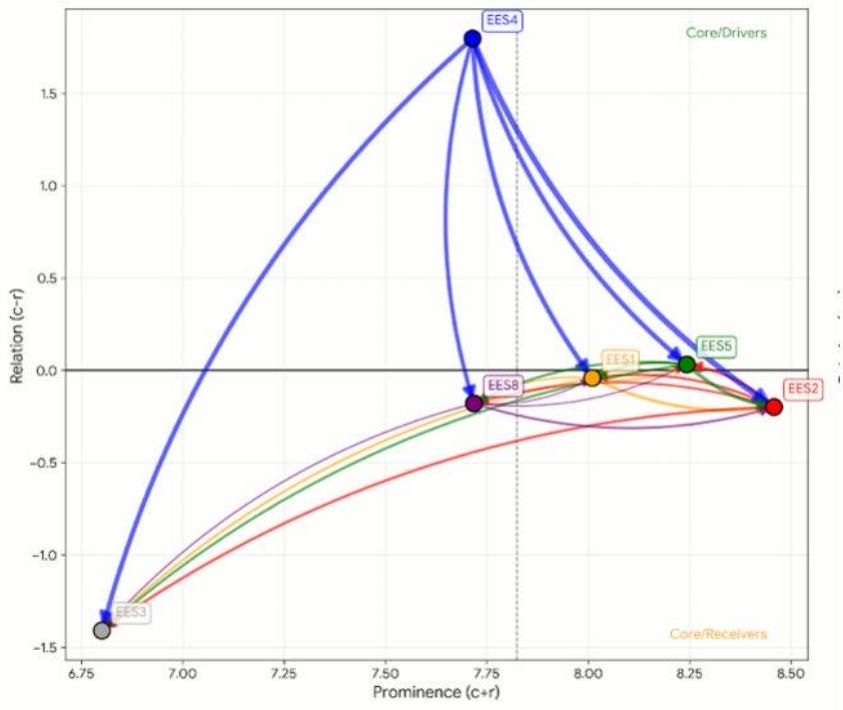
In the bamboo entrepreneurial ecosystem, "Local public support and consumer trends (EES4)" records the most significantly negative polarisation value of $c-r = -1.010$ within the computational matrix. This structural isolation suggests that global green consumerism narratives lack direct mechanical leverage over emerging grassroots bioeconomies; market demand does not organically trigger production but must be deliberately cultivated. Furthermore, financial and spatial configurations within this regime are similarly reactive. The "Presence of venture capital providers (EES2)" emerges as a deeply dependent systemic residue with a value of $c-r = -0.754$, while "Geographical embeddedness and proximity (EES3)" also acts as a passive systemic

outcome (c−r=−0.125). These empirical findings collectively indicate that both external market capitalisation and the physical clustering of supply chains heavily depend on prior internal institutional value creation and risk mitigation (Polzin, 2017). Consequently, state bureaucratic machinery and community cultural cohesion must necessarily initiate regional grassroots economic formalisation before private finance and structured geographic networks can be effectively mobilised to address existing institutional voids (Webb et al., 2020).

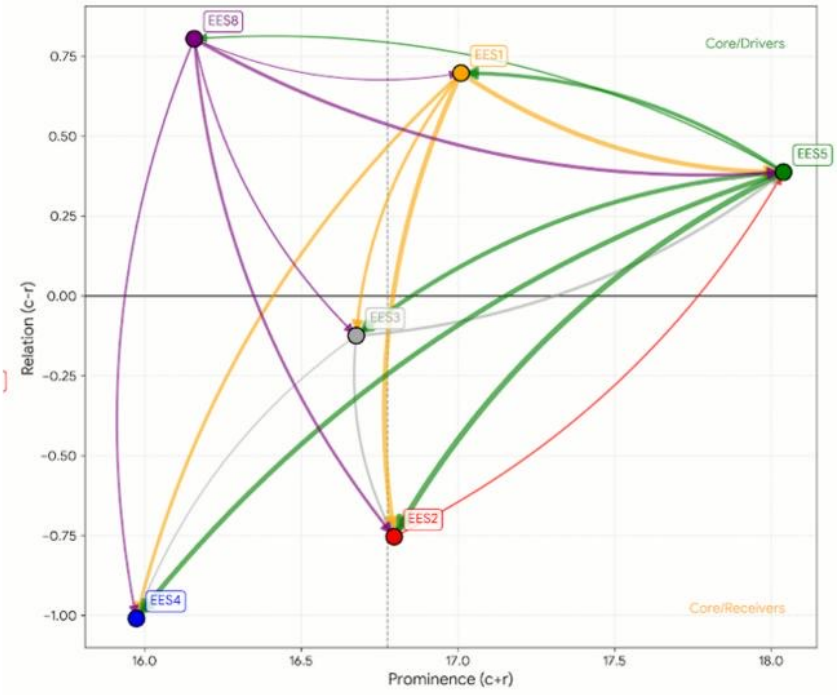
These asymmetric structural configurations provide critical empirical evidence for recalibrating regional bioeconomy policy intervention models. The systemic subordination of communal proximity in the teak industry potentially illustrates the phenomenon of 'disembeddedness' (Monteiro et al., 2021; Polanyi, 2021). As contemporary economic geography literature suggests, economic activities within deeply integrated global production networks may gradually detach from their original local social roots to comply with transnational standards (Coe & Yeung, 2015). Conversely, the structural marginalisation of global market trends within the bamboo ecosystem validates contemporary perspectives on the 'institutional voids' thesis (Webb et al., 2020). Price signals and international sustainability campaigns lack operational leverage within fragile peripheral grassroots institutional infrastructures. Therefore, introducing global market access for bamboo entrepreneurs requires establishing comprehensive prior local institutional safeguards. Attempting direct market interventions without resolving underlying grassroots institutional gaps may systematically produce suboptimal allocative outcomes.

5.3.4 Network Relationship Map (NRM) and Trajectory Divergence

Topologically, the structural configuration of these two bioeconomic regimes is projected through the network relationship map. This specific visual representation clearly demarcates the entrepreneurial ecosystem elements into four distinct functional quadrants. These four specific quadrants systematically represent the underlying hierarchical causal structure of the regional ecosystem (Figure *23*). The visual architecture of these two network maps indicates fundamentally divergent regional economic governance trajectories. Although both specific commodities originate from rural economies, their developmental pathways exhibit extreme causal polarisation. This topological divergence suggests that distinctly different institutional mechanisms consistently govern these regional bioeconomic trajectories.



(a) Network Relationship Map (NRM) in Teak Wood Furniture



(b) Network Relationship Map (NRM) in Bamboo Craft

Figure 23. Network Relationship Map (NRM): Teak and Bamboo EES

Source: Own

A. Entrepreneurial Ecosystem in Teak Wood Furniture

The Network Relationship Map (NRM) of the teak entrepreneurial ecosystem reveals a structural configuration in which systemic control is fundamentally externalised and

driven by global demand. The computational results indicate that local public support and consumer trends (EES4) act as the absolute "master driver" or apex node, possessing a commanding net causal influence of $c-r$ = +1.797. This massive causal trajectory underscores a rigid demand-pull mechanism, where international market preferences dictate the entire regional economic flow (Baldwin et al., 1984; Pasierbiak, 2018). Within this map, global standards do not merely influence but effectively subordinate government policy/fiscal support (EES1), pulling the state's regulatory apparatus into the dependent effect group with a score of $c-r$ = −0.041. Interestingly, while the role of culture (EES5) is technically categorised as a cause, its net influence is marginal ($c-r$ = +0.031), suggesting that traditional social orders are being reconstructed to serve external value regimes. The NRM further visualises how the high prominence of financial capital (EES2) ($c+r$ = 8.457), despite being a systemic effect, cascades into a suppressive force against geographical and relational proximity (EES3). The severe subordination of these grassroots ties, recording the lowest net relation score of $c-r$ = −1.409, reflects a structural transition in which formalised transactional efficiency systematically supplants traditional communal bonds to meet global standardisation requirements (Fomin & Keil, 2008; Ponte, 2020).

