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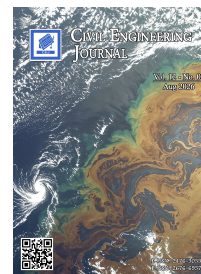
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From Commodities to Corridors: Siting and Financing Agro-Processing Along the Trans-Sumatra Toll Road

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Abstract

This research establishes a corridor-focused screening framework aimed at prioritizing agro-processing siting and funding along the northern section of the Trans-Sumatra Toll Road (JTTS) in Aceh and North Sumatra. Sectoral specialization is initially determined through the Location Quotient (LQ) based on the Gross Regional Domestic Product (GRDP) structure at the district level, subsequently refined via development-readiness indicators and assessed against corridor accessibility using distance bands to toll gates. Capital requirements are evaluated and adjusted to 2022 prices by applying the time value of money to create an indicative investment envelope. The evaluation procedure underscores nine essential regions and four vital sectors—rice milling, integrated coconut processing, food production, and palm oil refining. The findings suggest that proximity to the corridor significantly influences feasibility: sites within reasonable access bands demonstrate clearer short-term viability, while locations exceeding 15 km from toll access are conditionally feasible and highly sensitive to feeder-road stipulations. The estimated early funding framework is roughly IDR 15.87 trillion, chiefly directed towards capital-intensive palm oil areas. This study's contribution lies in implementing a transparent and auditable stepwise prioritization logic that connects specialization, readiness, access, and capital intensity into a screening-level decision-support tool, while explicitly addressing access constraints, utilization risks, and environmental compliance factors.

Keywords: Agro-Processing Prioritization; Corridor Accessibility; Sectoral Specialization; Investment Screening Framework.

1. Introduction

Sumatra remains one of Indonesia's principal commodity-producing regions, yet the translation of upstream production strength into downstream agro-processing and value-added activities remains uneven across districts [1]. The ongoing development of the Trans-Sumatra Toll Road (JTTS) has reduced inter-regional travel frictions and created new corridor linkages, but infrastructure provision alone does not automatically induce industrial upgrading [2]. Without targeted siting and investment prioritization, corridor infrastructure may experience suboptimal utilization or spatially concentrated benefits that are weakly connected to local production systems [3].

Existing studies on Indonesia's toll-road expansion and corridor development primarily evaluate engineering feasibility, traffic performance, financing mechanisms, or aggregate regional economic impacts [4]. Meanwhile, research on industrial siting and agro-processing potential often operates at macro scales without explicitly integrating

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corridor access thresholds and capital intensity considerations [5, 6]. As a result, there remains limited operational guidance on how to translate measurable sectoral specialization and district-level readiness into an investable shortlist of corridor-linked agro-processing projects.

This study addresses that gap by developing a transparent, stepwise screening framework that links sectoral specialization/Location Quotient (LQ), development readiness indicators, corridor access bands, and CAPEX benchmarking into a coherent prioritization logic. Methodologically, the framework differs from conventional weighted composite indices and generic multi-criteria siting models in three respects. First, it applies a sequential screening logic rather than a compensatory weighting scheme, so weak performance in a critical dimension cannot be fully offset by strength in another. Second, each stage relies on observable indicators and explicit thresholds, which improves transparency, auditability, and replicability for planning practice. Third, the framework incorporates indicative financial feasibility at the screening stage through CAPEX benchmarking and feeder-road stress testing, thereby linking spatial prioritization to investability rather than stopping at locational attractiveness alone [7, 8].

2. Related Work and Theoretical Framing

2.1. Integrating Location Theory with Economic Corridor Development

The relationship between transportation infrastructure and economic development has been extensively theorized in regional science and economic geography. Weber's industrial location theory [9] provides a foundational framework for understanding spatial economic patterns, positing that industries locate where transportation costs for raw materials and finished products are minimized. This theory establishes the critical role of transportation infrastructure in shaping industrial geography, with industries tending to concentrate near resource extraction points, markets, or intermediate locations where total transportation costs are optimized. Weber's model, though developed in an early industrial context, remains relevant for understanding how major infrastructure projects like the Trans Sumatra Toll Road can influence industrial location decisions in developing economies.

Complementing Weber's cost-based approach, Losch's optimal industrial location theory [10] introduces demand-side considerations, arguing that optimal industrial locations emerge where market coverage is maximized. This theory suggests that industries will develop in locations that allow them to dominate regional markets, creating spatial patterns of economic activity that align with transportation corridors. Losch's framework is particularly relevant for understanding how the JTTS can catalyse industrial development by connecting producers with broader markets across Sumatra Island.

The concept of economic corridors represents a modern theoretical integration of these classical location theories with contemporary development planning. Economic corridors are long-term projects that must address challenges beyond physical infrastructure to become fully operational [11]. Economic corridor development (ECD) functions as a spatial or area-based concept a process of widening, deepening, and integrating economic activities in a spatially targeted manner. This approach recognizes that infrastructure alone does not guarantee economic development; rather, it requires strategic alignment with regional economic potentials and industrial development planning. A successful ECD will increase connectivity through trade integration and infrastructure development leading to increased regional economic growth [12]. The LQ analysis serves as a critical methodological tool within this framework, enabling researchers to identify regionally specialized economic sectors by comparing local industry concentrations to national averages [13]. This analytical approach provides an empirical foundation for targeting industrial development strategies along transportation corridors. Figure 1 presents the conceptual framework that integrates these theoretical perspectives with the practical application to the JTTS corridor development:

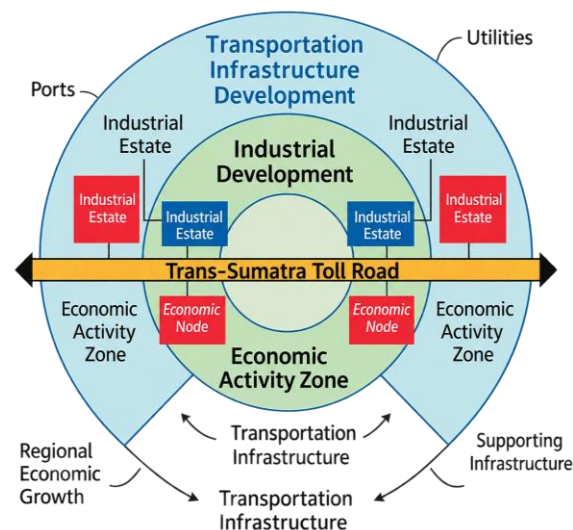


Figure 1. Conceptual Framework for Infrastructure-Industry Integration in Economic Corridor Development

2.2. Empirical Evidence on Infrastructure-Industry Integration

Empirical studies on infrastructure–industry integration show that transport corridors can improve connectivity, reduce generalized logistics costs, and create new opportunities for regional production systems. However, the literature also indicates that infrastructure provision alone does not automatically generate industrial upgrading. Many studies remain focused on engineering feasibility, aggregate regional impacts, or broad development effects, while offering limited operational guidance on how corridor investments should be translated into district-level industrial prioritization and project packaging [3, 8, 12].

A second stream of literature examines industrial siting, regional specialization, and investment potential, often using macroeconomic indicators or sectoral concentration measures to identify promising locations. While this work is useful for revealing where productive advantages may exist, it often stops short of specifying how those advantages should be filtered through practical access constraints, implementation readiness, and capital requirements. As a result, the connection between corridor opportunity and investment-ready agro-processing siting remains methodologically underdeveloped [5, 6, 14].

