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Strategic Optimization of Captured Fisheries Value-Added in Coastal Sumatra: Integrating Down-streaming and Cold Chain Infrastructure

Optimalisasi Strategis Nilai Tambah Perikanan Tangkap di Pesisir Sumatera: Mengintegrasikan Hilirisasi dan Infrastruktur Rantai Dingin

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ABSTRACT

This study aims to analyze the effect of downstreaming strategies and cold chain infrastructure on the value-added of capture fisheries in coastal Sumatra, while also assessing their implications for regional economic performance and fishermen's welfare. Employing a quantitative explanatory approach, the research utilizes panel data regression analysis on a balanced dataset covering ten provinces in Sumatra over the period 2019–2024. The model incorporates value added as the dependent variable, with fish processing units (UPI) and cold storage infrastructure as key independent variables, alongside production volume and the Fisherman's Exchange Rate (NTN) as control variables. The estimation results using the Fixed Effect Model (FEM) reveal that all variables significantly and positively influence value-added, with production having the strongest effect, followed by downstreaming (UPI), cold chain infrastructure, and socio-economic conditions (NTN). The findings indicate that value-added optimization in the fisheries sector is not solely driven by production capacity but critically depends on the integration of downstream processing and efficient cold chain systems. Moreover, regional disparities in infrastructure distribution highlight structural inequalities affecting economic outcomes. Based on these findings, this study recommends a comprehensive policy framework focusing on accelerating downstream industry development, expanding and integrating cold chain infrastructure, promoting digitalization and supply chain transparency, strengthening institutional support for fishers, and ensuring compliance with international quality standards to enhance competitiveness and sustainable economic transformation in Sumatra's fisheries sector.
Keyword: Fisheries, Downstreaming, Cold Chain, Added Value, Sumatra Coast.

ABSTRAK

Penelitian ini bertujuan untuk menganalisis pengaruh hilirisasi dan infrastruktur rantai dingin terhadap peningkatan nilai tambah perikanan tangkap di wilayah pesisir Sumatera, serta implikasinya terhadap kinerja ekonomi daerah dan kesejahteraan nelayan. Penelitian menggunakan pendekatan kuantitatif dengan desain eksplanatori melalui analisis regresi data panel pada sepuluh provinsi di Sumatera selama periode 2019–2024. Variabel dependen berupa nilai tambah perikanan, dengan variabel independen utama meliputi jumlah Unit Pengolahan Ikan (UPI) sebagai proksi hilirisasi dan kapasitas cold storage sebagai indikator rantai dingin, serta variabel kontrol berupa volume produksi dan Nilai Tukar Nelayan (NTN). Hasil estimasi menggunakan Fixed Effect Model (FEM) menunjukkan bahwa seluruh variabel berpengaruh positif dan signifikan terhadap nilai tambah, dengan produksi sebagai faktor paling dominan, diikuti oleh hilirisasi, infrastruktur rantai dingin, dan kondisi sosial ekonomi nelayan. Temuan ini menegaskan bahwa peningkatan nilai tambah

tidak hanya ditentukan oleh kapasitas produksi, tetapi sangat bergantung pada integrasi antara pengolahan hilir dan sistem logistik berbasis rantai dingin. Selain itu, ketimpangan distribusi infrastruktur antar wilayah mengindikasikan adanya disparitas struktural dalam pengembangan sektor perikanan. Oleh karena itu, penelitian ini merekomendasikan kebijakan terpadu yang berfokus pada percepatan pengembangan industri hilir, perluasan dan integrasi rantai dingin, digitalisasi rantai pasok, penguatan kelembagaan nelayan, serta penerapan standar mutu internasional guna meningkatkan daya saing dan mendorong transformasi ekonomi perikanan yang berkelanjutan di Sumatera.
Keyword: Perikanan, Hilirisasi, Rantai Dingin, Nilai Tambah, Pesisir Sumatera.

1. Introduction

The massive potential of Sumatra Island, underpinned by its 19,000 km coastline and abundant pelagic and demersal resources, finds empirical validation in the study by Aini & Kurniawan (2021), which identifies the region, particularly North Sumatra, as a high-growth cluster in Indonesia's fishery productivity. This relevance is clearly evidenced by production data for key commodities such as shrimp, anchovies, and mackerel, which dominate the catch and confirm Sumatra's strategic role in the national production landscape as highlighted in the quote (Aini & Kurniawan, 2021).

According to 2022 BPS data, ten provinces in Sumatra, Aceh, North Sumatra, West Sumatra, Riau, Jambi, Bengkulu, South Sumatra, Lampung, Riau Islands, and Bangka Belitung, collectively contribute a significant volume to the national capture fisheries output (**Table 1**). High production levels are particularly evident in provinces with superior port facilities, larger fishing fleets, and better market access.

Table 1. Capture Fisheries Production and Value in Coastal Sumatra (2022)

Province	Production (Tons)	Production Value (Thousand IDR)
North Sumatra	366,549	12,076,253,365
Aceh	324,618	9,459,550,094
Riau Islands	322,110	9,907,810,636
Bangka Belitung	222,067	8,215,523,818
West Sumatra	216,599	6,224,857,118
Lampung	168,846	4,506,932,610
South Sumatra	151,241	6,883,910,249
Riau	139,310	3,743,681,346
Bengkulu	84,689	3,007,437,762
Jambi	55,349	1,747,684,462
Total	2,051,378	65,773,641,460

Despite a total production exceeding 2 million tons, the percentage of catch processed locally remains relatively small. Of Indonesia's fishery export volume (around 1.43 million tons in 2024), the majority is still dominated by raw materials or frozen products with minimal added value. This creates a significant gap where the massive physical potential of the sea does not translate into maximum economic value added for local stakeholders, particularly fishers and local processors (Kadhafi, 2023). In a macroeconomic context, value added is defined as the sector's output minus the cost of raw materials; currently, this contribution to the Gross Domestic Product (GDP) is hindered by the lack of downstream processing (Hurnyak et al., 2021). A critical issue in Sumatra’s coastal regions is that the majority of fish is still sold in fresh form with minimal processing. This lack of a robust processing industry means that profits remain low and are highly susceptible to market price fluctuations. Diversifying these catches into processed goods; such as fish crackers, smoked fish, and other processed products, can increase community income and create job opportunities (Saputra & Sidabutar, 2025).