These empirical network patterns provide quantitative evidence that the 'disembeddedness' thesis within contemporary institutional economics is largely rooted in Karl Polanyi's theory. As rural production centres integrate into global value chains, local social relations (EES3) tend to detach from economic activities, becoming secondary to formal contractual requirements (Dubois et al., 2011; Fløysand and Sjøholt, 2007; Vicol et al., 2018). As external market forces automatically dictate the operational parameters of the ecosystem, public regulations (EES1) are stripped of their proactive capacity for local industrial engineering. Instead, state bureaucracies primarily function as reactive compliance instruments to maintain international market legitimacy (Overdevest & Zeitlin, 2018). Consequently, the teak entrepreneurial ecosystem operates under strict supralocal orchestration, where spatial autonomy is sacrificed to maintain access to competitive export markets.

B. Entrepreneurial Ecosystem in Bamboo Craft

A radical structural inversion becomes empirically evident when analysing the topology of the bamboo ecosystem. Network Relationship Map (NRM) analysis of the bamboo entrepreneurial ecosystem reveals a structural architecture in which systemic

control is fundamentally internal and driven by institutional innovation alongside state support (Spigel, 2017; Wurth et al., 2021). The computational findings highlight that collaboration with research institutes and universities (EES8) serves as the apex node or "master driver," commanding a net causal influence ($c-r$) of +0.804. This causal trajectory indicates a proactive knowledge-push mechanism; academic and institutional research essentially dictate the direction of regional economic flow (Pugh et al., 2018). This landscape, government policy, and financial incentives (EES1) are not subordinated. Instead, they act as a formidable driving force alongside the research sector, firmly anchoring the state's regulatory apparatus in the cause group with a score of c-r = +0.697 (Brown & Mason, 2017; Mazzucato, 2016).

Interestingly, the role of culture (EES5) is not only classified as a cause ($c-r$ = +0.387) but also captures the absolute highest systemic prominence across the network ($c+r$ = 18.039). This finding implies that traditional social orders and local norms function as the fundamental anchor guiding the ecosystem's trajectory (Gaddefors & Anderson, 2017; Korsgaard et al., 2015). The NRM also visualises how pro-environmental consumer trends and local public support (EES4) elements, frequently assumed to be primary market drivers, operate as highly dependent effects. The sharp subordination of these market trends, marked by the lowest net relation score *of* $c-r$ = −1.010, reflects a structural setup in which both market dynamics and financial capital (EES2, $c-r$ = −0.754) are systematically shaped by local institutional, policy, and cultural paradigms rather than being pulled by external market demands (Audretsch et al., 2018).

These empirical network patterns offer quantitative evidence that the bamboo entrepreneurial ecosystem remains deeply 'embedded' within its local socio-institutional context. Such findings present a stark antithesis to the 'disembeddedness' thesis found in contemporary institutional economics, which heavily roots itself in Karl Polanyi's original formulations (Polanyi, 1944; for contemporary contextualisation, see McKeever et al., 2015). As rural production centres expand, local culture and social norms (EES5) survive as the gravitational centre of economic activities rather than being marginalised by rigid global contractual demands (Muñoz & Cohen, 2017). Because the operational dynamics of the ecosystem are proactively dictated by internal institutional and cultural forces, public regulations (EES1) fully retain their capacity to engineer local industry. Rather than reducing state bureaucracy to a mere reactive compliance tool for maintaining international market legitimacy, the state actively leads the ecosystem's development in synergy with academic institutions (Wei, 2021). Ultimately, the bamboo entrepreneurial

ecosystem operates under strong local and institutional orchestration, where spatial autonomy, cultural preservation, and research-driven innovation are effectively utilised to build a resilient and self-reliant regional industry.

5.3.5 Causal Architecture of Rural Entrepreneurial Ecosystems - Discussions

The fuzzy DEMATEL estimations reveal a stark structural fracture between the teak and bamboo entrepreneurial configurations. In the teak system, external market dynamics are pivotal. Causal pathways stemming from local public support and consumer trends (EES4) outline a regional economic engine overwhelmingly subordinated to external demand. This cascade of demand exerts a profound gravitational pull-on government policy and fiscal support (EES1). Instead of operating as a proactive lever for local empowerment, state intervention is frequently reduced to a mere compliance apparatus with international market standards. This has resulted in a pronounced disembeddedness phenomenon, where economic activities are progressively uprooted from their native sociocultural foundations, a trajectory frequently warned against in critical rural entrepreneurship studies (Lang et al., 2013; Müller & Korsgaard, 2017).

Such external orchestration inevitably fractures the traditional social order of these teak clusters. As financial capital penetrates more aggressively, it systematically erodes geographical embeddedness and proximity (EES3), which once bound local entrepreneurs together. Because formalised transactional efficiency begins to overwrite the role of culture in norms and behaviour (EES5), reciprocal communal ties that have historically fortified the rural economic base tend to dissolve. The resulting erosion of spatial autonomy within the teak ecosystem provides a striking empirical alignment with recent theoretical critiques. As Giuliani et al. (2019) observe, deep integration into global value chains frequently hollows out localised institutional governance and transfers substantive power to lead firms abroad.

Conversely, the bamboo ecosystem operates under a radically inverted causal structure. Here, local public support and consumer trends (EES4) drop into the lowest effect zone, functioning almost exclusively as passive terminal receivers. This specific configuration lends substantial empirical weight to the institutional voids thesis, demonstrating how formal market pulls are severely blunted in peripheral regional economies (Barbar, 2025; Olthaar et al., 2016). Navigating this void requires grassroots actors to elevate the role of culture in norms and behaviour (EES5) as a central orchestrating force. In this context, relational proximity acts as an informal hedging

mechanism that directly compensates for the structural deficit in the presence of financial capital providers (EES2). Therefore, survival in these marginal rural ecosystems does not stem from formal market efficiency. Rather, it is anchored in the profound resilience of behavioural norms and community reciprocity (Spigel 2023).

Nonetheless, breaking free from this cycle of mere survival demands more than just localised resilience; the bamboo network still relies significantly on external institutional catalysts. Both government policy/fiscal support (EES1) and collaboration with research institutions (EES8) emerged from the data as definitive structural drivers. The significant impetus provided by governmental and academic entities injects crucial developmental energy into a previously overlooked sector, offering strong empirical support for the institutional-push thesis in the context of bio-economy transitions (Dietz et al., 2018; Schot & Steinmueller, 2018).

However, identifying these contrasting causal pathways only addresses a fraction of the developmental puzzle. While mapping causal topologies clearly exposes the fundamental structural divergence between the two commodity networks, it remains a purely diagnostic exercise. The fuzzy-DEMATEL framework successfully maps how these ecosystems elements interact, but it cannot prescribe where public authorities should deploy limited resources for optimal impact. Causality alone is an insufficient foundation for actionable policy formulation, a limitation increasingly acknowledged in the advanced multi-criteria decision-making (MCDM) literature (Si et al., 2018). Translating these structural diagnostics into precise strategic interventions necessitates a methodological pivot in which causal prominence is mathematically intersected with empirical performance evaluations. To prevent institutional misalignment and develop a truly unique set of policies, the following section (Sub-chapter 4.4) advances this investigation. This study moves from theory to practical planning by adding these cause-and-effect points to a mixed policy chart.

5.4 Designing Policy Interventions for Forest-Based Bioeconomy Systems

The preceding empirical exploration reveals significant structural divergences within conventional regional bioeconomy transition governance frameworks. Quantitative data indicate that global market forces primarily orchestrate the mature hardwood timber trade regime. Conversely, community-based bamboo commodities fundamentally require proactive institutional engineering to stimulate sustainable regional economic development. Applying uniform policy interventions across these

fundamentally distinct regimes may generate significant regional allocative inefficiencies. Therefore, this section translates aggregate quantitative diagnostic findings into highly targeted regional policy intervention architectures. The primary objective involves designing asymmetric regulatory frameworks that strategically target specific systemic leverage points. These proposed interventions rely explicitly upon the net-cause mappings previously established within the network relationship map.

Formulating effective regional bioeconomy policies requires systematically identifying structural variables that function as systemic orchestrators. This sub-chapter introduces a specific methodological integration to enhance the precision of regional policy design. The analytical framework strategically hybridises Importance-Performance Map Analysis with the causal topology of fuzzy DEMATEL. This combined empirical approach systematically identifies highly critical structural variables demonstrating suboptimal regional operational performance. Simultaneously, the integrated quantitative matrix precisely isolates specific intervention points operating as primary systemic drivers. This methodological synthesis ensures that proposed regional interventions target fundamental structural causes rather than derivative effects.

