International Journal of Sustainable Development and Planning
Vol. 21, No. 9, September, 2026, pp. 4003-4014
Journal homepage: http://iieta.org/journals/ijsdp

Diagnosing Indonesia's Red-Chilli Production–Export Disparity: Recorded Trade Intensity, Product Composition, Regional Concentration and Eco-Spatial Policy Implications

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https://doi.org/10.18280/ijsdp.210905

Received: 9 July 2026
Revised: 14 August 2026
Accepted: 21 August 2026
Available online: 30 September 2026

Keywords:
agrifood value chain, dried-export share, eco-spatial screening, export intensity, Indonesia, postharvest infrastructure, red chilli, spatial concentration

ABSTRACT

Indonesia produces more than 1.4 million t of large chilli each year, yet only a marginal share is recorded in fresh or dried export channels. This study diagnoses that production–trade disparity and derives its implications for value-chain and territorial planning. Annual secondary data for 2020-2024 were compiled from BPS horticultural statistics and WITS/UN Comtrade for HS 070960, 090421 and 090422. The Sustainable Production-Trade-Space (SPTS) diagnostic applies three indicators-the production-to-export conversion ratio (PECR), the dried-export share (DES) and the six-province concentration ratio (CR6)-together with criteria-based cross-country benchmarking, a proof-of-concept land-cover screening overlay for Jambi, and conditional 2029 scenarios tested against three production-growth assumptions. In 2024, production reached 1,469,325 t while recorded fresh and dried exports totalled 709.744 t, equivalent to a PECR of 0.0483%. DES fell from 88.59% in 2021 to 38.07% in 2024, and six provinces supplied 74.07% of national output. A 0.25% PECR in 2029 implies 3,673-4,916 t of exports, a 5.2- to 6.9-fold increase on the 2024 base. The findings indicate that export readiness depends on aggregation, postharvest control, traceability, processing and buyer coordination, and that claims about spatial expansion require district-level land-use evidence.

1. INTRODUCTION

Red chilli (Capsicum annuum L.) occupies an unusual position in Indonesia's food economy. It is simultaneously an everyday culinary staple, a principal source of smallholder cash income, and one of the most persistent contributors to headline food-price volatility. Its policy significance therefore extends well beyond farm output, reaching into household consumption, inflation management, rural livelihoods, agro-processing, logistics and regional land-use governance. Statistics Indonesia (BPS) recorded 1.469 million t of large-chilli production in 2024, following a peak of 1.554 million t in 2023 [1]. Earlier multidimensional assessment in North Sumatra nevertheless classified the commodity's sustainability as only moderately secure, with uneven economic, social and environmental performance across the dimensions examined [2]. Production scale alone is therefore an incomplete measure of whether the chilli system is resilient, or whether it is capable of generating durable regional value.

1.1 The empirical disparity

The limitation becomes visible as soon as domestic output is placed alongside internationally recorded trade. In 2024, Indonesia exported 439.577 t under HS 070960 and 270.167 t under HS 090421 and HS 090422 combined, a total equivalent to 0.0483% of national production. This is not a physical commodity balance, and the present study does not present it as one. BPS 'large chilli' is a national production proxy; HS 070960 covers all fresh or chilled Capsicum and Pimenta fruits; and HS 090421 and HS 090422 cover dried whole and dried crushed or ground fruits respectively, excluding sauces, pastes and mixed preparations [3, 4]. Fresh and dried masses are also not moisture-equivalent. The resulting ratio is consequently interpreted throughout as a reproducible indicator of recorded trade intensity, not as the proportion of a botanically identical crop physically converted into export consignments.

A low recorded export ratio is not, by itself, undesirable. Indonesia has a large and growing domestic market, and in the absence of consistent series on domestic consumption, industrial utilisation, postharvest losses and stock changes, the production-export difference cannot legitimately be labelled a market failure. The narrower and more defensible analytical concern is twofold. First, recorded export intensity remained very small throughout the observation window while production expanded. Second, the composition of the recorded export basket shifted decisively away from dried products, which are less perishable, more storable and more readily traded over distance.