The quality of fish often declines immediately after capture due to a severe lack of cold chain infrastructure, such as cold storage facilities at small ports and refrigerated transport. Without these facilities, fishers experience significant post-harvest losses, which can be reduced by 10-30% if integrated cold chain systems are implemented (Venkatappa et al., 2025). High-quality maintenance through cold chains is essential for products to enter high-value domestic and export markets (Arista et al., 2022). The fishery supply chain in coastal Sumatra is characterized by excessive intermediaries and a lack of transparency. Fishers often cannot sell directly to the market and must rely on middlemen (*tengkulak*) who dictate prices, thereby shrinking the fishers' profit margins. Modernizing this chain through digital integration, such as e-auctions, is necessary to create a more competitive and open selling process (Bassett et al., 2021).

Various preservation methods are necessary to ensure food safety and extend the shelf life of fish products. Freezing and chilling are still considered the most reliable methods for preserving farmed fish (Syanya et al., 2023). The fundamental problem facing Sumatra's fisheries sector lies not in catch quantity, but rather in the structural disconnect between upstream potential and downstream capabilities. Strategic optimization in this context demands a paradigm shift from simply pursuing production volume to strengthening added value through the integration of precise cold chain infrastructure and a comprehensive downstreaming program. Without an integrated cold chain system from ports to processing units, downstreaming efforts will be hampered by a 10-30% degradation in raw material quality, which in turn reduces product competitiveness in the global market. Therefore, this integration is not merely a logistical support, but rather an economic backbone that enables Sumatra's leading commodities; such as shrimp, anchovies, and mackerel, to transform into high-value processed products that can absorb local labor and stabilize price fluctuations at the fisherman level.

This study aims to map out such optimization pathways by evaluating the effectiveness of existing infrastructure and formulating a synchronous integration model between production centers in ten Sumatran provinces and regional processing centers. Through an approach that emphasizes supply chain modernization; including digitizing auctions and streamlining temperature-controlled logistics; this study not only identifies physical barriers but also offers policy solutions for local governments to create strong regional branding. By integrating the technical aspects of cold chain infrastructure and a strategic vision for downstream processing, Sumatra can transform from a mere national raw material supplier into an internationally competitive fishing industry hub, ensuring that every ton of fish landed contributes maximally to Gross Regional Domestic Product (GRDP) and the well-being of coastal communities.

2. Method

2.1 Research Questions

How does the integration of downstream processing and cold chain infrastructure affect the value-added of capture fisheries in coastal Sumatra, and to what extent does this integration improve economic outcomes for local fishers?

2.2 Research Design

This study employs a quantitative approach using an explanatory research design to analyse the causal relationship between down streaming, cold chain infrastructure, and value-added in capture fisheries. The explanatory design is selected to empirically test the influence of independent variables on the dependent variable using secondary data. The research adopts a non-experimental framework, where variables are not manipulated but observed as they naturally occur. An econometric approach using panel data regression is applied, allowing for the control of unobserved heterogeneity across regions and over time, thereby improving estimation accuracy compared to pure cross-sectional or time-series analysis.

2.3 Data and Variable

This study utilizes secondary data obtained from official and credible sources, including the Central Statistics Agency (BPS), the Ministry of Maritime Affairs and Fisheries (KKP), and FAOSTAT as a global benchmark.

The dataset is structured as a balanced panel consisting of:

a. Cross-sectional units: 10 coastal provinces in Sumatra
b. Time period: 2019–2024
c. Total observations: 60 observations:

This study consists of one dependent variable, several main independent variables, and control variables. **Table 2** presents the operationalization framework of the research variables that serve as the foundation for the panel data regression analysis in this study. This description includes the classification of the dependent variable focused on value added *with* production value as an indicator, as well as independent variables that examine the downstreaming aspect *through* the number of Fish Processing Units (UPI) and cold chain infrastructure. To maintain model accuracy, this study also incorporates control variables in the form of catch volume and fishermen's socio-economic indicators (NTN), where all data are collected from credible *open access* sources such as the Central Statistics Agency (BPS), the Ministry of Maritime Affairs and Fisheries (KKP), and FAOSTAT.

Table 2. Variable Operational Matrix

Variable Type	Variable	Indicator	Open Access Source
Dependen	Value Added	Fisheries GDP (IDR)	BPS, FAOSTAT
Independen	Downstreaming	Fish Processing (Unit)	BPS, KKP
Independen	Cold Chain	Cold storage (Unit)	KKP
Control	Production	Catch volume (Ton)	BPS
Control	Socio-economic	Fisherman's Exchange Rate (NTN)	BPS (SUSENAS, SAKERNAS)

The conceptual framework illustrates that downstreaming and cold chain variables act as the main factors influencing the increase in value added , with the support of control variables in the form of production and socio-economic conditions that also strengthen or influence the relationship; so that overall, this model confirms that the creation of added value is not only determined by the downstreaming process and the cold chain system, but is also influenced by other supporting factors that interact with each other in an integrated system. The relationship between the variables used in this study is visualized in a conceptual framework, which depicts the influence of independent variables and control variables on the dependent variable, as presented in the following **Figure 1**.