Relying purely upon isolated statistical methods may occasionally produce broad or untargeted regional policy recommendations. Therefore, integrating predictive performance metrics with relational causality mapping provides stronger empirical foundations for governance. The subsequent sections translate these integrated empirical findings into a comprehensive regional bioeconomy policy blueprint. This proposed policy matrix systematically delineates specific functional responsibilities across multiple relevant regional institutional actors. Identified stakeholders include technical government ministries, regional administrative authorities, academic institutions, and communal business entities. This structured alignment aims to facilitate precise policy execution within distinct regional bioresource entrepreneurial ecosystems.

5.4.1 Structural level of Bioeconomy Transformation

Importance-Performance Map Analysis systematically translates statistical predictive proxies into highly precise regional policy topographies. This specific analytical instrument explicitly avoids normative bias during regional economic transition policy formulation. The empirical analysis systematically categorises the ecosystem landscape into a precise four-quadrant strategic matrix (Figure 24). These quadrants include Concentrate Here, Keep Up the Good Work, Low Priority, and Possible

Overkill. Each specific latent variable's position strictly depends upon its transformative systemic leverage and current operational performance. The Importance axis represents the variable's systemic leverage, while the Performance axis reflects actual field achievements. This specific spatial deconstruction directly reveals fundamental structural asymmetries within regional bioeconomic governance frameworks. Consequently, this strategic quadrant mapping functions as a primary navigation instrument for efficient public resource allocation. This objective empirical evidence helps identify and potentially resolve persistent systemic governance inefficiencies across distinct ecosystems.

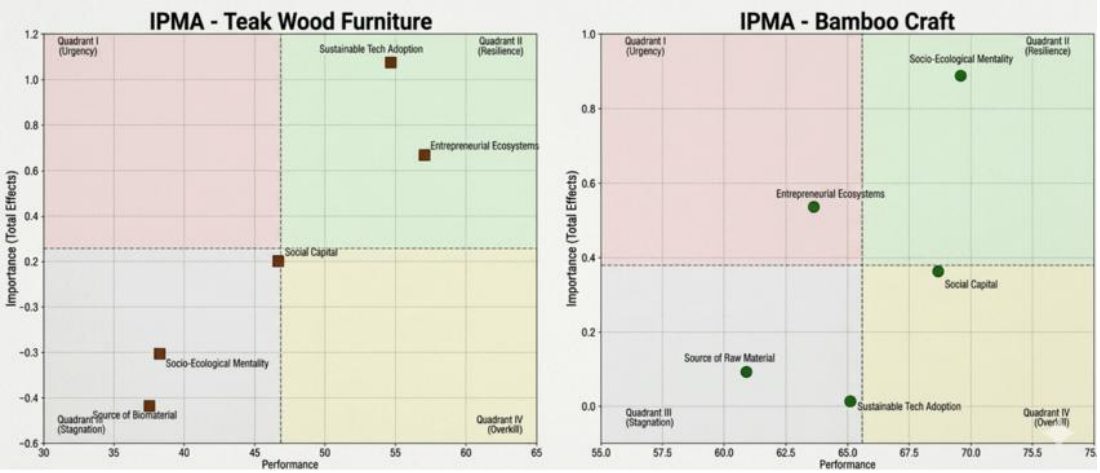


Figure 24. Structural Policy Positioning Matrix

Source: Own Analysis

A. Teak Wood Policy Positioning

In the teak empirical matrix, Sustainable Tech Adoption (TEA) and Entrepreneurial Ecosystems (EES) are positioned within the resilience area identified as Quadrant II. These elements displayed high systemic leverage scores (Importance/Total Effects), with TEA recording the highest score at approximately 1.08 and EES at 0.67. Both maintain strong empirical performance levels of 54.5 and 57.0, respectively. This configuration is highly strategic for a regional bioeconomy transition. This suggests that the teak sector already possesses the crucial socio-technical drivers required to shift toward high-value, sustainable bio-based production. This positioning strongly aligns with transformative bioeconomy policy frameworks, indicating that current green transitions are effectively propelled by robust eco-technological upgrading and a dynamic entrepreneurial environment (Viaggi, 2018). From a transition governance perspective, public policy interventions must capitalise on this structural quadrant to accelerate the regional

bioeconomy. Rather than requiring urgent remediation, regional authorities should focus on continuous facilitation to scale up circular and bio-based business models. The successful and ongoing adoption of advanced green technologies fundamentally requires maintaining supportive local institutional networks and ensuring continuous collaborative learning among bioeconomy actors (Cheng et al., 2025; Simarasl et al., 2024; Javed et al., 2025).

Meanwhile, the empirical analysis identifies Social Capital (SCP) as positioned near the centre intersection, falling just below the high systemic leverage threshold into the upper right boundary of Quadrant III (Stagnation). It holds an importance score of 0.20 and an average performance level of 46.5. While social networks remain a functional component of the sector, they do not currently act as the primary catalyst for a deep bioeconomic transformation. Consequently, transition policies should monitor this asset to ensure that stakeholder engagement remains stable, rather than targeting it for extensive structural intervention (Brännmark & Benn, 2012; Gonzalez-Porras et al., 2021). Crucially, the empirical configuration highlights profound structural vulnerabilities regarding the bioeconomy's foundation: Socio-Ecological Mentality (SOM) and Source of Biomaterial (SUB). Both variables are situated deep within Quadrant III (stagnation). The SOM shows a negative importance score of -0.30 and a low performance of 38.2, while the SUB exhibits the lowest importance of -0.42 and a performance of 37.5. From a conventional linear economic optimisation perspective, variables with negative systemic leverage may appear strategically irrelevant. However, from a circular bioeconomy perspective, this configuration is concerning. Declining performance in these areas signals severe emerging pressures on the biophysical limits and institutional conditions that underpin the entire bio-based sector.

The relatively low urgency (importance) scores observed in this quadrant expose a classic market failure often addressed by bioeconomy policies, which the current economic system significantly undervalues the ecological dimensions of biomass production. From a biophysical standpoint, the low performance (37.5) in Source of biomaterial (SUB) directly indicates increasing extraction pressure and the potential depletion of regional sustainable biomass. These patterns serve as a strong warning to regional policymakers that the biological resource base is fundamentally at risk of depletion. Ignoring the structural weaknesses in Quadrant III poses existential risks to the long-term viability of the regional bioeconomy. Therefore, regional transition governance must implement a strictly balanced policy mix. Quadrant II requires innovation policies

that sustain and scale up existing eco-technological (TEA) and entrepreneurial (EES) capacities, while Quadrant III demands urgent regulatory safeguards to restore and protect ecological foundations (SOM and SUB).

B. Bamboo Policy Positioning

The spatial instrument reveals a structurally distinct socio-technical configuration within the community-based bamboo craft ecosystem. In stark contrast to the mechanically driven teak industry, the fundamental engine of the bamboo bioeconomy is rooted in its Socio-Ecological Mentality (SOM). Positioned firmly in the resilience zone of Quadrant II, SOM records the highest systemic leverage (Importance score of approximately 0.88) while demonstrating robust operational Performance (69.0). In the context of bioeconomy transitions, this indicates that the sector is fundamentally sustained by traditional ecological knowledge and strong community-nature symbiosis. Unlike dominant industrial bioeconomy models that often struggle to internalise environmental values and risk ecological overshoots (D'Amato & Korhonen, 2021; Gawel et al., 2019), economic resilience in this regional bamboo sector is intrinsically coupled with shared ecological awareness. In line with common governance theory (Ostrom, 1990), recent socio-ecological studies confirm that such embedded ecological values function as resilient informal institutions that prevent the over-extraction of local biomass (Bauwens et al., 2020; Kluvánková & Gežík, 2016). Transition governance must therefore strictly prioritise the preservation of this socio-ecological bedrock, avoiding aggressive, top-down commodification strategies that could erode the community's intrinsic conservation ethos.

However, moving from a traditional craft sector to a highly functional circular bioeconomy requires overcoming a critical bottleneck: the Entrepreneurial Ecosystems (EES). Situated squarely in Quadrant I (Urgency), EES exerts high systemic leverage (Importance 0.53) but exhibits comparatively limited Performance (63.5), falling below the empirical threshold (65.5). This structural gap highlights a classic "valley of death" often observed in decentralised bioeconomy transitions (Acs et al., 2017; Hellsmark et al., 2016; Neumeyer & Corbett, 2017). The regional system possesses sustainable biomass and an ecological mindset, but severely lacks the formal institutional infrastructure required to commercialise high-value bio-based products. To catalyse a genuine transition, transformative public policy must urgently deploy niche-support mechanisms (Schot & Steinmueller, 2018). Authorities should create protected

incubation spaces to foster grassroots bio-innovation, empowering village-owned economic enterprises (BUMDes) and craft cooperatives to capture higher margins in the circular economy, without being prematurely marginalised by conventional market pressures.