Taken together, the literature tends to bifurcate into two strands: corridor and infrastructure studies that emphasize connectivity and broad economic effects, and industrial or financing studies that emphasize sectoral potential or investment logic. What remains insufficiently developed is a transparent and replicable screening framework that can connect a named corridor to district-level industrial prioritization using explicit economic signals, practical accessibility criteria, and indicative investment feasibility. The present study addresses this gap by proposing a stepwise and auditable screening logic that links specialization, readiness, access, and CAPEX benchmarking into a corridor-oriented decision-support tool [7, 15, 16].

This framing positions the study not as a broad corridor-impact assessment, but as an implementation-oriented prioritization framework designed to improve transparency and auditability in early-stage industrial screening.

2.3. Analytical Logic and Theoretical Grounding of the Screening Workflow

The research adopts a corridor-centric locational framework wherein transportation infrastructure influences industrial placement primarily by altering generalized trade expenses and market accessibility, while the realization of investments is contingent upon local productive capacities and financial viability constraints. In this context, the Trans Sumatra Toll Road (JTTS) is conceptualized as a principal corridor that can facilitate agro-processing solely when prospective districts integrate (i) comparative production advantages, (ii) adequate local preparedness to initiate and expand industrial operations, and (iii) effective connectivity to corridor nodes that mitigate first-mile/last-mile inefficiencies [17, 18].

The analytical framework interlinks three complementary dimensions. In the beginning, economic-base theory is the backbone of using Location Quotient (LQ) as a clear gauge of sector-specific specialization and relative production prowess. While LQ does not establish causative relationships, it serves as a transparent evaluative measure to discern sectors that are plausibly amenable to downstream processing. Subsequently, location theory and corridor economics underscore the significance of logistical expenses and accessibility; this necessitates explicit access parameters to toll gates and acknowledges that the conditions of feeder roads may become restrictive beyond a certain practical threshold. Finally, the logic of project finance necessitates the benchmarking of capital expenditures (CAPEX) and the normalization of costs through the time value of money, as corridor-driven industrialization ultimately necessitates investable projects rather than merely spatial potential [5, 13, 19].

This study addresses the implementation gap between corridor planning and project-level industrial prioritization by operationalizing a sequential decision hierarchy that moves from specialization to readiness, from readiness to access, and from access to indicative capital feasibility. Unlike weighted composite approaches, this hierarchy preserves the analytical distinctiveness of each filter and improves auditability because each inclusion or exclusion decision can be traced back to explicit criteria. Expert interviews are used not to generate subjective scores or re-weighting coefficients, but to validate the plausibility, practicality, and implementation relevance of the shortlisted outcomes. The framework is therefore positioned as a screening-level decision-support mechanism rather than a causal impact model, with its main contribution lying in the integration of spatial accessibility and financial feasibility into a transparent corridor-oriented industrial siting logic [3, 5, 15].

3. Research Methodology

This study employs a mixed-methods research design that integrates quantitative analysis with qualitative validation to systematically identify and develop industrial estates from leading economic sectors in Northern Sumatra region. The research follows a case study approach focused on Nanggroe Aceh Darussalam and North Sumatra provinces, which represent a critical section of the JTTS corridor where strategic industrial development can significantly impact

infrastructure utilization. This methodological choice is justified by the need to address complex, context-specific questions regarding infrastructure-industry integration in developing country contexts, where both numerical data and contextual understanding are essential for developing actionable strategies.

The research design incorporates elements of explanatory sequential mixed methods, where quantitative analysis of regional economic data precedes and informs subsequent qualitative validation through expert interviews. This approach enables the systematic identification of leading economic sectors through objective metrics, followed by practical validation of development strategies with industry experts. The mixed-methods design addresses the limitations of previous studies that have tended to focus exclusively on either technical/financial aspects or broad economic potential assessments without integrating these domains [20].

The study focuses on Northern Sumatra region, encompassing Nanggroe Aceh Darussalam and North Sumatra provinces, which constitute the northern segment of the JTTS corridor. This region was selected as the research location due to its strategic importance in the overall toll road network and its significant economic potential that remains underutilized. The research utilized economic data primarily from 2020, as this represents the most recent comprehensive dataset available at the time of analysis and provides a consistent baseline for cross-regional comparison. The research was conducted between January 2021 and June 2022, allowing sufficient time for data collection, analysis, and expert validation prior to the anticipated completion timeline of the JTTS project in 2029.

This research encompasses all economic sectors operating within 34 regencies and municipalities in Nanggroe Aceh Darussalam and North Sumatra provinces as its population base. A purposive sampling method was utilized to select leading economic sectors determined through regional specialization indicators. Location Quotient (LQ) analysis was conducted on Gross Regional Domestic Product (GRDP) data to detect sectors exhibiting substantial regional concentration relative to national benchmarks. Consistent with Morrissey's [14] methodology, economic sectors demonstrating LQ coefficients above 1.0 were classified as regionally specialized, with additional stratification distinguishing moderately specialized sectors (LQ ranging from 1.0 to 1.5) from highly specialized sectors (LQ exceeding 1.5).

The sampling process involved two stages: first, identifying specialized economic sectors at the provincial level; and second, selecting specific regencies and cities for detailed analysis based on their contribution to specialized sectors. For the final analysis, five regencies or cities with the highest GRDP values in each specialized sector were selected for detailed investment cost estimation. This approach ensured that the analysis focused on areas with the greatest economic potential while maintaining manageable scope for detailed investigation.

The research employed three primary instruments for data collection: literature review, benchmarking, and in-depth interviews with industry experts. The literature review instrument focused on extracting relevant theoretical frameworks, methodological approaches, and empirical findings from academic publications, government reports, and industry documents related to infrastructure-industry integration. The benchmarking instrument compared the study region's economic indicators with successful corridor development cases globally to identify transferable strategies.

The in-depth interview protocol, validated through pilot testing with two industry experts, included 15 structured questions covering sector specialization, investment requirements, infrastructure needs, and implementation challenges. Interviews were recorded with participants' consent to ensure accurate documentation of responses and were subsequently transcribed for analysis. Table 1 presents the research variables and their operationalization:

Table 1. Research Variables and Operationalization

Variable Category	Indicator	Measurement Approach
Regional Development	Human Development Index	Analysis of education, health, and standard of living metrics at regency/city level
	Economic Growth	GRDP growth rate analysis
	Leading Sectors	LQ analysis of GRDP by economic sector
Investment Cost	Land Price	Identification of highest and lowest prices in target regions using data from National Land Agency (BPN) and property platforms
	Construction Price	Benchmarking against similar industrial development projects
	Equipment and Machinery	Capacity factor estimation method
	Infrastructure	Analysis of required supporting infrastructure

Data collection followed a systematic three-phase procedure, as illustrated in Figure 2. The first phase involved comprehensive literature review and secondary data collection from official sources including the Central Bureau of Statistics (BPS) for Aceh and North Sumatra provinces (2020-2021), National Development Planning Agency (Bappenas), and Ministry of Public Works and Housing. This phase yielded regional economic data, infrastructure plans, and policy documents essential for contextual understanding.



Figure 2. Data Collection Procedures

The second phase implemented benchmarking analysis, comparing the study region's economic indicators with successful economic corridor developments globally. This involved identifying best practices from international cases and assessing their applicability to the Northern Sumatra context. The benchmarking focused on corridor development strategies, industrial estate planning, and public-private partnership models.

The third phase consisted of in-depth interviews with eight industry experts possessing extensive experience in infrastructure development, industrial planning, and regional economic policy in Indonesia. The expert selection followed a snowball sampling technique, beginning with contacts from the research team's professional network and expanding through referrals. Interviews were conducted virtually between March and May 2022, each lasting approximately 60-90 minutes, and were recorded for accuracy with participants' consent.