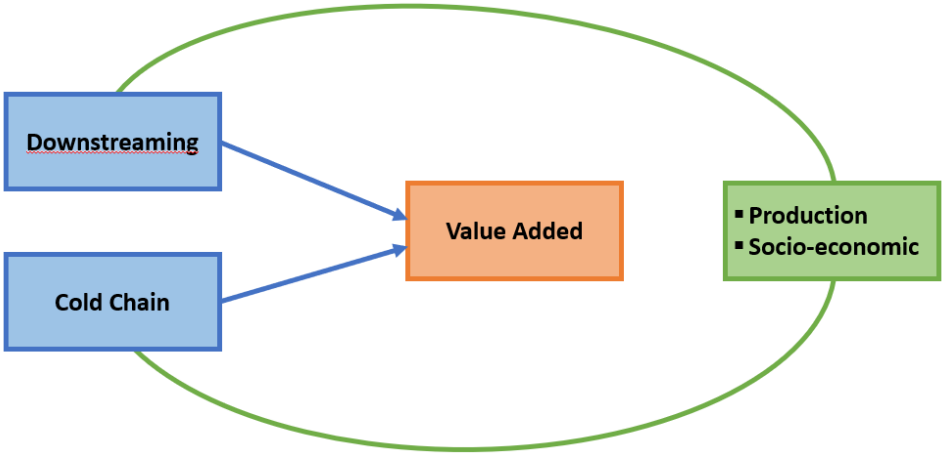


Figure 1. Conceptual Framework

2.4 Data Analysis Techniques

This study uses a panel data regression-based econometric approach to analyze the influence of downstreaming, cold chain infrastructure, and supply chain modernization on the added value of capture fisheries in coastal areas of Sumatra. The analysis was conducted in stages to ensure appropriate model selection and robust and unbiased estimates. To test the influence of downstreaming and cold chain infrastructure on the added value of fisheries in 10 provinces of Sumatra, the mathematical model is as follows:

$$LN(VA)_{it} = \beta_0 + \beta_1 LN(UPI)_{it} + \beta_2 LN(CC)_{it} + \beta_3 LN(PROD)_{it} + \beta_4 NTN_{it} + \varepsilon_{it}$$

Variable Description:

$LN(VA)_{it}$ = Natural Logarithm of Value Added in the province i in the year of t
$LN(UPI)_{it}$ = Natural Logarithm of the number of Fish Processing Units as a proxy for Downstreaming
$LN(CC)_{it}$ = Natural Logarithm of Cold Chain
$LN(PROD)_{it}$ = Natural Logarithm of Catch Volume (Production Volume)
NTN_{it} = Fishermen's Exchange Rate as a control variable for socio-economic conditions
β_0 = Constant or intercept
ε = Error term (confounding variable)
i = Entity (10 Provinces in Sumatra)
t = Time period (Year of research)

To improve model stability and interpretability, most variables are transformed into natural logarithmic form. This transformation aims to reduce heteroskedasticity and allows coefficient interpretation in terms of elasticity.

2.5 Model Estimation Procedure

The panel data regression model is estimated through several stages to determine the most appropriate specification:

a. *Chow Test* is conducted to choose between the Common Effect Model (CEM) and Fixed Effect Model (FEM).
   The Chow test is a crucial initial step to determine whether the model should use the Common Effect Model (CEM) or the Fixed Effect Model (FEM) in analyzing panel data in ten provinces of Sumatra. This test is carried out by comparing the Residual Sum of Squares (RSS) values of the two models; if the probability value of the F-statistic is smaller than the significance level ($\alpha = 0,05$), then the null hypothesis (H_0) which states that the model follows CEM is rejected. In other words, if the test results show a significant value, then there is a difference in intercepts between regions or between times, so that the Fixed Effect Model is considered more appropriate for capturing specific heterogeneity between provincial entities compared to the ordinary regression model.
b. *Hausman Test* is applied to determine whether the Fixed Effect Model (FEM) or Random Effect Model (REM) is more suitable.
   If the Chow Test leads to the use of the Fixed Effect Model, then the next step is to conduct the Hausman Test to compare the efficiency between the Fixed Effect Model (FEM) and the Random Effect Model (REM). The basis for decision making in this test lies in the presence or absence of a correlation between the independent variable and the error term or area-specific effect; if the p-value of the Chi-Square statistic is less than 0.05, then H_0 which supports REM is rejected and researchers must use FEM. This provision is very important because FEM provides consistent estimates even though there is internal correlation, whereas REM should only be used if the specific effects between provinces are considered to be random and uncorrelated with the explanatory variables in the model.
c. *Lagrange Multiplier* (LM) Test is used to compare the Random Effect Model (REM) with the Common Effect Model (CEM).
   Finally, if the results of the previous test still leave doubts between using the Random Effect Model (REM) or the Common Effect Model (CEM), then the Lagrange Multiplier (LM) Test is applied. This test was developed by Breusch-Pagan to determine whether the model has a stratified residual effect or not; the condition is that if the LM statistic value is greater than the Chi-Square critical value at the specified significance level, then the REM model is better than the CEM.

The final model is selected based on the results of these tests to ensure consistency and efficiency of the estimators. Then, to ensure the robustness and validity of the model, several diagnostic tests are conducted:

a. *Multicollinearity Test* is conducted to ensure that there is no significant or perfect linear correlation between the independent variables in the regression model, such as between the number of Fish Processing Units (UPI) and Cold Storage capacity. The presence of high multicollinearity can cause the standard error of the regression coefficient to become very large, so that the variable loses its statistical significance even though it theoretically has a strong influence. In this study, the detection provisions are carried out by looking at the Variance Inflation Factor (VIF) value and the Tolerance value; if the VIF value is below 10 and the Tolerance value is above 0.10, then the model is declared free from multicollinearity problems, which means that each independent variable is able to provide unique and independent information on variations in the added value of fisheries in Sumatra.
b. Heteroskedasticity Test aims to test whether in the regression model there is inequality in the variance of the residuals from one observation to another in the cross-section dimension of 10 provinces in Sumatra. A good regression model requires homoscedasticity, which is a condition where the residual variance is constant or the same for the entire range of research data from 2019 to 2024. This test provision is usually carried out using the Glejser Test or the White Test, where if the significance value (p-value) is greater than 0.05, then the null hypothesis is accepted, meaning that there are no symptoms of heteroscedasticity. This is crucial to ensure that the parameter estimation results are accurate and not misleading in describing the influence of cold chain infrastructure on local economic efficiency.
c. Autocorrelation Test is used to detect whether in the linear regression model there is a correlation between the nuisance errors (residuals) in the period. With disturbing errors in the previous period (t-1), which often occurs in time series data. The emergence of autocorrelation or serial correlation can