Crucially, the empirical matrix serves as a stark warning against techno-solutionism in bioeconomy policy. Sustainable Tech Adoption (TEA) demonstrates exceptionally limited structural leverage within this specific ecosystem, recording a near-zero Importance score of 0.01 alongside an average Performance of 65.0. This strongly suggests that simply injecting advanced machinery into small-scale bamboo operations does not trigger a systemic transition. In many developing bioeconomies, prioritising heavy technological interventions over institutional capacity building often results in "institutional isomorphic mimicry"—the adoption of modern-looking, mechanised reforms that fail to resolve deeper organisational constraints (Andrews et al., 2013; Sovacool et al., 2020). Furthermore, Source of Raw Material (SUB) is positioned in Quadrant III (Stagnation) (Importance 0.09, Performance 61.0), indicating that while bamboo is inherently renewable, its supply chain coordination remains underdeveloped and requires organisational, rather than purely mechanical, upgrading.

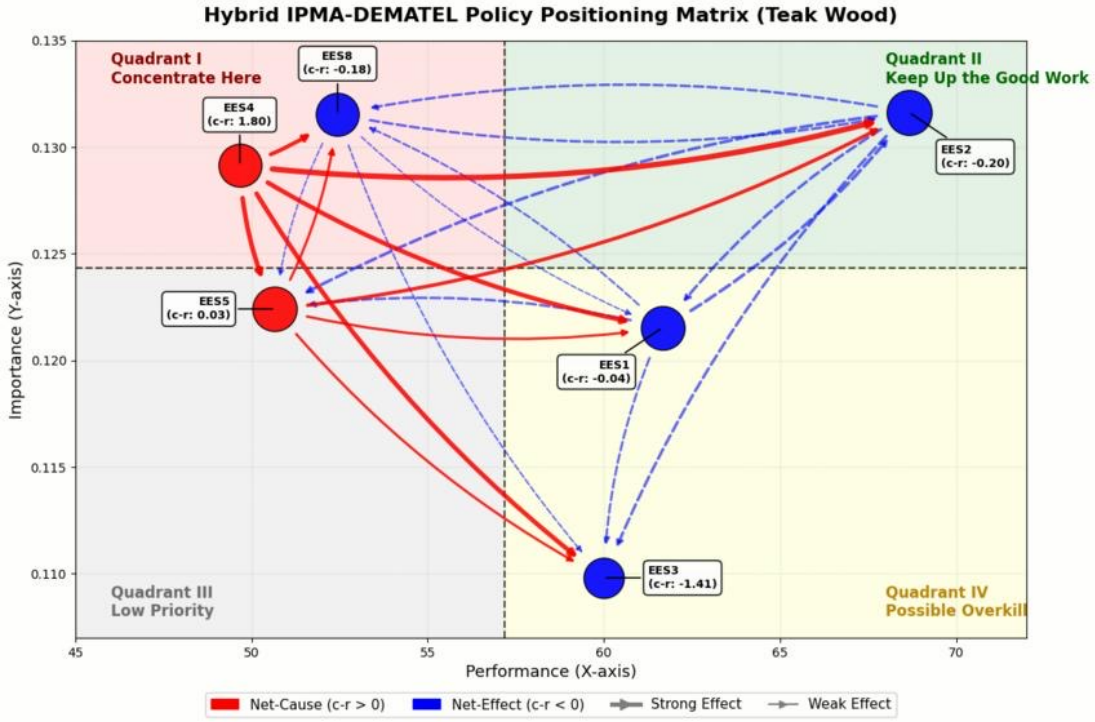
Interestingly, Social Capital (SCP) is positioned in Quadrant IV (Overkill), exhibiting high Performance (69.0) but lower structural leverage (Importance 0.37). This configuration reveals that while communal ties and trust are abundant, they are currently trapped in low-value socio-economic routines. Without targeted interventions in the entrepreneurial infrastructure (EES in Quadrant I) to mobilise these social networks, social cohesion will not spontaneously generate a structural shift toward an advanced bio-based economy (Bauer et al., 2018; Imbert et al., 2018).

The empirical contrast between the teak and bamboo matrices exposes the limitations of applying uniform policy architectures across distinct bioresource regimes. The export-oriented teak industry, which is heavily dependent on eco-technological capital and faces critical biophysical limits, necessitates a transition policy of "guarded ecological modernisation" where the state actively regulates resource depletion while facilitating technological efficiency (Schulz et al., 2021). Conversely, the community-based bamboo craft sector requires a decentralised, institution-building governance approach. Here, the primary role of the state is not to act as a supplier of industrial machinery, but as an institutional facilitator. Transformative bioeconomy policy for the bamboo sector must focus on bridging the entrepreneurial gap, transforming abundant

social capital and strong socio-ecological values into structured, market-ready cooperative enterprises capable of driving a grassroots circular economy

5.4.2 The Policy Intervention: A Hybrid IPMA-DEMATEL Approach

The spatial topography framework systematically divides the regional ecosystem into four distinct strategic performance quadrants. This specific analytical architecture systematically integrates three fundamental empirical data layers from advanced Fuzzy-DEMATEL computations. The colour dichotomy effectively distinguishes the fundamental structural hierarchy within the regional bioeconomic transition system. Red visual indicators systematically identify specific structural variables functioning primarily as systemic upstream causal triggers. Conversely, the specific blue spectrum explicitly identifies systemic variables functioning merely as derivative operational consequences. Node size variations accurately represent the overall prominence degree of specific indicators within the relational network. Directional network arrows map the complex causality propagation pathways throughout the entire regional entrepreneurial ecosystem.



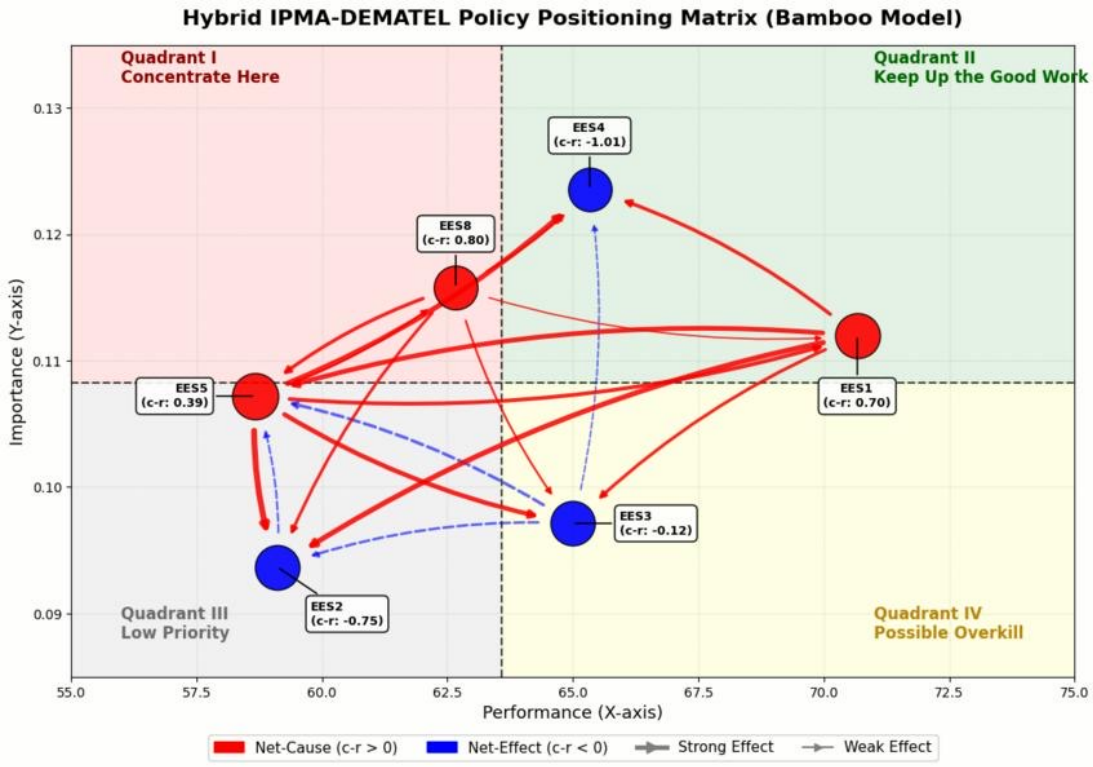


Figure 25. Hybrid IPMA-DEMATEL-NRM for Entrepreneurial Ecosystems

Source: Own Analysis

This hybrid visual architecture equips regional policymakers with a highly precise quantitative regional institutional governance instrument (Figure 25). This specific analytical compass strictly dictates optimal budget allocations across various regional systemic operational policy quadrants. Targeting precise structural levers potentially prevents significant regional public fiscal inefficiencies during complex policy implementation processes.