1.2 Value-chain coordination as the explanatory frame

Contemporary agrifood research treats access to international markets as a coordination problem rather than a volume problem. Participation depends on the capacity to satisfy codified standards, to aggregate consistent lots, to document residue and phytosanitary compliance, and to guarantee delivery schedules-capabilities that are difficult to assemble where production is fragmented among smallholders and postharvest functions are weakly governed [5]. Cold-chain deficiency compounds the problem by accelerating quality deterioration, raising loss rates and narrowing the economically feasible radius between farms, packhouses, processors and ports [6].

Indonesian evidence on red chilli specifically identifies planting coordination, postharvest handling, storage and drying technology, distribution flexibility and market information as the operative resilience mechanisms in smallholder chains [7, 8]. Chain-efficiency analysis in production centres shows that performance differs sharply across marketing channels, with transaction costs and margin distribution varying by the number and function of intermediaries [9]. Sectoral reviews further note that Indonesian fresh-chilli agribusiness remains constrained by seasonality, price instability and limited processing absorption rather than by a shortage of planting area [10]. At the macro level, participation in agricultural and food global value chains is associated with heterogeneous economic effects that depend on value-chain positioning and domestic capabilities; participation alone does not guarantee broad-based gains [11].

These mechanisms are treated in this study as literature-informed explanations and policy hypotheses. The secondary dataset assembled here documents an association; it does not estimate causal effects, and no causal language is used in the interpretation of the indicators.

1.3 Price instability and the inflation-management frame

Chilli is habitually governed in Indonesia as an inflation-sensitive commodity. Volatility analyses using ARCH-GARCH specifications confirm that red-chilli prices fluctuate at the beginning, middle and end of the calendar year, driven by climatic variation, festival-period demand shifts and episodic oversupply [12]. Institutional experiments such as the Sleman horticultural auction market demonstrate measurable moderation of local price dispersion, indicating that market architecture, not production volume alone, conditions price behaviour [13]. Comparative work on horticultural commodities in East Java attributes chilli's wider price band to perishability and the absence of on-farm storage, which forces distress selling at harvest [14]. Cross-commodity assessment of strategic foods likewise places chilli among the most volatile items in the national basket [15].

This governance orientation is legitimate, but it is also asymmetric. Policy attention intensifies when retail prices rise and relaxes when they fall, so the instruments deployed are predominantly short-run distribution measures. An export-development architecture-which requires multi-year investment in aggregation, verification and processing-is systematically crowded out by that cycle. Diagnosing the recorded export disparity is therefore not an argument for diverting supply away from domestic consumers; it is an argument for building a disciplined higher-value channel capable of absorbing quality-differentiated output and seasonal surpluses.

1.4 Spatial concentration and territorial risk

Production geography adds a further planning consideration. In 2024, West Java, North Sumatra, Central Java, West Sumatra, East Java and Jambi together supplied 74.07% of national output. Concentration of this magnitude can support specialised clusters and justify shared infrastructure, but it also exposes national availability to correlated climatic, phytosanitary, infrastructural and land-use shocks. Interregional input-output evidence for Indonesia shows that spatial agglomeration simultaneously raises productivity and widens regional disparity, so concentration is a planning variable rather than a neutral descriptive fact [16].

One province warrants particular attention. Jambi's recorded large-chilli production rose from 47,133 t in 2020 to 171,457 t in 2024. Provincial aggregates cannot distinguish yield-led intensification from harvested-area expansion or land-use substitution, and Jambi is a province where extractive and plantation dynamics already exert documented pressure on environmental quality and growth structure [17]. Indonesian land-use research further demonstrates that plantation and forest-cover trajectories are spatially heterogeneous and must be assessed with explicit land-use data rather than inferred from commodity statistics [18]. This study therefore adds a proof-of-concept land-cover screening overlay for Jambi instead of asserting a causal land-conversion pathway.

1.5 Contribution and research questions

The contribution of this study is the integration of recorded export intensity, product composition and production geography within a single Sustainable Production-Trade-Space (SPTS) diagnostic, supported by an explicit reproducibility protocol. The framework combines the production-to-export conversion ratio (PECR), the dried-export share (DES) and the six-province concentration ratio (CR6) with a criteria-based country benchmark, a public-data spatial screen and sensitivity-tested planning envelopes to 2029. This design responds to a recurring weakness in commodity-planning studies, which either report trade ratios without territorial content or propose spatial strategies without trade diagnostics. Comparable regional-planning research in Indonesia has shown the value of coupling production capacity with spatial carrying capacity [19], and sustainability-adjusted trade modelling has shown the value of subordinating export volume to sustainability objectives rather than maximising it as an isolated target [20].