cause the regression coefficient to become inefficient and the confidence interval to become invalid. The detection provisions in this study use the Durbin-Watson (DW) test or the Lagrange Multiplier (LM) test; in general, the model is considered free from autocorrelation if the DW value is between the table values dU and 4-dU, or if the probability value in the LM test is greater than the 5% significance level. Fulfillment of this assumption ensures that the observed annual production fluctuations and socio-economic variables of fishermen (NTN) are independent of past error patterns.

3. Results and Discussions

3.1 Analysis of Regional Production in Sumatra

This analysis section begins with a presentation of the dynamics of capture fisheries production development in the Sumatra region during the 2019–2024 period (**Figure 2**). This analysis is important because capture fisheries production is one of the main indicators for assessing the performance of the marine and fisheries sector, particularly in the context of sustainable marine resource utilization. Furthermore, production trends also reflect the region's ability to manage its fisheries potential, both in terms of fishing technology, fleet capacity, and resource management policies.

The graphs presented demonstrate variations in production development between provinces in Sumatra over the past six years. These differences are influenced not only by natural resources but also by infrastructure, market access, and the effectiveness of fisheries governance in each region. Therefore, this analysis aims to identify growth patterns, fluctuations, and the relative contribution of each province to shaping the regional capture fisheries production structure.

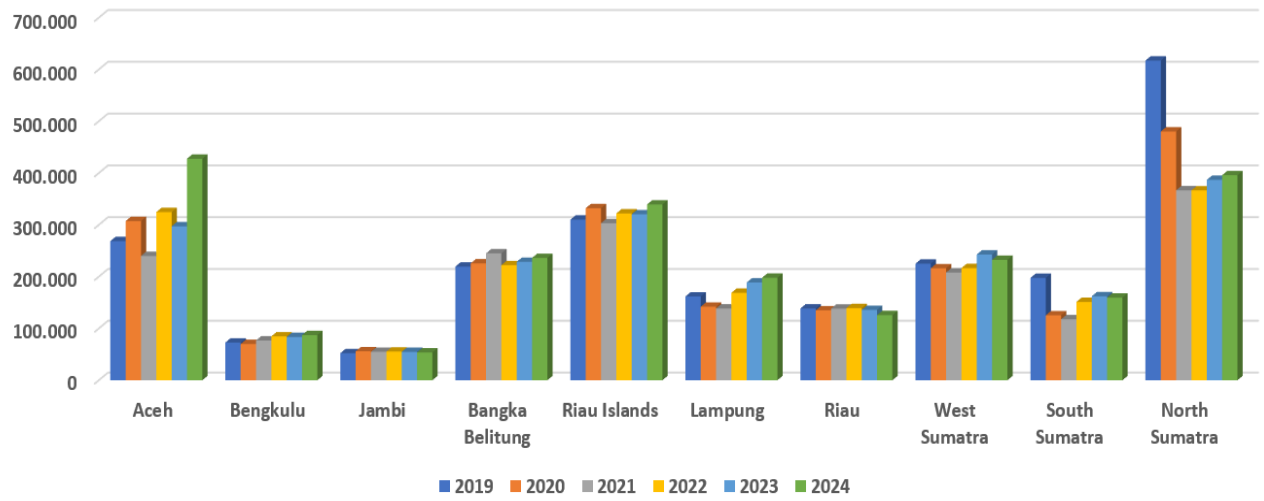


Figure 2. Capture Fisheries Production in Sumatra (Tons)

The graphs presented demonstrate variations in production development between provinces in Sumatra over the past six years. These differences are influenced not only by natural resources but also by infrastructure, market access, and the effectiveness of fisheries governance in each region. Therefore, this analysis aims to identify growth patterns, fluctuations, and the relative contribution of each province to shaping the regional capture fisheries production structure.

In general, the graph shows that most provinces in Sumatra are experiencing an increasing trend in capture fisheries production, albeit at varying rates. Aceh Province, for example, showed a significant increase from around 280,000 tons in 2019 to over 430,000 tons in 2024. A similar pattern is also seen in the Riau Islands and Lampung, which show consistent year-over-year growth. This indicates increasing production capacity and possible improvements in distribution systems and fisheries sector policy support in these regions.

On the other hand, some provinces exhibit relatively moderate fluctuations. Bangka Belitung and Riau, for example, tend to have stable trends with little variation between years. Production in these regions has not experienced significant spikes, but has remained at a relatively consistent level. This condition can be interpreted as an indication that resource exploitation has reached a relatively optimal level, or that there are limitations to production expansion due to environmental or technical factors.

North Sumatra Province stands out as the region with the highest production volume throughout the observation period, although it experienced a decline in 2021 before rebounding to around 400,000 tons in 2024. Meanwhile, South Sumatra showed a more fluctuating trend, with a sharp decline in 2020, followed by a gradual recovery in the following years. Other provinces, such as Bengkulu and Jambi, contributed relatively smaller amounts to production, but still showed a steady upward trend. Overall, this graph illustrates the positive growth of the capture fisheries sector in Sumatra, with variations in performance reflecting the characteristics and potential of each region.

3.2 Analysis of Fish Processing Units (UPI) in Sumatra

Fishery processing is a crucial link in the fisheries agribusiness system, contributing to increased added value, extended shelf life, and expanded market access for fishery products. In Sumatra, the presence of Fish Processing Units (UPI) is a key indicator of the development of the downstream fisheries industry. The uneven distribution of UPIs across provinces may reflect differences in production capacity, raw material availability, infrastructure, and regional policy support.