A. Teak wood entrepreneurial ecosystem policy positioning

Analysing the integrated matrix reveals specific structural realities regarding the regional teak wood entrepreneurial ecosystem policy governance. Market capture and regional entrepreneurial culture indicators distinctly emerge as primary upstream systemic causal regulatory triggers. Conversely, research collaboration and specific government regulatory support variables operate merely as derivative institutional effect receivers. This specific quantitative causal constellation empirically supports buyer-driven chain theories within contemporary global value chain literature. The teak industry supply chain fundamentally operates under strict coordination from powerful international market corporate buyers (Gereffi, 2019).

The European Union Deforestation Regulation directly mandates stringent environmental compliance for all regional timber commodity exports (EUDR 2023/1115). State regional policies primarily shift when international markets impose stringent new sustainable environmental production standard regulations. The Indonesian government continuously updates its Timber Legality Verification System to ensure strict international export compliance (MoEF Regulation 8/2021). Furthermore, local entrepreneurial culture functioning as a fundamental cause reinforces recent evolutionary economic geography theoretical perspectives. Historical entrepreneurial pathways establish crucial cognitive foundations shaping local enterprise responses to external global market shocks (Audretsch et al., 2023).

Allocating substantial research funding without guaranteed international buyer demand represents highly inefficient public financial resource allocation. Recent national procurement policies explicitly mandate prioritising certified sustainable local products within governmental institutional supply chains (LKPP Regulation 122/2022). Implementing demand-side innovation policy requires the regional government to function proactively as a strategic demand catalyst (Edler & Fagerberg, 2017). Mandatory green public procurement effectively stimulates regional competitive markets for certified sustainable legal wood furniture commodities. Strengthening this primary demand pull systematically encourages entrepreneurs to actively pursue sustainable academic institutional research collaboration.

B. Bamboo entrepreneurial ecosystem policy positioning

The integrated quantitative matrix presents a fundamentally divergent causal topography for regional bamboo handicraft entrepreneurial ecosystems. Unlike market-driven teak industries, the community-based bamboo ecosystem faces significant regional institutional economic knowledge isolation challenges. Spatial deconstruction specifically positions financial access, communal culture, and research collaboration within the critical acceleration priority quadrant. However, topological network analysis exposes collaborative academic research and communal culture strictly as upstream systemic causal triggers. Conversely, regional financial access and global market capture variables function entirely as derivative systemic structural dependent variables. This specific causal constellation severely challenges conventional regional policy frameworks concerning subsistence commodity enterprise institutional development.

Conventional regional policy assumptions frequently attribute economic stagnation solely toward financial resource deficits or market access. The systemic absence of academic technology transfer potentially confirms persistent regional grassroots institutional infrastructure capability voids (Wurth et al., 2021). Formal investors and global consumers generally avoid financing raw bamboo products lacking research-facilitated institutional economic value addition.

This specific empirical reading strongly supports quadruple helix innovation theories within contemporary regional economic transition development frameworks (McPhillips et al., 2024). Higher education institutions must urgently transition toward functioning as active regional industrial systemic market knowledge brokers (Carayannis & Campbell, 2009). Addressing this persistent structural deadlock requires aggressively leveraging proactive government policy within the excellence maintenance operational quadrant. Since grassroots bamboo entrepreneurs lack commercial bargaining power, regional governments must deliberately construct protected sustainable innovation spaces (Smith & Raven, 2012).

Recent national regulations regarding village enterprises provide concrete legal frameworks for establishing these local institutional protective spaces (Government Regulation 11/2021). Furthermore, specific micro-enterprise empowerment policies officially mandate structured regional academic incubation for rural subsistence community commodity sectors (Government Regulation 7/2021). Recent international forestry reports emphasise comprehensive institutional capacity building before exposing grassroots bamboo entrepreneurs to global markets (INBAR, 2024). Local administrative authorities should systematically utilise regulatory governance instruments to mandate collaborative product incubation academic research consortia. Fusing formal state administrative authority with dedicated academic knowledge intervention potentially resolves persistent regional subsistence economic challenges. Successful academic research collaboration improves core product quality and subsequently attracts necessary formal banking institutional finance mechanisms. This targeted regional institutional orchestration eventually stimulates organic market absorption without requiring continuous artificial public budget subsidies.

5.5 Synthesis of Empirical Findings and Policy Implications

The comparative empirical analysis suggests the presence of two distinct systemic configurations within the forest-based regional bioeconomy. The structural equation

modelling and relational network analyses consistently indicate divergent evolutionary pathways for local entrepreneurial ecosystems. The bamboo handicraft sector operates primarily through community-based institutional arrangements characterised by strong local sociocultural embeddedness. Conversely, the capital-intensive teak furniture industry demonstrates a highly formalised industrial structure driven predominantly by global market coordination. These specific empirical findings consistently indicate that local bioeconomic development avoids following a singular monolithic transition trajectory.

Examining the specific behavioural transition pathways reveals distinctly different cognitive mechanisms driving regional sustainable entrepreneurial intentions. The structural equation modelling results suggest that perceived behavioural control appears to play a significantly dominant role (Ajzen, 2020). Teak entrepreneurs heavily prioritise sustainable technological adoption to navigate severe resource scarcity and strict international market regulations. In strict contrast, the grassroots bamboo ecosystem relies fundamentally upon strong socio-ecological mentalities and communal subjective norms. Bamboo entrepreneurs systematically utilise deeply embedded environmental preservation values as their primary psychological drivers for sustainable business transformation.

The advanced network topology analysis further elucidates the underlying structural architecture governing these distinct regional entrepreneurial ecosystems. The quantitative causal mapping explicitly identifies global consumer trends as a key systemic driver within the teak industry. This specific market-driven configuration apparently subordinates local government regulations and traditional communal social proximity networks. Alternatively, the bamboo sector effectively functions as an institution-driven regional ecosystem requiring proactive state and academic collaborative intervention. The quantitative topology explicitly identifies collaborative academic research and public regulatory support as crucial upstream developmental triggers (Spigel, 2020).

These integrated empirical patterns provide substantial theoretical contributions to contemporary entrepreneurial ecosystem and socio-technical transition literature (Geels, 2019). The analytical results strongly suggest that natural resource characteristics significantly shape regional institutional coordination and innovation dynamics. Extracted biophysical properties appear to significantly influence whether local economic sectors require market-driven technological upgrading or grassroots protection. This specific empirical evidence raises fundamental questions regarding conventional

neoclassical assumptions about uniform institutional development across rural bioeconomies. Consequently, regional socio-technical transition trajectories seemingly remain highly contingent upon specific resource materialities and local socio-economic structural configurations (Wurth et al., 2021).

Building upon these theoretical insights, formulating effective regional bioeconomy transition strategies requires strictly bifurcated, context-specific public governance. The hybrid diagnostic policy matrix indicates that applying uniform regulatory frameworks generates significant policy mismatches between different sub-sectors. For mature, globally integrated industries like teak wood, where transition is heavily driven by sustainable technology adoption but threatened by raw material depletion policymakers must deploy 'guarded ecological modernisation' (Schot & Steinmueller, 2018). This strategy effectively couples strong technological incentives with strict biophysical extraction mitigation. Conversely, for community-based sectors like bamboo, empirical findings show that transition is driven by socio-ecological mentality rather than technological intervention. Therefore, these sectors require 'protective institutional orchestration' focusing heavily on proactive niche shielding, social capital development, and local capacity building (Smith & Raven, 2012)."