The data analysis employed a sequential mixed-methods approach combining quantitative and qualitative techniques. The primary quantitative method was LQ analysis, calculated using the formula:

$$LQ = \frac{e_i/e}{E_i/E} \quad (1)$$

where, e_i and e are the sectoral and total GRDP of a district/city, and E_i and E are the sectoral and total provincial GRDP. This analysis identified specialized economic sectors in each district and city, with LQ values >1.0 indicating regional specialization. The analysis was complemented by economic growth rate calculations to assess sector dynamism.

For investment cost estimation, TVM analysis was employed to project future investment requirements, incorporating inflation rates and opportunity costs. The analysis follows a feasibility-oriented cost-normalization logic adapted for industrial estate development [19]. Capacity factor estimation was applied to equipment and machinery costs using the 0.6 exponent rule [21], which accounts for economies of scale in industrial facility development.

Qualitative data from expert interviews underwent thematic analysis. The researcher analyzed the interview transcripts to identify recurring themes, critical feedback, and consensus points regarding the proposed industrial development strategy. This expert validation step ensured that the quantitative findings were not only analytically consistent but also contextually relevant and practically interpretable, which is important in corridor-oriented industrial screening studies where implementation conditions can materially alter project prioritization [20].

This integrated methodological approach enabled the systematic identification of leading economic sectors and the development of evidence-based strategies for industrial estate development along the JTTS corridor, providing a robust foundation for maximizing infrastructure utilization and regional economic development.

4. Results and Discussion

The results show that corridor-linked agro-processing prioritization in Northern Sumatra is shaped by the interaction of four screening dimensions: regional economic structure, district-level readiness, corridor accessibility, and indicative capital requirements. Rather than treating these dimensions as separate descriptive findings, the analysis is organized as a sequential screening logic that moves from economic concentration and sectoral specialization to access-sensitive filtering, investment implications, and expert-based interpretation. This structure helps clarify which district–industry combinations emerge as robust, which remain conditional, and which face material constraints before project-level feasibility analysis is undertaken.

4.1. Economic Structure and District-Level Industrial Screening

The 2020 GRDP profile, summarized in Table 2, indicates that economic activity in the northern JTTS corridor is spatially concentrated rather than evenly distributed. In Aceh, five districts—Aceh Utara, Banda Aceh, Aceh Besar, Bireuen, and Pidie—collectively account for 45.1% of provincial output. In North Sumatra, Medan, Deli Serdang, Langkat, Simalungun, and Asahan contribute 57.6% of the provincial GRDP. This concentration pattern suggests that corridor-linked industrialization should be anchored in districts where economic density, productive specialization, and factor mobility are already relatively strong, rather than dispersed uniformly across the corridor. The resulting spatial configuration also points to a functional complementarity between the two provinces: Aceh is more strongly associated with upstream commodity production, while North Sumatra plays a larger role in downstream processing, manufacturing, and market connectivity.

Table 2. Regional Economic Concentration (2020 GRDP)

Province	Top Contributing Districts	2020 GRDP	Share of Provincial GRDP (%)	Main Economic Role
Aceh	Aceh Utara	19,694,746.80	45.1	Agriculture, Mining, Trade
	Banda Aceh	18,287,592.30		
	Aceh Besar	13,329,465.29		
	Bireuen	13,090,471.00		
	Pidie	10,759,990.70		
North Sumatra	Medan	242,198,241.66	57.6	Manufacturing, Plantation, Logistics
	Deli Serdang	110,145,244.53		
	Langkat	43,207,997.56		
	Simalungun	39,441,345.32		
	Asahan	38,691,821.26		

As shown in Table 3, sectoral specialization measured through Location Quotient (LQ) refines this broad economic geography by identifying where tradable activities exhibit comparative regional strength. The results indicate differentiated specialization patterns across the shortlisted districts. In Aceh, agriculture remains dominant, particularly in Aceh Utara, Bireuen, and Pidie, while mining appears as an important secondary base in Aceh Utara and Aceh Besar. In North Sumatra, the structure is more dualistic, combining strong agricultural specialization in Langkat, Simalungun, and Asahan with manufacturing strength in Deli Serdang and, to a lesser extent, Asahan.

Table 3. LQ Analysis of Key Economic Sectors in The Northern JTTS corridor (Aceh and North Sumatra)

Regency/City	2020 GRDP (IDR million)	LQ Agriculture	LQ Mining	LQ Manufacturing	LQ Class (Agri)	LQ Class (Mining)	LQ Class (Manuf)
Aceh Utara	19,694,746.80	1.195	3.503	1.822	B	R	R
Banda Aceh	18,287,592.30	0.042	0	0.442	N	N	N
Aceh Besar	13,329,465.29	0.809	1.132	0.519	N	B	N
Bireuen	13,090,471.00	1.136	0.481	0.326	B	N	N
Pidie	10,759,990.70	1.349	0.618	0.616	M	N	N
Medan	242,198,241.66	0.053	0.001	0.727	N	N	N
Deli Serdang	110,145,244.53	0.494	0.566	1.600	N	N	R
Langkat	43,207,997.56	1.868	7.463	0.818	R	R	N
Simalungun	39,441,345.32	2.360	0.184	0.594	R	N	N
Asahan	38,691,821.26	1.710	0.163	1.197	R	N	B

Note: N = Not specialized (LQ < 1.00); B = Borderline (1.00–1.24); M = Moderate (1.25–1.49); R = Robust (≥ 1.50).

This confirms that the corridor does not traverse a uniform economic landscape, but rather a sequence of districts with distinct productive roles that can be matched to different agro-processing typologies.

The LQ interpretation is strengthened by distinguishing robust, moderate, and borderline specialization signals. This is analytically important because values marginally above 1.0 do not necessarily indicate strong industrial dominance. In the present study, candidates with stricter LQ performance remain more credible as corridor-linked

priorities, whereas borderline cases are treated more cautiously and require stronger corroboration through readiness, access, and feasibility filters [13, 14].

Economic specialization by itself is not sufficient to justify industrial prioritization. For that reason, the LQ results were cross-checked against three readiness dimensions: sectoral GRDP composition, provincial potential sectors, and Human Development Index (HDI). Taken together, these indicators help distinguish districts that are not only specialized, but also institutionally and socioeconomically better positioned to absorb corridor-linked industrial growth [22-24].

The readiness profile reveals a clear contrast between market-service hubs and production-oriented districts. Medan and Banda Aceh exhibit relatively high development indicators but lower relevance as primary locations for new agro-processing investment. By contrast, districts such as Aceh Utara, Pidie, Langkat, Simalungun, and Asahan combine stronger commodity-linked production structures with more compelling justification for industrial expansion. Table 4 summarizes the sectoral GRDP distribution in the priority areas used to support the readiness filter.