Four questions are addressed. First, how large was the recorded production-export disparity in 2020-2024, and how did it evolve? Second, how did the fresh-dried composition of recorded exports change, and what interpretations are and are not supported by the data? Third, how does Indonesia compare descriptively with selected exporters once differences in scale and domestic demand are acknowledged? Fourth, which value-chain interventions and spatial-screening procedures would permit sustainable upgrading without transferring environmental costs to vulnerable landscapes?

2. METHODOLOGY

2.1 Research design and analytical framework

The study adopts a quantitative-descriptive, diagnostic design based on annual secondary data for the five-year window 2020-2024. The design is deliberately descriptive: a five-year national series is too short to support reliable causal time-series estimation, and the commodity concordance between production and trade nomenclature is imperfect. Accordingly, the study reports transparent indicators, labels literature-derived mechanisms explicitly as hypotheses, and expresses forward-looking statements as conditional planning envelopes rather than forecasts.

Figure 1 presents the SPTS diagnostic framework. The framework locates a conversion gate between the production base and recorded trade. Additional output does not automatically generate exports; grading, aggregation, pre-cooling, food-safety assurance and traceability determine whether harvests become tradable fresh consignments or storable dried products. Eco-spatial safeguards operate across the entire system, ensuring that any upgrading strategy prioritises productivity and value capture on verified existing farmland rather than area expansion into protected or high-risk ecosystems.

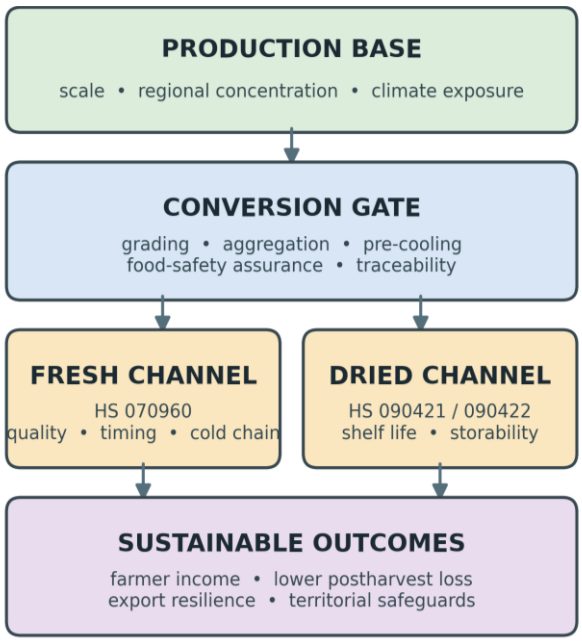


Figure 1. The Sustainable Production–Trade–Space (SPTS) diagnostic framework

2.2 Data sources and extraction protocol

National and provincial large-chilli production was transcribed from BPS horticultural statistics for the corresponding reference years [1]. Trade observations were extracted from the World Integrated Trade Solution interface to UN Comtrade [3] under a fixed extraction protocol: reporter country as specified; partner 'World'; trade flow 'Export'; annual frequency; and product codes HS 070960, HS 090421 and HS 090422. The extraction was performed on 7 July 2026, and the retrieval date is reported because Comtrade records are revised retrospectively.

Four handling rules were applied. Kilograms were converted to tonnes by division by 1,000. Duplicate reporter–year-product records arising from repeated submissions were aggregated once. Missing observations were retained as missing and were never replaced by zero or by imputed values. Indicators requiring both fresh and dried observations were computed only for years in which both were available, which is why 2020 is reported as not available for PECR and DES.

2.3 Commodity concordance and its limits

BPS large chilli and the selected HS categories are related but non-identical statistical objects, and the study treats this explicitly rather than by assumption. HS 070960 aggregates fresh or chilled fruits of the genera Capsicum and Pimenta, and therefore includes material outside the BPS large-chilli definition. HS 090421 and HS 090422 capture dried fruits, whole and crushed or ground respectively, under the current Harmonized System nomenclature [4]. Because drying removes moisture, fresh and dried tonnage are not additive in a physical sense; their sum is used solely as a recorded-trade aggregate. Chilli embodied in sauces, pastes and mixed preparations under HS 2001 and HS 2103 is not captured at all. Re-exports, informal cross-border trade and differences in national reporting practice may additionally affect cross-country comparison. These limitations narrow the interpretive scope of every indicator reported below and are carried explicitly into the discussion.