6 CONCLUSIONS

Key Findings

This dissertation investigates the transition mechanisms of forest-based bioeconomies in rural Indonesia. This study compares the entrepreneurial ecosystems of the teak furniture and bamboo handicraft sectors. The data demonstrate that the forest-based bioeconomy transition does not proceed uniformly across different sectors. Instead, the physical characteristics of local forest resources dictate the specific transformation pathways for each industry. This section concludes the investigation by synthesising the empirical evidence to explicitly answer the formulated research questions (RQs). To ensure strict methodological and theoretical alignment, the answers below are structured to directly mirror the core phrases and constructs of each enquiry.

Research Question 1 (RQ1): What are the main drivers of the bioeconomy transition in the rural forestry sector?

Addressing the main drivers of the bioeconomy transition, the empirical evidence reveals a profound structural bifurcation tied intimately to the physical materiality of the extracted resources. For the legacy teak industry, the transition is driven predominantly by technocratic and necessity-induced pressures. These act as pragmatic survival mechanisms designed to cope with severe raw material shortages and outdated production capacities. Conversely, within the bamboo clusters, the transition drivers are fundamentally sociological. The shift in this sector is fuelled by community reciprocity, ambitions for spatial market expansion, and the vital desire to transfer socio-emotional wealth across generations.

Research Question 2 (RQ2): How does entrepreneurial behaviour shape the readiness of local actors to adopt bioeconomy practices?

When examining how entrepreneurial behaviour shapes this readiness, the structural estimations uncover highly asymmetrical cognitive mechanisms. In capital-intensive networks like teak, entrepreneurial readiness is dictated almost exclusively by pragmatic technological mastery. Within this space, ecological ethics that fail to instantly improve operational efficiency are perceived strictly as a cost burden, reflecting a profound cognitive dissonance. On the other hand, in labour-intensive bamboo networks, readiness is shaped through a deeply internalised socio-ecological mentality. For these grassroots

actors, normative environmental values act as the absolute, non-negotiable filter for adopting new bio-based practices, demonstrating that behavioural readiness relies far more on cultural alignment than mere technological diffusion.

Research Question 3 (RQ3): What cause-and-effect relationships within the local entrepreneurial ecosystem determine the success of bioeconomy initiatives?

Mapping the cause-and-effect relationships that determine the success of these initiatives, the causal topologies expose two entirely contrasting systemic engines. In the teak sector, external consumer trends and formal financial liquidity operate as the primary causal drivers. This top-down orchestration heavily dictates government regulations, frequently resulting in a phenomenon of disembeddedness where economic activities are systematically uprooted from their native social anchors. Alternatively, the causal dynamics in the bamboo ecosystem are anchored centrally by the role of culture and behavioural norms. Operating within severe institutional voids, these informal relational ties act as the primary engine compensating for a lack of formal banking, though the ultimate success of these grassroots initiatives still strictly demands an institutional push from state and academic actors.

Research Question 4 (RQ4): What governance strategies can effectively close the gap between macro-level policies and local realities?

Finally, regarding the governance strategies required to effectively close this macro-local gap, the analytical findings unequivocally reject any monolithic, one-size-fits-all policy paradigm. To effectively bridge this divide in the teak sector, governance strategies must prioritise a "Financial Big Push." This requires targeted interventions, such as subsidised investment credit and technological upgrading support, to resolve severe operational bottlenecks. In stark contrast, governance strategies tailored for the bamboo sector must pivot to act as "Market Enablers." For these community-driven actors, the state must orchestrate soft infrastructure, institutional capacity building, and trade diplomacy, systematically elevating informal subsistence networks into formalised bioeconomy value chains.

Theoretical Contributions

The theoretical contributions of this dissertation are fundamentally anchored in the systematic verification of the structural hypotheses (H1–H7) across the bifurcated

models of teak and bamboo species. Rather than viewing these results as mere statistical outputs, the acceptance or rejection of each path provides a rigorous basis for re-evaluating established paradigms in transition studies, entrepreneurial ecosystems and behavioural economics.

The verification of the first four hypotheses, which examine the foundational relationships between Source of Biomaterial (SUB), Social Capital (SCP), and the Entrepreneurial Ecosystem (EES), provides empirical weight for the first major theoretical contribution.

H1: Source of Biomaterial (SUB) positively influences the development of the Entrepreneurial Ecosystem (EES). Rejected for both sectors. For Teak Wood, it has a significant negative impact ($\beta = -0.655$, $p < 0.001$). For Bamboo, the impact is not statistically significant ($\beta = 0.172$, $p = 0.081$).

H2: Social Capital (SCP) has a positive effect on the Entrepreneurial Ecosystem (EES). Accepted for both sectors. For Teak Wood, the impact is positive and significant ($\beta = 0.305$, $p < 0.001$). For Bamboo, the impact is positive and significant ($\beta = 0.675$, $p < 0.001$).

In the teak wood model, H1 (SUB → EES) and H2 (SCP → EES) were verified with a unique tension: teak entrepreneurs rely heavily on formal resource access (SUB) but face extreme operational friction due to the rigidity of regulations. Conversely, the bamboo model demonstrated superior strength in H2, where informal social capital (SCP) acts as the primary engine for ecosystem formation. This bifurcated verification expands the theoretical integration between the Natural-Resource-Based View (NRBV) (Hart, 1995) and the Multi-Level Perspective (MLP) (Geels, 2002). While previous socio-technical transition literature frequently ignores the physical materiality of natural resources (Coenen et al., 2012; Hansen & Coenen, 2014), this study proves that commodity biophysical characteristics directly shape industrial regime architectures. The heavy, slow-growing nature of teak creates a highly rigid and capital-intensive institutional regime, whereas the renewable and flexible nature of bamboo facilitates highly elastic niche innovations. Consequently, this study confirms that bioeconomy transitions are strictly resource-specific, necessitating the formal incorporation of physical material constraints into the transformation analysis of conventional MLP frameworks.

H3: The Entrepreneurial Ecosystem (EES) positively drives Sustainable Technology Adoption (TEA). Accepted for both sectors. For Teak Wood, the impact is positive and significant ($\beta = 0.922$, $p < 0.001$). For Bamboo, the impact is positive and significant ($\beta = 0.892$, $p < 0.001$).

H4: The Entrepreneurial Ecosystem (EES) positively affects the formation of Socio-Ecological Mentality (SOM). Accepted for both sectors. For Teak Wood, the impact is positive and significant ($\beta = 0.781$, $p < 0.001$). For Bamboo, the impact is positive and significant ($\beta = 0.849$, $p < 0.001$).

Bridging this upstream institutional formation with downstream strategic actions, the uniform acceptance of Hypotheses 3 (H3) and 4 (H4) across both commodity models injects a crucial theoretical nuance regarding mid-stream capability diffusion. In both the teak and bamboo clusters, the Entrepreneurial Ecosystem (EES) was proven to highly facilitate Sustainable Technological Adoption (TEA) and significantly incubate Socio-Ecological Mentality (SOM). This universal validation bridges macro-level institutional theories and micro-level capability frameworks. This confirms that while rural entrepreneurial ecosystems operate under severe resource and structural constraints, they function exceptionally well as systemic incubators for capability upgrading (Korsgaard et al., 2015; Müller & Korsgaard, 2017). These findings contribute to the conversation on entrepreneurial ecosystems by effectively spreading both concrete green technologies and abstract environmental ethics. They prove that an ecosystem's fundamental value in peripheral economies lies not in forcing immediate strategic shifts but in its capacity to equip marginalised actors with the prerequisite cognitive and technical faculties required for sustainability transitions.

H5: The Entrepreneurial Ecosystem (EES) directly and positively impacts Bioeconomic Transformation Intentions (BOT). Rejected for both sectors. For Teak Wood, the impact is not significant ($\beta = -0.162$, $p = 0.274$). For Bamboo, the impact is not significant ($\beta = -0.229$, $p = 0.274$).

A pivotal theoretical shift occurs through the verification of Hypothesis 5 (H5), which posited a direct positive influence of the Entrepreneurial Ecosystem (EES) on Bioeconomy Transformation Intentions (BOT). H5 was firmly rejected in both models, with the direct effect remaining statistically insignificant or even exhibiting a negative sign reversal in the teak cluster. This falsification makes a profound contribution to the entrepreneurial ecosystem literature by shifting the analytical focus from urban (Brown

& Mason, 2017), high-technology clusters to rural, bio-based economies. Existing frameworks generally assume that robust, formal institutions automatically trigger entrepreneurial action. In contrast, the rejection of H5, further supported by the causal topologies mapped in Chapter 4, demonstrates how rural ecosystems function under persistent "institutional voids" (Mair & Martí, 2009; Webb et al., 2020). This dissertation proves that rural entrepreneurial ecosystems are not merely scaled-down versions of urban models; they are distinct economic structures in which formal institutional support is inherently inert unless it is effectively metabolised through communal trust and informal relational mechanisms.