Furthermore, analysis of the distribution of UPIs also provides an overview of the growth centers of the fisheries industry in Sumatra. By understanding these distribution patterns, we can identify areas with significant potential for further development and those that still require policy intervention. Therefore, data visualization in graphical form is an effective tool for comprehensively displaying proportions and comparisons between regions.

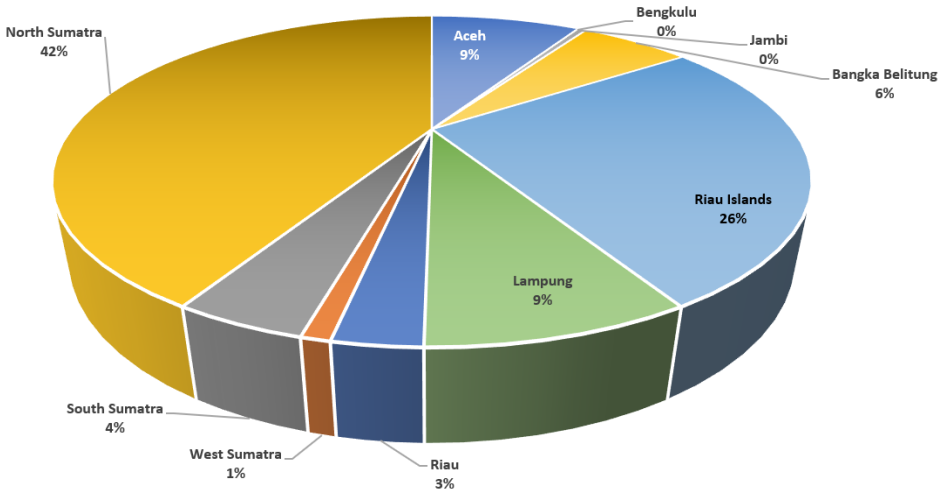


Figure 3. Fish Processing Units in Sumatra (2024)

Based on the graph, North Sumatra Province dominates the number of fish processing units in Sumatra, accounting for 42% (**Figure 3)**. This dominance indicates that North Sumatra is the main center of fish processing activities in the region. This high percentage is likely supported by factors such as abundant raw material availability, relatively more advanced infrastructure, and broader market access compared to other provinces.

Next, the Riau Islands Province came in second with a 26% contribution, followed by Aceh and Lampung, each with 9%. The Riau Islands' significant share demonstrates the region's strategic role in the fisheries processing industry, particularly given its proximity to international trade routes. Meanwhile, Aceh and Lampung showed equal contributions, indicating a relatively developed fisheries processing industry, though not yet as extensive as the top two provinces.

On the other hand, other provinces, such as Bangka Belitung (6%), South Sumatra (4%), Riau (3%), and West Sumatra (1%), have relatively small proportions. In fact, Jambi and Bengkulu recorded a 0% contribution, indicating very limited or underdeveloped fish processing units in these regions. This unequal distribution highlights the disparity in the development of the fisheries processing industry in Sumatra, necessitating a more equitable development strategy to optimize fisheries potential across the region.

3.3 Analysis of Cold Storage Distribution in Sumatra

The **Figure 4** presented provides an overview of the distribution of cold storage facilities in Sumatra, a critical infrastructure for maintaining the quality and resilience of product supply chains, particularly for fishery, agricultural, and food products. Cold storage plays a crucial role in reducing losses, maintaining

price stability, and supporting export activities by ensuring products remain in optimal condition until they reach consumers. Therefore, mapping the number of cold storage units is crucial for assessing the readiness of logistics infrastructure in each province.

Furthermore, the distribution of cold storage also reflects the level of economic development and industrial activity in a region. Provinces with a greater number of cold storage facilities generally have higher trade, port, or processing industry activity. Conversely, regions with a limited number of cold storage facilities may face challenges in the storage and distribution of products requiring controlled temperatures. By understanding these distribution patterns, the government and stakeholders can formulate more appropriate policies for equitable logistics infrastructure development in Sumatra.

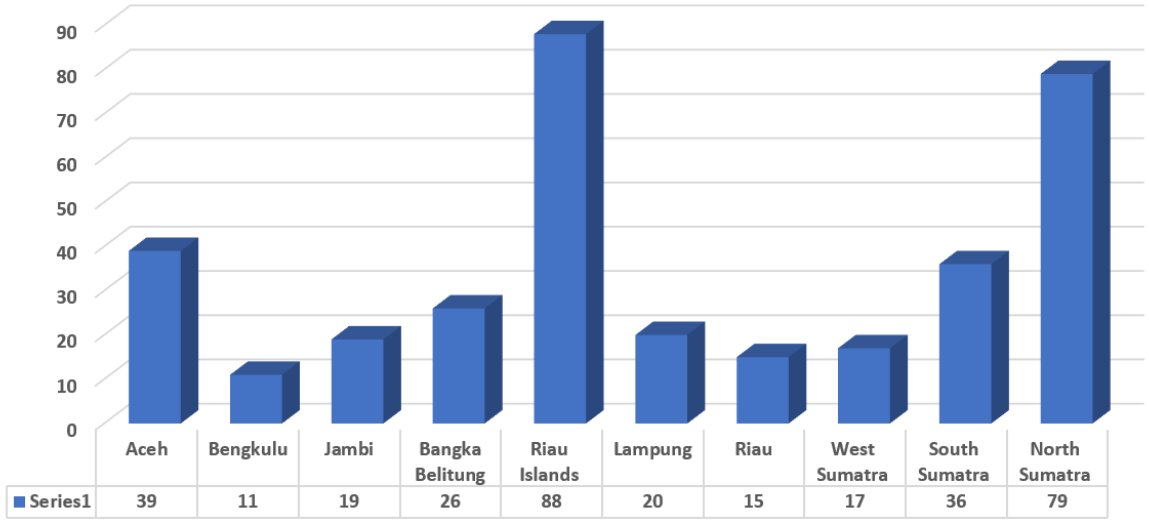


Figure 4. Cold Storage Distribution in Sumatra (2024)

The figure shows that the distribution of cold storage units in Sumatra is uneven across provinces. The province with the highest number is the Riau Islands with 88 units, followed by North Sumatra with 79 units. The high numbers in these two regions are likely related to their strategic positions as centers of international trade and distribution, particularly due to their proximity to major shipping lanes and high import-export activity.