2.4 Diagnostic indicators and estimation

Three indicators and one relative measure constitute the SPTS diagnostic. Their definitions and permitted interpretations are summarised in Table 1. For year t, the indicators are computed as follows.

$$PECR_t = [(X_{fresh,t} + X_{dried,t})/P_t] \times 100 \quad (1)$$

$$DES_t = [X_{dried,t}/(X_{fresh,t} + X_{dried,t})] \times 100 \quad (2)$$

$$CR6_t = [\Sigma_{i=1}{}^{6} P_{i,t}/P_{national,t}] \times 100 \quad (3)$$

$$M_{j,t} = X_{j,t}/X_{Indonesia,t} \quad (4)$$

Here X_{fresh} and X_{dried} denote recorded export volumes in tonnes under HS 070960 and HS 090421 + HS 090422 respectively; P denotes national large-chilli production in tonnes; P_i denotes production in province i, ranked by 2024 output; and M_j is the benchmark multiple of comparator country j relative to Indonesia for the same product grouping and year.

Two measurement decisions require justification. First, PECR is deliberately not corrected to fresh-weight equivalents, because no defensible Indonesia-specific dry-matter conversion factor for the relevant Capsicum varieties was available; introducing a borrowed coefficient would substitute an unverifiable assumption for a disclosed limitation. Second, the indicator previously designated the Export Upgrading Index has been renamed the DES. The share of dried product in a recorded export basket documents composition; it does not by itself establish product, process or functional upgrading in the value-chain sense, and the revised terminology prevents that inference.

Table 1. Sustainable Production-Trade-Space (SPTS) diagnostic indicators, definitions and permitted interpretation

Indicator	Definition	Permitted Interpretation (and Explicit Limit)
PECR	(Fresh + dried recorded exports) / national production × 100	Intensity of recorded export activity relative to the production proxy. Not a physical conversion rate and not a measure of profitability or domestic sufficiency.
DES	Dried exports / (fresh + dried recorded exports) × 100	Composition of the recorded export basket attributable to storable dried products. Not a measure of product, process or functional upgrading, and not a measure of the national processing industry.
CR6	Output of the six largest provinces / national production × 100	Degree of geographical concentration and exposure to correlated territorial shocks. Not a measure of cluster efficiency.
Benchmark multiple	Comparator export volume / Indonesian export volume, same code group and year	Order-of-magnitude distance between recorded export channels. Not a causal estimate of productivity, competitiveness or sustainability performance.

Note: PECR and DES are reported only for years in which both fresh and dried observations are available. All indicators are computed from unrounded observations; rounding is applied only to displayed results. production-to-export conversion ratio (PECR), dried-export share (DES), six-province concentration ratio (CR6).

Table 2. Comparator-country selection criteria and screening outcome

Country	C1: Analytical Role	C2: Complete 2024 Observations	C3: Consistent HS Reporting	C4: Not Entrepôt-Dominated	Outcome
Indonesia	Focal country	Met	Met	Met	Retained
China	Global high-volume reference	Met	Met	Met	Retained
Myanmar	Proximate regional comparator	Met	Met	Met	Retained
Malaysia	Proximate regional comparator	Met	Met	Met	Retained
Vietnam	Proximate regional comparator	Not met	–	–	Excluded, not imputed

Note: Criteria were applied sequentially; failure at any criterion terminated assessment. Exclusion of Vietnam is a complete-case decision and is discussed as a source of selection bias in Section 2.5.

2.5 Comparator selection and benchmarking protocol

Comparator selection followed a stated, sequential and reproducible screen rather than convenience. Four criteria were applied in order, and their outcome is documented in Table 2. Criterion 1 required a defined analytical role: a global high-volume reference, a geographically proximate Southeast Asian comparator, or the focal country. Criterion 2 required complete 2024 observations across all three product codes in the assembled extract, so that fresh and dried channels could be compared without imputation. Criterion 3 required consistent reporting under the same HS revision. Criterion 4 excluded economies whose recorded volumes are dominated by documented entrepôt re-export functions, since such volumes would not be interpretable as national supply performance.