Table 4. Sectoral GRDP Distribution in Priority Areas (% of GRDP)

Province	Regency/City	Agriculture	Mining	Manufacturing	Sum of 3 Sectors
Aceh	Aceh Utara	36.38	15.76	8.45	60.59
	Banda Aceh	1.29	0	2.05	3.34
	Aceh Besar	24.6	5.09	2.4	32.09
	Bireuen	34.57	2.16	1.51	38.24
	Pidie	41.06	2.78	2.86	46.7
North Sumatra	Medan	1.11	0	14.12	15.23
	Deli Serdang	10.46	0.70	31.05	42.21
	Langkat	39.57	9.22	15.89	64.68
	Simalungun	49.99	0.23	11.54	61.76
	Asahan	36.22	0.20	23.24	59.66

Three indicators structure readiness: sectoral GRDP distribution, province-level potential sectors, and the Human Development Index (HDI). The sectoral distribution shows high tradables shares in commodity and processing districts. In Aceh, the combined share of agriculture, mining, and manufacturing reaches 60.59% in Aceh Utara, 46.70% in Pidie, 38.24% in Bireuen, and 32.09% in Aceh Besar, while Banda Aceh is 3.34% due to its service profile. In North Sumatra, the totals are 61.76% in Simalungun, 59.66% in Asahan, 64.68% in Langkat, 42.21% in Deli Serdang, and 15.23% in Medan, confirming Medan's role as a market node rather than a production base.

Table 5 confirms that potential sectors at the provincial level align with this pattern. In Aceh, within agriculture, plantation crops lead and—along with food crops—anchor upstream supply; within manufacturing, food and beverages ranks first. In North Sumatra the dominance is stronger: agriculture totals IDR 173.08 trillion with plantation crops at IDR 86.50 trillion, and manufacturing totals IDR 156.50 trillion with food and beverages at IDR 114.88 trillion. These values justify palm-oil and food processing in North Sumatra and rice–coconut chains in Aceh.

Table 5. Provincial “Potential Sectors”

Province	Sector	GRDP (IDR million)	Leading Subsector	GRDP (IDR million)
Aceh	Agriculture, Forestry, Fisheries	51,545,380	Plantation Crops	13,150,770
	Manufacturing	7,593,030	Food & Beverages	3,161,700
North Sumatra	Agriculture, Forestry, Fisheries	173,083,470	Plantation Crops	86,501,670
	Manufacturing	156,503,610	Food & Beverages	114,881,700

HDI introduces a labor-readiness lens and a social-equity filter. Table 6 reveals that Aceh's Banda Aceh is “very high,” so not a primary target for new industrialization; Aceh Utara is “medium,” and Aceh Besar, Bireuen, and Pidie are “high,” suitable for employment expansion. In North Sumatra, Medan is “very high,” Deli Serdang–Simalungun–Langkat are “high,” and Asahan is upper “medium–high,” suggesting the largest marginal gains from industrialization in Asahan–Langkat–Simalungun. Categories follow BPS thresholds: very high (≥ 80), high ($70 < 80$), medium ($60 < 70$), low (< 60).

Table 6. Human Development Index (HDI) and Readiness Class (Average 2018–2020)

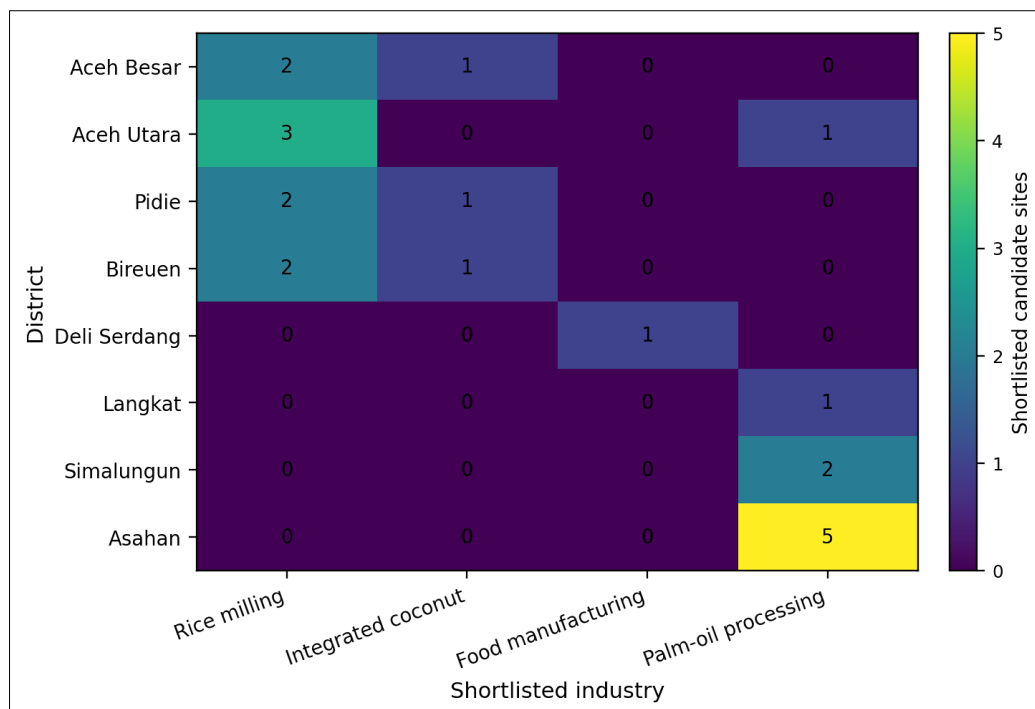
Province	Regency/City	Avg. HDI	BPS Class	Population 2020
Aceh	Aceh Utara	69.030	Medium	602,793
	Banda Aceh	84.987	Very High	252,899
	Aceh Besar	73.283	High	405,535
	Bireuen	71.940	High	436,418
	Pidie	70.380	High	435,275
North Sumatra	Medan	80.867	Very High	2,435,252
	Deli Serdang	75.263	High	1,931,441
	Langkat	70.677	High	1,030,202
	Simalungun	72.907	High	990,246
	Asahan	69.900	Medium–High	769,960

Commodity data further sharpen the industry selection process. In Aceh, rice production is concentrated in districts such as Aceh Utara and Pidie, while coconut-related potential supports integrated coconut processing in Aceh Besar and Bireuen. In North Sumatra, palm-oil production is strongly concentrated in Asahan, Simalungun, and Langkat, whereas Deli Serdang stands out as the most plausible node for food manufacturing due to its stronger industrial base and market accessibility.

The screening process therefore yields four prioritized industrial typologies: rice milling, integrated coconut processing, food manufacturing, and palm-oil processing. These typologies are not assigned generically across the corridor, but matched to districts whose economic profiles indicate both commodity fit and implementation relevance.

These results indicate that corridor-linked agro-processing development should not be treated as a generic regional industrialization strategy. Instead, the evidence supports a differentiated district–sector matching logic, in which industrial typologies are prioritized according to local resource endowments, development readiness, and practical access conditions.

Figure 3 summarizes the spatial distribution of the shortlisted industrial typologies across the principal districts identified in the screening process. The pattern is clearly differentiated rather than uniform. Aceh-based districts are more strongly associated with rice milling and integrated coconut processing, reflecting the province's upstream commodity structure and the concentration of paddy and coconut resources. By contrast, North Sumatra shows a stronger orientation toward palm-oil processing, especially in Asahan and Simalungun, while Deli Serdang emerges as a localized node for food manufacturing due to its stronger market access, industrial base, and corridor connectivity.

**Figure 3. Comparative sectoral prioritization across shortlisted districts**

This comparative view strengthens the argument that corridor-linked agro-processing development should not be treated as a generic regional industrialization strategy. In analytical terms, the figure complements the tabular results by making the territorial pattern of sectoral prioritization more visible and by clarifying how the corridor framework translates regional economic structure into a geographically distributed shortlist of investment opportunities. While sectoral specialization and readiness help identify where corridor-linked agro-processing is plausible, practical prioritization depends on whether shortlisted locations can access the JTTS under feasible first-mile conditions.