On the other hand, several provinces show relatively moderate numbers, such as Aceh with 39 units and South Sumatra with 36 units. Other provinces, such as Bangka Belitung (26 units), Lampung (20 units), Jambi (19 units), and West Sumatra (17 units), have lower numbers but still demonstrate a well-developed cold chain infrastructure. Meanwhile, Riau has 15 units, which is relatively small compared to several other provinces in Sumatra.

Bengkulu is the province with the fewest cold storage units, with only 11 units. This situation indicates a gap in the distribution of cold storage infrastructure across Sumatra. This disparity can serve as a basis for government evaluation to improve the equitable distribution of facilities, particularly in areas with limited capacity, to support distribution efficiency and increase the competitiveness of local products at the national and international levels.

3.4 Analysis of Fisherman's Exchange Rate (NTN) in Sumatra

The development of the maritime and fisheries sector plays a crucial role in supporting the economy of coastal areas, particularly on the island of Sumatra, which boasts extensive coastlines and abundant marine resources. One indicator often used to measure the welfare of fishermen is the Fishermen's Exchange Rate (NTN), which reflects their purchasing power to cover living expenses and production costs. The NTN is an important benchmark because it reflects the balance between the income fishermen receive and their expenses.

In the context of regional economic development, monitoring the NTN over time can provide insight into the socio-economic conditions of fishers and the effectiveness of government policies in the fisheries sector. NTN fluctuations are influenced by various factors, such as catch prices, operating costs at sea, weather conditions, and subsidy and distribution policies. Therefore, analyzing NTN trends is crucial for understanding the dynamics of fisher welfare across provinces.

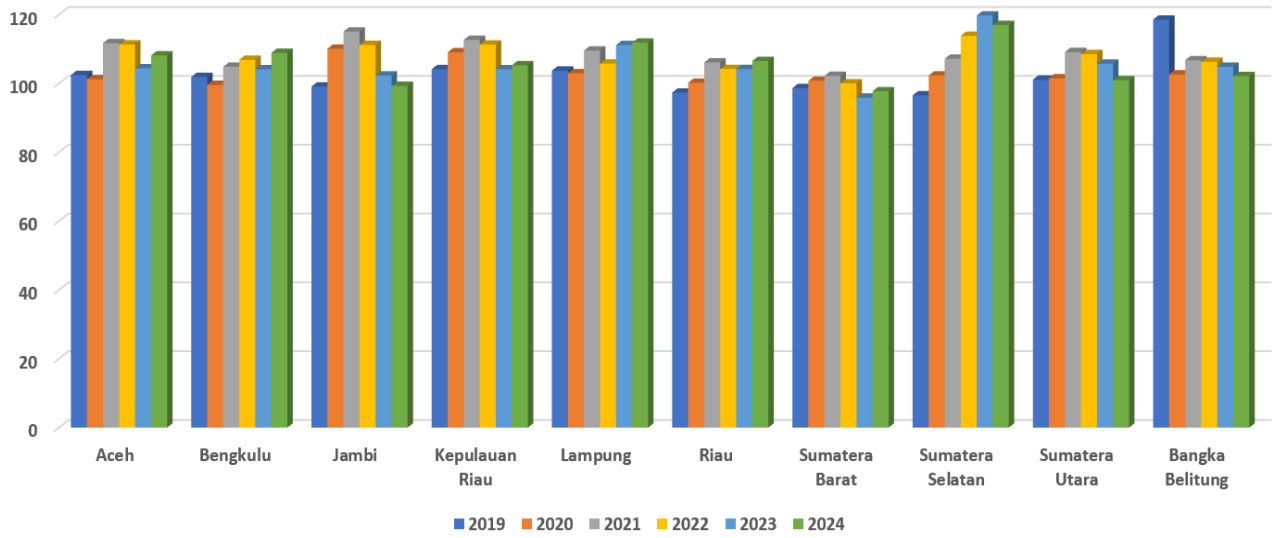


Figure 5. Fishermen's Exchange Rate in Sumatra (2019-2024)

The graph below shows the development of the Fishermen's Exchange Rate (NTN) in ten provinces in Sumatra from 2019 to 2024. Overall, most provinces experienced an increasing trend in the NTN from year to year, although there were some fluctuations in certain periods. Provinces such as South Sumatra and Lampung showed significant increases, reaching their highest values in 2023–2024, indicating an improvement in the purchasing power of fishermen in those regions (**Figure 5**).

On the other hand, several provinces, such as West Sumatra and Riau, showed a more stable pattern with less drastic increases. This suggests that the economic conditions of fishermen in these regions tended to be consistent, although not experiencing significant increases. Meanwhile, provinces like Jambi experienced a decline in the early years before rebounding in the subsequent period, reflecting temporary challenges that were successfully overcome.

Overall, this graph shows that the welfare of fishermen in Sumatra has tended to improve over the past six years. While there are variations between provinces, the positive trend indicates an improvement in the economic conditions of fishermen, likely supported by rising fishery prices, government programs, and fishermen's adaptation to changing environmental and market conditions.