Vietnam satisfied Criterion 1 but failed Criterion 2 for the 2024 cross-section and was excluded rather than imputed. This complete-case rule improves reproducibility, but it also introduces two acknowledged forms of selection bias. Availability bias arises because countries with weaker or delayed reporting are systematically excluded, and those countries are not randomly distributed with respect to trade performance. Purposive bias arises because the retained comparators were chosen to illustrate an order-of-magnitude gap and therefore include a global leader. Both biases operate in the direction of exaggerating Indonesia's relative distance from the comparator set, and the interpretation in Section 3.4 is restricted accordingly.

The benchmark is presented on logarithmic axes so that China's substantially larger values do not compress the remaining series. It is an order-of-magnitude illustration only. Normalisation by export-to-production ratios was attempted but not completed, because harmonised production denominators matching the broader Capsicum and Pimenta HS aggregates were unavailable for all four countries on a consistent basis; normalisation by population or by apparent domestic consumption was likewise not attempted, because a mismatched denominator would create a spuriously precise indicator. The data requirements for a properly normalised benchmark are stated in Section 3.8 as a research priority rather than silently omitted.

2.6 Scenario architecture and sensitivity design

Forward-looking analysis uses a two-part deterministic structure that separates the production denominator from the policy variable. The 2029 production denominator is generated by Eq. (5), and implied export volumes by Eq. (6):

$$P_{2029} = P_{2024} \times (1 + g)^5 \quad (5)$$

$$X_{2029} = P_{2029} \times (PECR_{2029}/100) \quad (6)$$

The baseline growth rate g is the observed 2020–2024 compound annual growth rate of national production, 3.8308% before rounding (3.83% displayed). Four PECR pathways are then imposed as policy envelopes: deterioration to 0.0300%, stabilisation at the observed 2024 ratio of 0.0483%, recovery to the observed 2021 ratio of 0.1589%, and transformation to 0.2500%. The first three values are anchored in observed data. The transformation value is a normative planning threshold rather than an estimate: it is set at approximately 5.2 times the 2024 ratio, while remaining only one quarter of one percent of projected production, so that it is simultaneously demanding in capability terms and modest in

terms of the domestic supply it would divert. This dual property is the reason the threshold was chosen, and it is stated explicitly so that readers do not mistake it for a fitted value.

The reviewer-identified tension between a positive 2020–2024 CAGR and the 5.48% contraction observed between 2023 and 2024 is addressed by sensitivity testing rather than by asserting either figure. Three production-growth assumptions are applied to every scenario: a low bound of g = 0%, which reflects the possibility that the recent contraction persists or offsets later recovery; the observed baseline of g = 3.83%; and a high bound of g = 6.00%, which functions as a transparent upward stress test. This produces a full four-by-three grid of implied export volumes, reported in the scenario results in Section 3.6. At a fixed PECR, changes in the assumed production scale change implied export volumes proportionally; this is a deterministic sensitivity relation, not an estimated elasticity.

2.7 Spatial screening procedure

The spatial component was designed as a proof-of-concept screening exercise, prompted by the unusually rapid increase in Jambi's recorded production. The area of interest was the first-order administrative polygon for Jambi Province from the GADM database, version 4.1 [21]. ESA WorldCover 2021 v200 cloud-optimised GeoTIFF tiles were retrieved in EPSG:4326 and clipped to the provincial polygon. WorldCover is generated from Sentinel-1 and Sentinel-2 observations at 10 m resolution and contains eleven land-cover classes aligned with the FAO Land Cover Classification System [22]. For publication-scale visualisation, class codes were resampled by nearest neighbour onto an approximately 0.001-degree grid, roughly 100 m near the equator; nearest-neighbour resampling was selected because any interpolating method would generate invalid categorical values. The provincial boundary was overlaid and the original ESA class legend retained.