Because the GRDP structure used for LQ is based on 2020 data, pandemic-year shocks may distort sectoral shares and therefore affect borderline specialization signals. For that reason, LQ values are treated as screening proxies rather than causal indicators, and borderline cases are interpreted cautiously [13, 14]. To address the concern that LQ values marginally above 1.0 may not indicate economically dominant specialization, the study applies a threshold sensitivity framing using stricter cutoffs ($LQ \geq 1.25$ and $LQ \geq 1.5$) to distinguish robust priorities from conditional ones [13, 14].

4.2. Corridor Accessibility and Access-Sensitive Prioritization

As illustrated in Figure 4, industrial siting in the study follows two linked rules: processing facilities should be located in high-productivity sub-districts to secure raw-material capture, while also minimizing access distance to the JTTS in order to reduce first-mile and last-mile costs. On that basis, candidate sites were mapped in Google Earth Pro and measured against the nearest toll gate or corridor segment using Euclidean distance. At the screening stage, this metric serves as a transparent and spatially explicit proxy for accessibility rather than as a substitute for network distance or travel time. Its value lies in enabling direct comparison across heterogeneous districts before more detailed engineering and logistics data are introduced [5, 6].

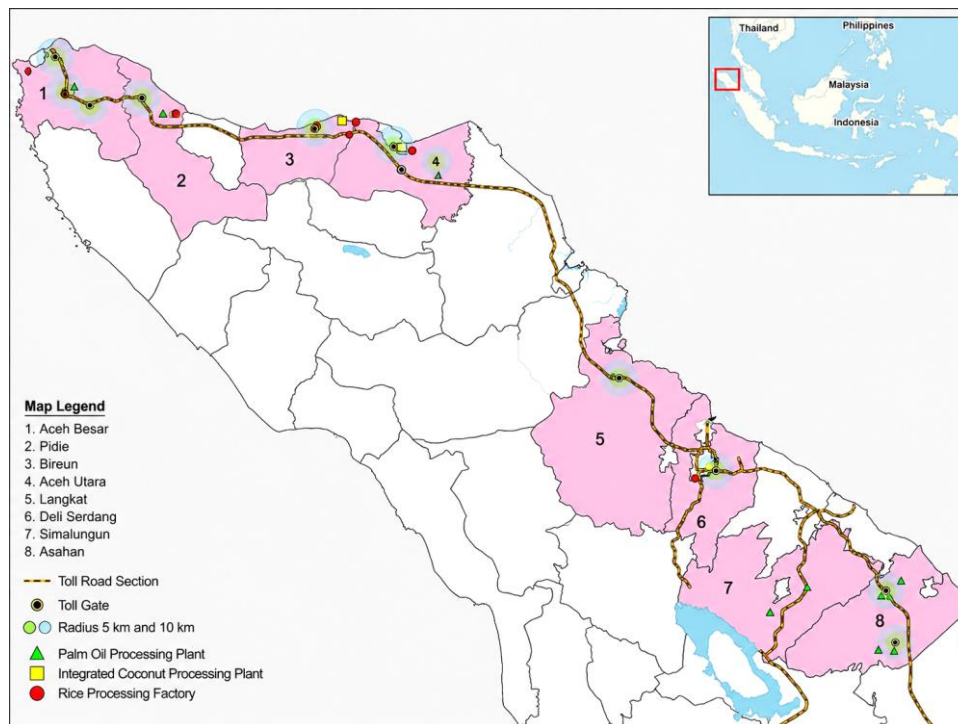


Figure 4. Proposed Locations of 22 Industrial Estates along the JTTS Corridor in Northern Sumatra

The representative access distances reported in Table 7 reveal substantial heterogeneity in practical corridor access. In Aceh Besar, Seulimeum lies within sub-kilometer reach of the Jantho gate, while Lhoknga is far more distant. In Aceh Utara, candidate sites range from relatively accessible locations such as Cot Girek to more distant rice-milling locations such as Muara Batu and Sawang. Pidie presents the clearest case of access stress, with all shortlisted sites concentrated at relatively long distances from the Padang Tiji gate. In contrast, Simalungun contains both near-corridor and farther-removed palm-oil candidates, illustrating how the same district may contain markedly different logistics conditions depending on the exact siting choice.

These patterns show that corridor presence alone is insufficient as an accessibility indicator. What matters for investment screening is not merely whether a district lies on the corridor, but whether candidate sites can connect to corridor nodes under cost conditions compatible with agro-processing operations [5, 25].

Because Euclidean distance is a lower-bound proxy that ignores road-network circuitry, terrain, and local connectivity quality, the analysis does not treat access bands as exact logistics cost measures. Instead, the bands are interpreted as

screening-stage indicators, with threshold-sensitive cases explicitly flagged for subsequent validation using network-based distance and travel-time analysis [5, 7].

Table 7. Representative JTTS Access Distances by Candidate Sites

Province	District	Site	Industry	Nearest JTTS Gate / Segment	Distance (km)
Aceh	Aceh Besar	Seulimeum	Integrated coconut	TG Jantho	0.854
		Kuta Cot Glie	Rice milling	TG Indrapuri	1.968
		Lhoknga	Rice milling	TG Kutabaro	16.748
	Aceh Utara	Cot Girek	Palm-oil mill	TG Lhoksukon	5.567
		Meurah Mulia	Rice milling	TG Lhokseumawe	10.215
		Sawang	Rice milling	TG Bireuen	17.076
		Muara Batu	Rice milling	TG Bireuen	19.874
	Pidie	Mutiara	Integrated coconut	TG Padang Tiji	18.176
		Mutiara Timur	Rice milling	TG Padang Tiji	20.082
		Glumpang Baro	Rice milling	TG Padang Tiji	22.731
	Bireuen	Kota Juang	Rice milling	TG Bireuen	1.567
		Kuala	Rice milling	TG Bireuen	2.102
	Deli Serdang	Gandapura	Integrated coconut	TG Bireuen	12.946
		Pancur Batu	food manufacturing	TG Amplas	11.169
	North Sumatra	Langkat	Brandan Barat	TG Pangkalan brandan	0.78
		Asahan	Air Batu	TG Kisaran	2.545
			Aek Kuasan	TG Asahan	4.784
			Air Joman	TG Kisaran	8.944
			Aek Songsongan	TG Asahan	9.570
			Buntu Pane	TG Kisaran	4.102
		Simalungun	Jorlang Hataran	Kuala Tanjung–Tebing Tinggi–Parapat	0.615
	Simalungun	Jawa Maraja Bah Jambi	Palm-oil mill	Kuala Tanjung–Tebing Tinggi–Parapat	13.979

4.3. Investment Envelope and Implementation Implications

After spatial and access-sensitive filtering, the shortlisted candidates were translated into an indicative investment envelope using cross-facility benchmarking and time-value-of-money normalization to 2022 prices. This approach makes it possible to compare industrial typologies and districts on a consistent cost basis. The resulting cost structure is shaped by three main components: land acquisition, building construction, and machinery or equipment [19, 21]. Table 8 summarizes the benchmark industrial typologies and the district-level candidate distribution used to structure this investment envelope.

The district-level profile shows marked heterogeneity in capital requirements. In Aceh, the combined programs in Aceh Utara, Aceh Besar, Bireuen, and Pidie generate a substantial investment envelope driven by the mix of rice and coconut facilities. In North Sumatra, the capital burden is even more concentrated, especially in Simalungun and Asahan, where multiple palm-oil mills and larger land footprints push costs upward.