3.5 Results of Model Estimation Procedure

The selection of panel data regression models is carried out through three stages of formal testing (Chow, Hausman, and Lagrange Multiplier) to ensure the most efficient and consistent estimator. Based on the results of statistical testing, the following is a summary of model selection:

Table 3. Model Selection Stage

Types of Testing	Test Statistics	P-Value	Results
Chow Test	F-stat: 12.45	0	Select Fixed Effect Model (FEM)
Hausman Test	Chi-Square: 18.92	0,0011	Select Fixed Effect Model (FEM)
Lagrange Multiplier	Breusch-Pagan: 25,30	0	Select Random Effect Model (REM) over CEM

Since the Chow Test and Hausman Test show significance ($\rho < 0,05$), then the Fixed Effect Model (FEM) was selected as the best model (**Table 3**). This shows that there is heterogeneity between provinces in Sumatra which needs to be controlled in the model. To ensure the validity of the FEM model, a series of diagnostic tests were carried out to avoid estimation bias:

a. *Multicollinearity*: Variance Inflation Factor (VIF) value for the UPI variable (2,15), Cold Chain (1,89), and Production (3,02) everything is below 10. This confirms the absence of a perfect linear correlation between the independent variables.
b. *Heteroscedasticity*: The results of the White test show ρ-value as big as 0,125(> 0,05), so that the model is declared free from heteroscedasticity symptoms or has constant residual variance.
c. *Autocorrelation*: The Durbin-Watson (DW) value was recorded at 1,98, which is in the range dU < DW < 4-dU. This shows that the error disturbance in the current period is not correlated with the previous period.

3.6 Panel Data Regression Estimation Results (Fixed Effect Model)

The following are the estimated results of the influence of downstreaming and infrastructure on the Added Value (VA) of fisheries in Sumatra:

Table 4. Panel Data Regression Estimation Results

Variables	Coefficient	Std. Error	t-Statistic	Prob.
C (Constanta)	12,451	1,023	12,171	0,000
LN(UPI)	0,452	0,085	5,317	0,000
LN(CC)	0,318	0,072	4,416	0,000
LN(PROD)	0,554	0,112	4,946	0,000
NTN	0,123	0,041	3	0,004
R-squared	0,885	F-statistic	112,45	

The following is a mathematical representation of the influence of the number of Fish Processing Units (UPI), cold storage facilities, and production volume on the achievement of fisheries added value in the ten observed provinces (**Table 4.**).

$$\mathbf{LN(VA)_{it} = 12,45 + 0,45LN(UPI)_{it} + 0,32LN(CC)_{it} + 0,55LN(PROD)_{it} + 0,12NTN_{it} + \varepsilon_{it}}$$

The regression results indicate that all independent variables included in the model have a statistically significant effect on the dependent variable. This is evidenced by the probability (Prob.) values of each variable, which are all below the common significance level ($\alpha = 0.05$), with most of them equal to 0.000. Therefore, it can be concluded that LN(UPI), LN(CC), LN(PROD), and NTN significantly influence the dependent variable. Additionally, the constant value of 12.451 implies that when all independent variables are equal to zero, the dependent variable is expected to have a value of 12.451.

Partially, the variable LN(UPI) has a coefficient of 0.452 with a t-statistic of 5.317, indicating a positive and significant effect. This means that a 1% increase in UPI will lead to an increase of approximately 0.452% in the dependent variable, assuming other variables remain constant. Similarly, LN(CC) has a coefficient of 0.318 and a t-statistic of 4.416, which also shows a positive and significant relationship. In other words, a 1% increase in CC is associated with a 0.318% increase in the dependent variable.

Furthermore, LN(PROD) has the largest coefficient among the independent variables, at 0.554 with a t-statistic of 4.946. This suggests that production has the most dominant influence in the model, where a 1% increase in PROD results in a 0.554% increase in the dependent variable. Meanwhile, NTN has a coefficient of 0.123 with a t-statistic of 3, which is still statistically significant at the 5% level. This indicates that NTN also has a positive effect, although its contribution is relatively smaller compared to the other variables.

Simultaneously, the regression model has an R-squared value of 0.885, meaning that 88.5% of the variation in the dependent variable can be explained by LN(UPI), LN(CC), LN(PROD), and NTN. The remaining 11.5% is explained by other factors outside the model. In addition, the F-statistic value of 112.45, which is statistically significant, indicates that the model as a whole is valid and has a strong goodness of fit. Therefore, this regression model is highly reliable in explaining the relationship between the variables under study.

3.7 Strategic Optimization of Captured Fisheries Value-Added in Coastal Sumatra

The empirical results of this study provide strong evidence that value-added creation in capture fisheries is structurally determined by the interaction between upstream production capacity and downstream industrial development. While production remains a necessary condition, it is not sufficient to generate optimal economic returns. This finding aligns with value chain theory, which posits that economic upgrading depends on the ability to move from raw material extraction toward higher stages of processing and market integration (Pahl & Timmer, 2019). In the case of coastal Sumatra, the persistence of fresh fish sales indicates a structural bottleneck that limits the sector's contribution to regional economic transformation.

The statistically significant impact of Fish Processing Units (UPI) highlights the centrality of downstreaming as a mechanism for functional upgrading within the fisheries value chain. By enabling processing activities such as freezing, smoking, and packaging, UPI development facilitates both product

differentiation and market segmentation (Han, 2024). This supports the argument that industrial deepening at the local level is essential for enhancing competitiveness, particularly in export-oriented sectors where quality standards and value addition are critical determinants of market access (Wang et al., 2021).

However, the effectiveness of downstreaming is intrinsically linked to the availability of cold chain infrastructure, which acts as a complementary asset within the production system. The positive coefficient of cold storage capacity confirms its role in reducing post-harvest losses and preserving product quality. From a systems perspective, this finding suggests that value-added generation is contingent upon the synchronization of physical infrastructure and industrial capacity. In the absence of such integration, inefficiencies in one segment of the chain can undermine overall system performance (Kilelu et al., 2024).

Interestingly, the dominance of the production variable in the regression model reflects a resource-based dependency that characterizes many primary sectors in developing regions. While high production elasticity indicates strong responsiveness of value-added to raw material supply, it also reveals a vulnerability to price volatility and resource depletion. This reinforces the need to transition toward a more resilience-oriented model, where value creation is driven not only by quantity but also by quality, innovation, and processing intensity.