H6: Sustainable Technology Adoption (TEA) positively influences Bioeconomic Transformation Intentions (BOT). Accepted for Teak Wood but Rejected for Bamboo. For Teak Wood, the impact is positive and significant ($\beta = 1.076$, $p < 0.001$). For Bamboo, the impact is not significant ($\beta = 0.013$, $p = 0.963$).

H7: Socio-Ecological Mentality (SOM) positively affects Bioeconomic Transformation Intentions (BOT). Rejected for Teak Wood but Accepted for Bamboo. For Teak Wood, the impact is not significant ($\beta = -0.209$, $p = 0.051$). For Bamboo, the impact is positive and significant ($\beta = 0.889$, $p < 0.001$).

The most striking theoretical advancement emerges from the asymmetrical verification of the mediation hypotheses, H6 (TEA) and H7 (SOM). In the teak sector, H6 was supported with near-unity supremacy, while H7 was rejected, reflecting a purely technocratic transition oriented around physical production efficiency. In stark contrast, the bamboo sector saw the full support of H7 (Socio-Ecological Mentality) as the obligatory passage point, while H6 was rejected due to pathway decoupling. These results enrich the Theory of Planned Behaviour (TPB) (Ajzen, 1991) within sustainability contexts (Belz & Binder, 2015; Yuriev et al., 2020) by challenging the core assumption of a universal cognitive rationality. Instead, this study identifies divergent behavioural rationalities dictated strictly by specific industrial structures. In capital-intensive sectors (teak), perceived behavioural control depends entirely on technological capabilities, whereas subjective norms and ecological ethics dominate intentions within labour-intensive sectors (bamboo). This dissertation demonstrates that pro-environmental motivations are intrinsically linked to the specific structural characteristics of local ecosystems, thereby asserting that models of entrepreneurial behaviour must be tailored to specific spatial and material contexts to maintain theoretical validity.

Practical Implications

Empirical evidence indicates that uniform national policy frameworks demonstrate significant operational limitations. Policymakers require differentiated strategies based strictly on specific commodity characteristics. Tailored interventions may effectively address the distinct structural barriers within each rural sector.

At the macroeconomic policy level, state interventions may support the teak sector through hardware-oriented instruments. This specific approach includes providing targeted machinery subsidies and establishing formal quality certification systems. These tangible policies may resolve prevailing information asymmetries and overcome technological stagnation. Conversely, policy designs for the bamboo sector require soft infrastructure development. Governments may support bamboo entrepreneurs by establishing accessible digital payment gateways. Additionally, active state trade diplomacy may facilitate new global market access. These targeted soft interventions may protect bamboo entrepreneurs from severe domestic market saturation.

At the practical entrepreneurial ecosystem level, these findings may inform strategic capacity-building initiatives. Teak furniture entrepreneurs frequently face severe capital constraints and technological obsolescence. Regional ecosystem stakeholders may support this sector by facilitating formal financial integration. Improved formal financial access allows teak entrepreneurs to upgrade their physical production technologies safely. This targeted technological upgrading may directly enhance their perceived behavioural control. Consequently, improved operational control may accelerate their transition toward sustainable manufacturing practices without risking personal household assets.

The bamboo handicraft sector faces fundamentally different practical operational challenges. Bamboo communities primarily struggle with digital isolation and generic product commoditization. Local institutions may support these communities through specialised capacity-building programs. These practical initiatives may focus strictly on digital literacy and cross-border marketing strategies. Enhancing digital capabilities allows bamboo entrepreneurs to bypass traditional supply chain intermediaries. This strategic disintermediation may significantly improve their operational profit margins. Ultimately, these practical capacity-building efforts may strengthen the overall resilience of rural bio-based entrepreneurial ecosystems.

Limitations and Future Research Directions

A key conceptual contribution of this research is the operationalisation of the entrepreneurial ecosystem as 'Perceived Ecosystem Conduciveness.' While this focus on subjective perception provides a direct link to the psychological drivers of the Theory of Planned Behaviour (TPB), it also acknowledges a research limitation. Future studies could integrate objective regional performance data with these subjective perceptions to provide a multi-dimensional view of ecosystem maturity

The geographic and empirical scope focuses exclusively on the teak and bamboo sectors within specific Indonesian regions. Other unexamined bio-based agricultural commodities could potentially exhibit fundamentally different entrepreneurial ecosystem dynamics. However, these two selected sectors effectively illustrate the fundamental dichotomy between capital-intensive and labour-intensive rural industries. Future researchers must expand this material scope to include critical commodities like rattan or biomass waste. Expanding the material scope will further validate the Natural-Resource-Based View within diverse rural contexts. Additionally, international scholars should conduct comprehensive cross-country comparative analyses across various other developing nations. These comparative international studies will validate the proposed resource-specific transition pathways under differing macro-political regimes.

The chosen quantitative methodology introduces specific analytical constraints regarding the accurate measurement of rural entrepreneurial behaviour. The applied structural equation modelling relies entirely on cross-sectional survey data to evaluate the ecosystem. This specific statistical approach primarily measures self-reported behavioural intentions rather than actual sustainable business practices. Contemporary behavioural economics literature widely recognises this specific phenomenon as the problematic intention-behaviour gap (Sheeran, 2002; Hassan et al., 2016). To effectively resolve this specific limitation, subsequent academic studies must actively employ longitudinal research designs. Longitudinal tracking mechanisms can accurately measure dynamic ecosystem transformations and behavioural shifts over extended timeframes. This continuous empirical observation will successfully bridge the identified intention-behaviour gap within forest-based bioeconomy transitions.

The meso-level entrepreneurial ecosystem evaluation presents an additional analytical boundary concerning institutional coordination mechanisms. The applied decision-making evaluation tools generate a strictly static snapshot of the rural business environment. These predictive structural models cannot immediately capture sudden

macroeconomic shocks or dynamic global regulatory shifts. Current empirical findings simultaneously highlight a massive reliance on invisible, informal communal trust networks. Future academic investigations should deeply integrate Social Network Analysis methodologies to overcome these descriptive boundaries. This advanced analytical integration can mathematically map the hidden informal network structures within rural ecosystems. Consequently, future researchers can quantitatively evaluate the exact flow of social capital among rural micro-entrepreneurs.

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ANNEX 1

SEM-PLS QUESTIONNAIRE: THE ROLE OF WOOD/BAMBOO-BASED ENTREPRENEURS IN THE BIOECONOMIC TRANSITION IN INDONESIA

We would like to thank you for your willingness to take the time to fill out this questionnaire. This questionnaire was prepared for doctoral program research at Warsaw University of Life Sciences, Poland. This research is entitled "Timber-based bioeconomy transition in Indonesia". This questionnaire aims to analyse the factors influencing the transition of the timber-based bioeconomy in Indonesia. This study uses the Structural Equation Modelling - Partial Least Squares (SEM-PLS) method to identify the relationship between latent variables and relevant indicators.

The data you provide will be used solely for this research and will be kept confidential. Your participation means a lot to us and will make a valuable contribution to the development of science and the improvement of the quality of wood-based craftsmen in Indonesia.

This questionnaire consists of several sections that need to be filled in carefully and honestly according to the actual conditions. We understand that your time is very valuable, therefore we try to compile this questionnaire in a short but still comprehensive way.

For your participation and cooperation, we would like to express our gratitude.