Plant counts per district are anchored in annual raw-material balance, 300 operating days, and benchmark plant capacities; market concentration informs the single food factory siting in Deli Serdang, while commodity productivity and toll access determine rice, coconut, and palm-oil allocations elsewhere. For Langkat's 110.4 thousand tons/year of FFB, the capacity rule yields 0.341 of a standard unit, rounded to one mill and then sited in high-productivity sub-districts; the same rationing logic underpins the Aceh rice and coconut programs.

Benchmark plant capacities are treated as nameplate planning references for CAPEX normalization and should not be interpreted as guaranteed operating levels at each shortlisted district. In commodity-based systems, upstream supply can fluctuate seasonally and inter-annually due to harvest cycles, weather variability, farm-gate price dynamics, and procurement competition. This creates an overcapacity risk if facilities are sized assuming sustained high utilization while effective procurement catchments and first-mile logistics cannot reliably support it. At screening level, this uncertainty is addressed by treating capacity choices as conditional and emphasizing phased or modular scaling, widened sourcing catchments (where feasible), and supporting measures such as storage, scheduling, and contract-farming arrangements in subsequent feasibility work [26, 27].

Table 8. Benchmark Plant Capacities and Candidate Units by District

Province	District	Industry	Units	Benchmark capacity
Aceh	Aceh Utara	Rice milling + Palm oil	4	360 - 1,080 t/day
	Aceh Besar	Rice milling + Integrated coconut	3	360–400 t/day
	Bireuen	Rice milling + Integrated coconut	3	360–400 t/day
	Pidie	Rice milling + Integrated coconut	3	360–400 t/day
North Sumatra	Deli Serdang	Food manufacturing	1	0.55 t/hour
	Langkat	Palm oil	1	1,080 t/day
	Simalungun	Palm oil	2	1,080 t/day
	Asahan	Palm oil	5	1,080 t/day

At the aggregate level, the study estimates a total initial investment requirement of approximately IDR 15.87 trillion across eight districts and four priority industries. The investment envelope is not merely an accounting total, but an indicator of the scale of transformation required to convert Northern Sumatra's commodity base into a corridor-linked agro-industrial system.

The financial interpretation of these estimates is important because corridor industrialization is likely to be highly uneven in capital intensity. Palm-oil clusters in Simalungun and Asahan require much heavier financial commitment than rice milling or food manufacturing, meaning that project packaging, sequencing, and financing structure cannot be standardized across all shortlisted candidates.

From an implementation perspective, the investment results support a phased corridor-development strategy. Sites with short access distances and manageable feeder burdens are more suitable for near-term packaging, while access-dependent candidates should proceed only when feeder-road commitments, public co-investment, or hybrid financing arrangements become clearer [16, 28].

To assess the financial viability of access-dependent candidates once first-mile upgrading is factored in, Table 9 classifies six industrial sites in Aceh Province into three priority tiers based on feeder-road CAPEX impact under medium-cost assumptions. All six sites are located beyond the practical 15-km access threshold, with excess upgrade lengths ranging from 1.7 km to 7.7 km. The results reveal a clear risk gradient: near-term candidates face relatively modest CAPEX increases, conditional candidates show wider cost penalties and greater implementation uncertainty, and the most distant site becomes a high-risk proposition.

Table 9. Feeder-Road Cost Stress Test: Priority-Based Classification

Priority	Site	District	Distance from Toll (km)	Upgrade Length L (km)	Feeder Cost* (IDR bn)	CAPEX Impact* (%)
Near-term	Lhoknga	Aceh Besar	16.748	1.748	17.5	+10.7%
Near-term	Sawang	Aceh Utara	17.076	2.076	20.8	+12.7%
Conditional	Mutiara	Pidie	18.176	3.176	31.8	+6.4%
Conditional	Muara Batu	Aceh Utara	19.874	4.874	48.7	+29.7%
Conditional	Mutiara Timur	Pidie	20.082	5.082	50.8	+31.0%
High-risk	Glumpang Baro	Pidie	22.731	7.731	77.3	+47.1%

* Feeder cost assumes IDR 10 billion/km (medium-cost case). CAPEX impact = feeder-road cost / baseline industrial-facility CAPEX × 100. Upgrade length $L = \max(d - 15, 0)$, where d is the distance from the nearest toll gate.

Figure 5 visualizes the relationship between distance from the nearest JTTS toll gate and feeder-road CAPEX impact for the six access-dependent sites assessed in Aceh Province. The overall pattern is positive: sites located farther beyond the practical 15-km access threshold tend to face larger feeder-road CAPEX penalties. Near-term candidates such as Lhoknga and Sawang remain associated with relatively modest cost impacts, while conditional candidates display greater dispersion due to differences in baseline project size and cost structure. Glumpang Baro stands out as the clearest high-risk case, combining the greatest excess distance with the largest CAPEX burden.

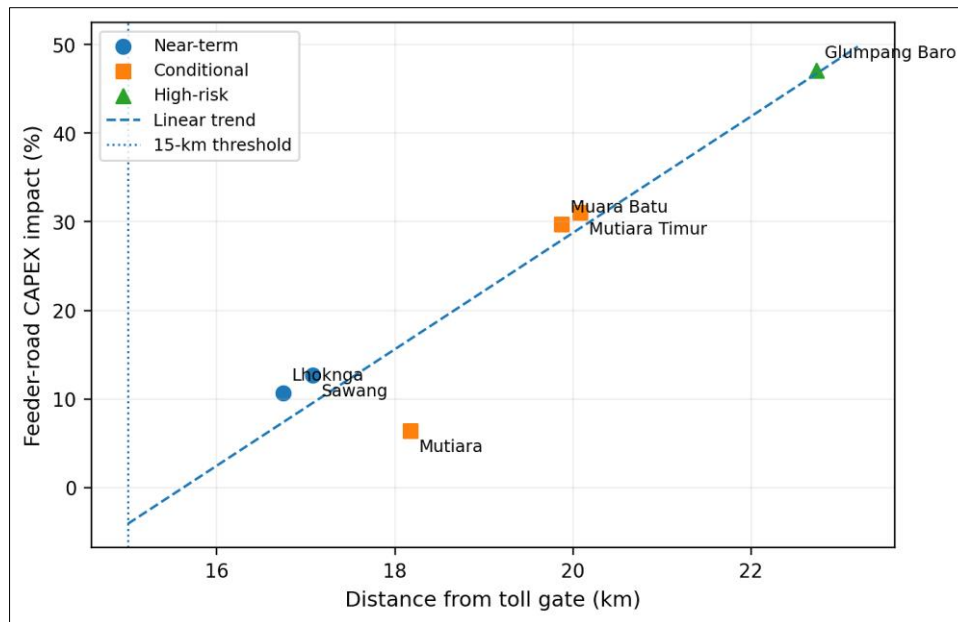


Figure 5. Relationship between toll-gate distance and feeder-road CAPEX impact

The analytical value of Figure 5 lies in making the first-mile constraint more legible. The relationship is not perfectly linear because project scale and cost structure still matter, but the visual pattern confirms that corridor distance is a financially material variable in investment screening. In practical terms, the figure supports the study's distinction between near-term, conditional, and high-risk priorities by showing that feeder upgrading requirements increasingly alter project viability as candidate sites move farther from trunk infrastructure [5].

These findings also clarify why some apparently promising district–industry pairs cannot be treated as equally investable. A strong commodity base and plausible industrial fit may still yield only conditional priority status when feeder-road burdens become sufficiently large.