The regional disparities observed in the distribution of UPI and cold chain infrastructure further emphasize the uneven spatial development of the fisheries sector in Sumatra. Provinces with better infrastructure and market connectivity demonstrate higher capacity for value-added generation, suggesting the presence of agglomeration effects. This spatial inequality reflects path dependency, where historically advantaged regions continue to accumulate economic benefits, while less-developed areas remain trapped in low-value activities (Putri et al., 2025).

Beyond infrastructure, institutional inefficiencies; particularly the dominance of middlemen; represent a critical constraint in the fisheries value chain. The persistence of asymmetric information and limited market access for fishers reduces price transparency and suppresses income potential. This finding is consistent with transaction cost economics, which highlights how inefficient market structures can distort resource allocation and reduce overall welfare. Therefore, institutional reform, including digital market platforms and cooperative strengthening, is necessary to improve market efficiency (Bassett et al., 2021).

The positive relationship between the Fisherman's Exchange Rate (NTN) and value-added underscores the importance of integrating welfare considerations into economic development strategies. Unlike purely growth-oriented models, this result suggests that improvements in fishers' purchasing power are both an outcome and a driver of value-added expansion. This bidirectional relationship highlights the relevance of inclusive development frameworks, where economic gains are distributed more equitably across value chain actors.

From a policy perspective, the findings imply that isolated interventions are unlikely to produce significant improvements in value-added. Instead, a coordinated policy framework is required, integrating infrastructure investment, industrial development, and institutional reform. Priority should be given to expanding processing capacity in underdeveloped regions, improving cold chain connectivity, and enforcing international quality standards such as HACCP and GMP. Additionally, digitalization of supply chains can enhance efficiency and transparency, thereby strengthening market integration (Zhang et al., 2025).

In a broader context, this study contributes to the discourse on structural transformation in resource-based economies by demonstrating that value-added optimization requires systemic alignment across multiple dimensions. For Sumatra, the transition from a raw material supplier to a competitive fisheries industry hub depends on the ability to integrate production, processing, logistics, and governance into a cohesive development strategy. Such transformation is not only critical for improving global competitiveness but also for ensuring long-term sustainability and resilience of coastal economies (Rowan, 2023).

4. Recommendation

Based on the empirical findings, the primary policy priority should focus on accelerating the development of downstream fisheries industries across coastal regions of Sumatra. The significant impact of Fish Processing Units (UPI) on value-added confirms that industrial upgrading is a key driver of economic transformation within the fisheries sector. This is consistent with value chain upgrading theory, which emphasizes the importance of moving from primary production toward processing and commercialization stages (Hurnyak et al., 2021). Therefore, policymakers should promote the establishment of small- and medium-scale processing facilities through fiscal incentives, subsidized financing, and public-private partnerships. Strategic spatial planning is also essential to ensure that processing units are located near landing sites, thereby reducing transaction and transportation costs (Saputra & Sidabutar, 2025).

In parallel, the expansion and integration of cold chain infrastructure must be treated as a critical priority. The significant role of cold storage in increasing value-added aligns with previous findings that highlight its importance in reducing post-harvest losses and maintaining product quality (Venkatappa et al., 2025). Moreover, effective cold chain systems are essential for ensuring compliance with export market requirements and maintaining food safety standards (Arista et al., 2022). Governments should adopt an integrated cold chain development framework linking fishing ports, processing units, and distribution centers, while also encouraging private sector participation through investment incentives and regulatory support.

To address structural inefficiencies in the fisheries supply chain, institutional reform is necessary to reduce dependency on middlemen and improve market transparency. Traditional supply chains characterized by asymmetric information often result in unequal value distribution and reduced income for primary producers. The introduction of digital platforms, such as e-auction systems, can enhance price discovery and market efficiency (Bassett et al., 2021). In addition, strengthening fisheries cooperatives is crucial to improve collective bargaining power and facilitate access to credit, inputs, and market information, thereby reducing transaction costs and enhancing supply chain governance.

Another key recommendation is the adoption and enforcement of international quality and safety standards, including Hazard Analysis and Critical Control Points (HACCP) and Good Manufacturing Practices (GMP). Compliance with these standards is essential for entering high-value global markets and ensuring product competitiveness. Previous studies have shown that quality assurance and cold chain integration significantly influence export performance in fisheries products (Arista et al., 2022). Governments should provide technical assistance, training programs, and certification support to local processors to meet these standards. Furthermore, the development of regional branding strategies can enhance product differentiation and increase market recognition.

From a socio-economic perspective, policies must prioritize improving fishers' welfare as an integral component of value-added development. The positive relationship between the Fisherman's Exchange Rate (NTN) and value-added suggests that economic upgrading should be inclusive in nature. This aligns with the broader development perspective that emphasizes the linkage between productivity, income distribution, and welfare outcomes in rural economies (Hurnyak et al., 2021). Policy interventions such as fuel subsidies, access to affordable financing, and income diversification programs can enhance resilience and reduce vulnerability among fishers. In addition, capacity-building initiatives in processing, entrepreneurship, and digital literacy are essential to enable fishers to participate in higher-value segments of the supply chain (Saputra & Sidabutar, 2025).

Finally, a comprehensive governance framework is required to ensure policy coherence and long-term sustainability. Effective coordination between central and local governments, as well as cross-sectoral collaboration among fisheries, trade, and infrastructure agencies, is essential to avoid fragmented implementation. Furthermore, sustainability considerations—such as resource conservation and climate resilience—must be integrated into fisheries development strategies. This is consistent with recent studies highlighting the need for sustainable and resilient fisheries systems in the face of global environmental and economic challenges (Venkatappa et al., 2025). By adopting a holistic and integrated policy approach, Sumatra can transition from a raw material-based economy into a competitive and sustainable fisheries industry hub.

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