Sincerely,

Adhitya Rahmana
PhD Student, Institute of Economics and Finance, Warsaw University of Life Science, Poland
Email : (was provided)
Telephone: (was provided)

PART 1:

General Information & Conditions of the entrepreneurial ecosystem

Put a cross (X) for the selected question in the column that has been provided

1	Enterprise Name		
2	Address		
3	Phone/email number		
4	Age of the business owner		
5	Year of establishment of the Enterprises/business		
6	Why did you start this business? **(Option only one)**	(A)	Family business from the past
		(B)	Seeing that there is a business opportunity
		(C)	A hobby that is a business
		(D)	Others, mention:
7	Where do you get the money to start this business **(Option only one)**	(A)	Own savings
		(B)	Borrow at the bank
		(C)	Assistance from the government/public
		(D)	Others, mention:
8	Business Scale	(A)	Micro (maximum turnover of Rp. 300,000,000)
		(B)	Small (maximum turnover > Rp. 300,000,000-Rp. 2.5 Billion)
		(C)	Medium (maximum turnover > Rp. 2.5 M-Rp. 50 Billion)
9	How many people do you work with? (including the families involved)	Number	
	a. Man		
	b. Woman		
10	Main raw materials used **(Choice can be more than one)**	(A)	Wood (solid, plywood, etc.)
		(B)	Bamboo

		(C)	Rattan
		(D)	Other....
11	Quantity of main raw material requirements		
12	Main products produced **(Options <u>can be</u> more than one)**	(A)	Furniture and/or wood-working
		(B)	Craft
13	Main source of raw materials **(Options <u>can be</u> more than one)**	(A)	Timber distributor/seller
		(B)	Forest/direct land
		(C)	Other.....
14	What is your biggest problem in sourcing raw materials **The option <u>can be</u> more than one)**	(A)	Accessibility of raw materials
		(B)	The price of raw materials is expensive
		(C)	The quality of raw materials is not good
		(D)	Others, mention:
15	Main market for product sales **(Option only one)**	(A)	domestic
		(B)	export
16	Are you having trouble selling products **(Option only one)**	(A)	YES, What are the obstacles?
		(B)	NO
17	What are your plans for this venture in the next 5 years? **(The option <u>can be</u> more than one)**	(A)	Expanding the market
		(B)	Create a new product
		(C)	Increase production capacity
		(D)	Others, mention:

18	What do you expect from the government or others to help your business? **(The option <u>can be</u> more than one)**	(A)	Helping with market access
		(B)	Provide training or courses
		(C)	Providing financial assistance
		(D)	Others, mention:

PART 2: Behaviour in the bioeconomic transition

CODE	INDICATORS	(X)	DEGREE
SUB1	I know that raw materials are always available in sufficient quantities to meet production needs.	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
SUB2	I prioritise raw materials that are easily accessible and close.	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
SUB3	I use legally and ethically sourced raw materials, in accordance with sustainability standards.	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree

CODE	INDICATORS	(X)	DEGREE
SCP 1	I have a strong tradition and entrepreneurial values in the family	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
SCP2	I received active support from the surrounding community, including moral assistance and business promotion	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree

CODE	INDICATORS	(X)	DEGREE
SCP3	I was supported by entrepreneurial groups or communities to gain insights, networks, and business opportunities	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree

CODE	INDICATORS	(X)	DEGREE
SOM1	I participates in education and training about environmental issues and their impact on operations.	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
SOM2	I considers the limitations of natural resources and the risks posed by climate change when making decisions	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
SOM3	I integrates business activities with ecosystem sustainability.	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
SOM4	I prioritise long-term environmental and social benefits, even over short-term profits.	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree

CODE	INDICATORS	(X)	DEGREE
SOM5	I adapts to public expectations regarding responsible resource management and environmental protection	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
SOM6	I implements awareness campaigns and initiatives promoting environmental responsibility	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree

CODE	INDICATORS	(X)	DEGREE
TEA1	The technology I use is easy to integrate into my business operations and improves efficiency	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
TEA2	My enterprise maximizes the efficient use of all biomass resource components	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
TEA3	My enterprise follows government policies and regulations on sustainable technology use	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree

CODE	INDICATORS	(X)	DEGREE
TEA4	My enterprise has access to local knowledge, skills, and resources that support sustainable technological adoption	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
TEA5	My enterprise considers the environmental and social impacts of technology adoption and seeks to minimize negative effects.	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree
TEA6	My enterprise used technologies in my enterprise are economically feasible and cost-effective.	(1)	Strongly disagree
		(2)	Disagree
		(3)	Neutral
		(4)	Agree
		(5)	Strongly agree

INDICATORS	(X)	DEGREE
I feel that the government provides adequate fiscal support and incentives for businesses like mine.	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree
I feel that the availability of financial services here is highly supportive of my business growth.	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree

INDICATORS	(X)	DEGREE
The geographical proximity here facilitates intense and easy interactions with my business partners.	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree
I feel a high level of acceptance and support from the local public for my business activities.	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree
The prevailing social norms and work ethics in this region are highly conducive to my business success.	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree
I feel that the quality of the local workforce strongly supports my business development.	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree
I experience smooth and synergistic collaboration across different business sectors in this region.	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree

INDICATORS	(X)	DEGREE
I have excellent access to research, knowledge, and innovation facilities provided by academic institutions.	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree

INDICATORS	(X)	DEGREE
I intent to support the use of biomass-based energy from wood/bamboo (bioenergy) as a sustainable and environmentally friendly energy solution	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree
I intent support the creation of value-added products through the recycling process of waste or wood/rattan/bamboo waste to reduce waste and improve resource efficiency.	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree
I intent support innovation in the use of more environmentally friendly natural materials by reducing/replacing synthetic, fossil, and chemical materials	(1)	Strongly disagree
	(2)	Disagree
	(3)	Neutral
	(4)	Agree
	(5)	Strongly agree

PERSONAL DATA PROTECTION CONSENT STATEMENT

Introduction

This research was conducted to understand more deeply the condition of the entrepreneurial ecosystem and behaviour in the bioeconomic transition among entrepreneurs engaged in the production of wood, bamboo, or rattan. We are committed to protecting your data following the General Data Protection Regulation (GDPR) and applicable regulations.

Objectives and Benefits of the Research

The purpose of this study is to identify challenges and opportunities in the entrepreneurial ecosystem and measure awareness and behaviour in the transition to the bioeconomy. The data collected will help develop more effective strategies to support the entrepreneurial ecosystem.

Treatment/Things Participants Will Experience

During this study, you will be asked to fill out a questionnaire consisting of several sections, including general information about your company and your views on the entrepreneurial ecosystem as well as the bioeconomy. Filling out this questionnaire is expected to take about 20-30 minutes**.**

Possible Risks

There were no physical or emotional risks expected from participation in this study. However, you may feel a little uncomfortable when providing information related to the company and personal views.

Benefit

Your participation will help provide useful insights for policy development and support for entrepreneurs in the sector. While there are no immediate benefits to you, the results of this study will provide long-term benefits to the entrepreneurial community.

Right to Refuse or Withdraw from Activities

Participation in this study is voluntary. You have the right to refuse to participate in or withdraw from the study at any time, without any consequences.

Data Confidentiality

All data collected will be kept confidential. The information you provide will be anonymised and used only for research purposes. Your data will not be shared with third parties without your consent.

Incentives Provided

Shopping vouchers for those who participate in this survey

Researcher to Contact (Research-Related)

If you have any questions related to this research, you can contact the researcher at Adhitya Rahmana via phone (was provided)

Please contact the researcher if you have any further questions or need clarification regarding this research. By signing this form, you represent that you understand the information provided and agree to participate in this research.

By signing, I give my consent to the collection and processing of my data following the above statement.

Signature:

Name of Respondent:

Place and Date:

ANNEX 2

Questionnaire Fuzzy-DEMATEL: Entrepreneurial Ecosystems dan Bioeconomic Transformations

This questionnaire aims to identify and analyse the causal relationships between components in Entrepreneurial Ecosystems (EES) using the DEMATEL (Decision Making Trial and Evaluation Laboratory) method. In the table provided, please give an assessment of the level of influence of each component (on the row) on the other components (in the column) based on your professional knowledge and experience.

0= No influence
1 = Low influence
2 = Medium influence
3 = Strong influence
4 = Very strong influence

EES1 – Government policy/fiscal support	4	3	2	1	0	1	2	3	4	EES2 – Presence of venture capital providers
										EES3 – Geographical embeddedness and proximity
										EES4 – Local public support and consumer trends
										EES5 – The role of culture in norms and behavior
										EES8 – Collaboration with research institutions
EES2 – Presence of venture capital providers										EES3 – Geographical embeddedness and proximity
										EES4 – Local public support and consumer trends
										EES5 – The role of culture in norms and behavior
										EES8 – Collaboration with research institutions

EES3 – Geographical embeddedness and proximity										EES4 – Local public support and consumer trends
										EES5 – The role of culture in norms and behavior
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EES4 – Local public support and consumer trends										EES5 – The role of culture in norms and behavior
										EES8 – Collaboration with research institutions
EES5 – The role of culture in norms and behavior										EES8 – Collaboration with research institutions