4.4. Expert Validation

As summarized in Table 10, the expert inputs converge on the importance of explicit access screening, realistic cost normalization, and clearer distinction between robust and conditional candidates. The expert validation exercise generally supports the analytical direction of the framework while also clarifying its operational boundaries. Practitioners in industrial development and regional infrastructure agreed that agro-based industries remain the most viable corridor-linked growth engines in the study area, particularly when toll access and feeder connectivity are treated as explicit enabling conditions. There was also broad agreement that network-based accessibility would be preferable at implementation stage, but that simplified spatial distance remains acceptable at screening stage so long as its limitations are stated clearly and threshold-sensitive cases are identified transparently.

Table 10. Structured summary of expert validation

Validation Theme	Level of Consensus	Main Expert Observation	Analytical Implication
Priority of agro-processing sectors	High	Rice, coconut, palm oil, and food processing remain the most realistic corridor-linked industries in the study area.	Supports the shortlisted sectoral focus.
Use of accessibility metrics	High	Network-based accessibility is preferable for implementation, but simplified spatial distance remains acceptable for early-stage screening.	Supports Euclidean distance as a screening proxy with limitations.
CAPEX normalization method	High	TVM-based normalization is necessary for comparability across time and locations.	Supports the financial benchmarking framework.
Cost refinement needs	Medium	HSBGN and local land-price variation should be incorporated in later-stage estimates.	Positions current CAPEX estimates as indicative rather than final.
Feeder-road bottlenecks	High	First-mile and last-mile connectivity remains a binding constraint even where trunk corridor access exists.	Justifies conditional or deferred classification for distant sites.

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access and feeder connectivity are treated as explicit enabling conditions. There was also broad agreement that network-based accessibility would be preferable at implementation stage, but that simplified spatial distance remains acceptable at screening stage so long as its limitations are stated clearly and threshold-sensitive cases are identified transparently.

Experts likewise endorsed TVM-based CAPEX normalization as an appropriate method for cross-provincial and cross-temporal comparison, while recommending that later feasibility work should integrate local construction indices and more precise land-price adjustments. A recurring concern across the expert input was that first-mile bottlenecks remain a binding constraint even where the main corridor is available. In this respect, the validation process did not overturn the shortlisted outcomes, but sharpened their interpretation by reinforcing the distinction between robust candidates and those requiring further access, cost, or implementation due diligence.

4.5. Synthesis of Corridor Screening Logic

Taken together, the results reveal that industrial development outcomes along the northern JTTS corridor are shaped by the interaction of three closely connected mechanisms: sectoral composition, logistics accessibility, and capital requirements. Sectoral specialization and readiness determine whether a district is a plausible candidate for corridor-linked agro-processing. Accessibility determines whether that plausibility can be translated into operationally credible siting. Capital requirements determine whether the resulting sites remain investable once land, buildings, machinery, and first-mile upgrading are considered together [8, 29-31].

This is also where the present study distinguishes itself from more generic corridor-impact analysis and from opaque weighted siting models. Rather than producing a black-box composite rank, the framework makes each prioritization step visible: it shows which candidates are supported by specialization, which survive readiness screening, which remain viable under access constraints, and which face material financial penalties. That transparency improves auditability and makes the shortlist more useful for planning practice [7, 8].

At the same time, the screening logic should not be interpreted as a causal model or a substitute for full feasibility analysis. Several limitations remain explicit. LQ results based on pandemic-year sectoral data may affect borderline cases; Euclidean distance is a lower-bound proxy rather than a final logistics measure; benchmark plant sizes are planning references rather than guaranteed operating capacities; and environmental compliance, permitting, and water-waste infrastructure still require more detailed project-level appraisal [13, 32, 33].

In policy terms, the results support a toll-oriented but selectively phased development approach. Sub-kilometer and lower-risk sites can be advanced earlier, 1–15 km sites may remain viable with adequate supporting infrastructure, and more distant access-dependent sites should proceed only when feeder investments and financing mechanisms are sufficiently credible. In this sense, the framework does not replace feasibility analysis; it improves it by clarifying where scarce planning and investment effort should be directed first [8, 16, 31, 34].

5. Conclusion

This study develops a corridor-oriented screening framework for translating commodity-based regional potential into a prioritized and investment-relevant shortlist of agro-processing opportunities along the northern segment of the Trans-Sumatra Toll Road. By combining sectoral specialization, development readiness, corridor accessibility, and indicative CAPEX benchmarking within a transparent stepwise structure, the framework identifies nine priority districts and four principal industrial typologies: rice milling, integrated coconut processing, food manufacturing, and palm-oil processing. The results show that specialization alone is insufficient for prioritization. Instead, feasible corridor-linked industrialization depends on the interaction between local economic strength, practical toll access, and the capital implications of first-mile constraints. In particular, sites located within favorable access bands display stronger near-term viability, whereas candidates beyond the practical 15-km threshold become conditional on feeder-road upgrading and more careful project packaging.

The framework is intentionally positioned as a screening-level decision-support tool rather than a causal or fully predictive model, and its robustness depends on several clearly acknowledged assumptions. Pandemic-year sectoral data may affect borderline LQ signals; Euclidean distance provides a lower-bound accessibility proxy rather than a final logistics metric; and benchmark plant capacities represent planning references rather than guaranteed operating conditions. Nevertheless, the combination of threshold sensitivity checks, feeder-road stress testing, and expert validation improves the credibility and auditability of the prioritization results. The aggregate investment envelope, estimated at approximately IDR 15.87 trillion, underscores the scale of transformation required to build a corridor-linked agro-industrial system in Northern Sumatra. Accordingly, the main value of the framework lies in helping planners distinguish robust, conditional, and high-risk candidates before proceeding to more resource-intensive engineering, financial, and environmental feasibility studies.

6. Declarations

6.1. Author Contributions

Conceptualization, G.S. and M.A.B.; methodology, G.S. and H.W.; software, H.W. and M.S.; validation, G.S., M.A.B., and P.M.; formal analysis, G.S. and S.R.U.; investigation, H.W.; resources, M.S.; data curation, H.W.; writing—original draft preparation, G.S. and M.S.; writing—review and editing, M.A.B. and M.S.; visualization, M.S.; supervision, M.A.B., S.R.U., and P.M.; project administration, G.S. and M.S. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

7. References

- [1] Putra Pratama, M. R., Pasmawati, Y., Desi Kusmindari, C., & Gunarto, M. (2024). Clustering of Leading Food Products in the south Sumatra Region. *International Journal of Scientific Research and Management (IJSRM)*, 12(02), 1028–1039. doi:10.18535/ijssrm/v12i02.ec02.
- [2] Kusumaatmaja, G., & Ekananda, M. (2023). The Impact of Trans Sumatra Toll Road on the Retail Industry. *EKO-REGIONAL: Jurnal Pembangunan Ekonomi Wilayah*, 18(2), 223–237. doi:10.32424/1.erjpe.2023.18.2.3449.
- [3] Lakhminarayanan, S., Nair, S. R., & Chandrasekar, P. (2024). Economic Growth and Spatial Analysis in Transport Corridors: A Preliminary Review. *Journal of Applied Engineering Sciences*, 14(1), 117–124. doi:10.2478/jaes-2024-0014.
- [4] Ikhsan, M. A., & Gunawan, F. E. (2025). Evaluating and Strengthening Green Policy Implementation on Indonesian Toll Roads. *International Journal of Environmental Sciences*, 11(7), 267–277. doi:10.64252/kvc0vn47.
- [5] Weisbrod, G., & Goldberg, J. (2023). Relationship of Regional, Freight, and Intermodal Market Access to Industry Location and Productivity. *Transportation Research Record*, 2677(5), 403–419. doi:10.1177/03611981221131306.
- [6] Wang, J., Konar, M., Baylis, K., Estes, L., Hadunka, P., Xiong, S., & Caylor, K. (2023). Potential impacts of transportation infrastructure improvements to maize and cassava supply chains in Zambia. *Environmental Research: Infrastructure and Sustainability*, 3(4), 45006. doi:10.1088/2634-4505/ad04e4.
- [7] Downs, J., Hu, Y., & Tao, R. (2025). A Waypoint-Based Flow Capture Location Model for Siting Facilities on Transportation Networks. *Future Transportation*, 5(3), 93. doi:10.3390/futuretrans5030093.
- [8] Rosik, P., & Wójcik, J. (2023). Transport Infrastructure and Regional Development: A Survey of Literature on Wider Economic and Spatial Impacts. *Sustainability (Switzerland)*, 15(1), 548. doi:10.3390/su15010548.
- [9] Church, R. L. (2023). Alfred Weber (1868–1958): The Father of Industrial Location Theory and Supply-Chain Design. *Great Minds in Regional Science, Footprints of Regional Science*, Springer, Cham, Switzerland. doi:10.1007/978-3-031-13440-1_4.
- [10] Kuby, M. (1989). A Location- Allocation Model of Lösch's Central Place Theory: Testing on a Uniform Lattice Network. *Geographical Analysis*, 21(4), 316–337. doi:10.1111/j.1538-4632.1989.tb00899.x.
- [11] Wolf, S. O. (2020). The Conceptual Framework Regarding Economic Corridors. *The China-Pakistan Economic Corridor of the Belt and Road Initiative*. *Contemporary South Asian Studies*, Springer, Cham, Switzerland. doi:10.1007/978-3-030-16198-9_2.
- [12] Asian Development Bank. (2023). *Economic Corridor Development*. Asian Development Bank, Manila, Philippines. doi:10.22617/TCS230348-2.
- [13] Pominova, M., Gabe, T., & Crawley, A. (2022). The Stability of Location Quotients. *Review of Regional Studies*, 52(3), 296–320. doi:10.52324/001c.66197.
- [14] Morrissey, K. (2016). A location quotient approach to producing regional production multipliers for the Irish economy. *Papers in Regional Science*, 95(3), 491–506. doi:10.1111/pirs.12143.
- [15] Cupiadi, H., & Siswanti, T. (2025). Addressing Financial and Regulatory Challenges in Logistics Hub Development. *Sinergi International Journal of Logistics*, 3(1), 15–28. doi:10.61194/sijl.v3i1.736.

- [16] Fauzan, M., Kuswanto, H., & Utomo, C. (2023). Implementing Toll Road Infrastructure Financing in Indonesia: Critical Success Factors from the Perspective of Toll Road Companies. *International Journal of Financial Studies*, 11(4), 135. doi:10.3390/ijfs11040135.
- [17] Hariyanto, A. D., Rendra Graha, D. T., & Afrianto, F. (2024). Regional Economic Agglomeration and Trans-Sumatra Toll Road Development: A Network and Spatial Review. *Journal of Infrastructure Policy and Management*, 7(1), 75–95. doi:10.35166/jipm.v7i1.38.
- [18] Berawi, M. A., Zagloel, T. Y., Miraj, P., Berawi, A. B., Titahelu, W., & Bin Abd Karim, S. B. (2016). Developing Road Infrastructure Route Planning: Increasing Feasibility of Toll Road Project. *Makara Journal of Technology*, 20(3), 147. doi:10.7454/mst.v20i3.3070.
- [19] Berawi, M. A. (2017). Empowering Added Value in Highway Project: A Strategy to Improve the Feasibility. *Highway Engineering*, IntechOpen, London, United Kingdom. doi:10.5772/intechopen.71778.
- [20] Akbar, M. S. (2017). Indonesia 2045: regional development modeling analysis and initial cost estimation in eastern Indonesia as industrial center of manufacturing production. Universitas Indonesia, Depok, Indonesia. Available online: <https://lib.ui.ac.id/detail?id=20456654&lokasi=lokal> (accessed on July 2026). (In Indonesian).
- [21] Towler, G., & Sinnott, R. (2021). *Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design*. Butterworth-Heinemann, Oxford, United Kingdom. doi:10.1016/B978-0-12-821179-3.01001-3.
- [22] Ginanjar, R. A. F., Sutjipto, H., Suhendra, I., & Anwar, C. J. (2024). A Theil Decomposition of Regional Grouping in Indonesia's Human Development Index. *Economics Development Analysis Journal*, 13(3). doi:10.15294/edaj.v13i3.13802.
- [23] Az Zaakiyyah, H. K. (2024). Factors Influencing Industrial Agglomeration in Indonesia. *Dinasti International Journal of Economics, Finance & Accounting*, 5(5), 5153–5169. doi:10.38035/dijefa.v5i5.3394.
- [24] Solimano, A., & Zapata-Román, G. (2022). Structural Transformations and the Lack of Inclusive Growth. *The Developer's Dilemma*, 227–250. doi:10.1093/oso/9780192855299.003.0011.
- [25] Takatsuka, H., & Zeng, D. Z. (2013). Industrial configuration in an economy with low transportation costs. *The Annals of Regional Science*, 51(2), 593–620. doi:10.1007/s00168-013-0553-5.
- [26] Nguyen, M. H., Vu, H. D., Thanh, T. T. M., & Pham, S. A. (2025). Machinery Usage and Productivity in Manufacturing: Firm-Level Matter in Developing Countries. *Emerging Science Journal*, 9(4), 2026–2044. doi:10.28991/ESJ-2025-09-04-015.
- [27] Scholvin, S., Franco, L., & Atienza, M. (2024). Why multinational development corridors don't move ahead: insights from the Bioceanic Corridor in South America. *Area Development and Policy*, 9(3), 365–384. doi:10.1080/23792949.2024.2303655.
- [28] Berawi, M. A., Putri, C. R., Sari, M., Salim, A. V., Saroji, G., & Miraj, P. (2021). An Infrastructure Financing Scheme for Industrial Development. *International Journal of Technology*, 12(5), 935–945. doi:10.14716/ijtech.v12i5.5202.
- [29] Adamopoulos, T. (2025). Spatial Integration and Agricultural Productivity: Quantifying the Impact of New Roads. *American Economic Journal: Macroeconomics*, 17(1), 343–378. doi:10.1257/mac.20200149.
- [30] McMillan, M., & Rodrik, D. (2011). *Globalization, Structural Change and Productivity Growth*. National Bureau of Economic Research, Cambridge, United States. doi:10.3386/w17143.
- [31] Banerjee, A., Duflo, E., & Qian, N. (2020). On the road: Access to transportation infrastructure and economic growth in China. *Journal of Development Economics*, 145. doi:10.1016/j.jdevco.2020.102442.
- [32] Gerardo, S., & Song, W. (2025). Lithium recovery from U.S. oil and gas produced waters: resource quality and siting considerations. *Environmental Science: Water Research and Technology*, 11(3), 536–541. doi:10.1039/d4ew00422a.
- [33] Dashti, A. F., Fatehah, M. O., & Zahed, M. A. (2021). Waste management of the palm oil industry: Present status and future perspective. *Journal of Environmental Engineering and Science*, 17(2), 75–88. doi:10.1680/jenes.20.00059.
- [34] Rahmadana, M. F., & Putra, I. M. (2025). Community dynamics towards the existence of toll roads in Indonesia: a literature and spatial study. *Frontiers in Built Environment*, 11. doi:10.3389/fbuil.2025.1515186.