Three restrictions were treated as analytical safeguards rather than as incidental caveats. First, the screen is cross-sectional: it answers where broad land-cover classes occur within the province, not whether chilli cultivation caused any class transition. Second, no pixel was labelled as chilli, because the available production series is provincial and lacks geocoded holdings, district harvested area or crop-specific remote-sensing labels; the overlay therefore cannot compute the intersection between chilli expansion and forest, peat or plantation land. Third, the WorldCover tree-cover class aggregates structurally similar canopies and does not separate natural forest from oil palm, rubber or other tree crops. The overlay is consequently used to identify the additional layers required for a decision-grade assessment, and integrated remote-sensing and GIS workflows for Indonesian spatial planning provide the established template for that extension.

2.8 Validation, reconciliation, uncertainty and reproducibility

Validation was conducted at five levels. First, all units were standardised to tonnes before computing the ratios in Table 3. Second, national totals were cross-checked against the sum of displayed provincial categories, and the residual was assigned to the 'other provinces' category so that Table 4 reconciles exactly with the published national totals for both 2023 and 2024. Third, every reported ratio was recalculated from unrounded observations, with rounding applied only at the point of display; the six displayed provincial shares in Table 4 consequently sum to 74.07%, which is identical to CR6 computed from raw tonnage (74.0737%). Fourth, missing 2020 dried-export data were retained as missing so that no false zero could enter PECR or DES. Fifth, both the year-on-year and the full-period provincial changes are displayed side by side, with the governing formula stated in the note to Table 4, so that no change column can be read ambiguously.

Uncertainty is handled by claim restriction and scenario bounds rather than by inferential confidence intervals, which the design does not support. Reproduction of the analysis requires the BPS source tables for the relevant reference years, the WITS extraction settings and retrieval date reported in Section 2.2, Eqs. (1)-(6), the unrounded intermediate values, the complete-case comparator rule of Section 2.5, and the geospatial product versions and boundary source of Section 2.7. All of these are stated in the text so that an independent analyst can reconstruct every figure reported below.

3. RESULTS AND DISCUSSION

3.1 Production trajectory and recorded export intensity

Table 3 reports the annual series and the derived diagnostics. National production rose from 1.264 million t in 2020 to a peak of 1.554 million t in 2023, before contracting by 5.48% to 1.469 million t in 2024. The contraction is itself informative: a large production base is not synonymous with a stable one, and chilli supply remains exposed to seasonal rainfall, crop health, planting-calendar decisions and distribution conditions-the same factors that drive the price instability documented for the commodity.

The recorded trade series moves in the opposite direction to production. PECR fell from 0.1589% in 2021 to 0.0483% in 2024. Over that interval, combined recorded exports declined by 67.18% while production rose by 7.99%. The divergence does not, by itself, demonstrate market failure, because domestic consumption, industrial utilisation, losses and stock changes were not observed. What it does establish is narrower and still consequential: recorded fresh and dried export volumes did not expand in proportion to the production proxy, and the gap widened monotonically across four consecutive years. Figure 2 display the divergence between the production trajectory, the volume composition of recorded exports and the two derived indicators.

3.2 Product composition and the decline in dried-export share

The second pattern concerns composition. DES declined from 88.59% in 2021 to 38.07% in 2024, and the underlying movement is substantial: dried exports fell from 1,915.630 t to 270.167 t, while fresh exports partially recovered from 246.753 t to 439.577 t. The recorded export basket therefore became markedly more dependent on perishable fresh product and markedly less dependent on the storable dried segment.

The defensible interpretation of this movement is a compositional shift within the observed HS categories. It is explicitly not evidence of an economy-wide processing downgrade, and the earlier wording to that effect has been withdrawn throughout the manuscript. At least four alternative mechanisms are consistent with the same observation and

cannot be discriminated with the present data: growth in fresh-market export demand; a fall in relative dried prices that reduced the margin on dried consignments; increased domestic absorption of dried chilli by the food-processing sector; and migration of value into sauces, pastes and preparations recorded under HS 2001 and HS 2103, which lie outside the observed codes entirely. The direction of the strategic concern is nonetheless independent of which mechanism dominates. Drying extends shelf life, absorbs off-peak and lower-grade output, reduces the urgency of distress sales at harvest and widens the feasible marketing radius, provided that moisture, energy use, contamination and colour retention are controlled-a set of process conditions on which the technical literature is now extensive [23]. A shrinking storable channel therefore removes one of the few structural buffers available to a highly seasonal, highly perishable commodity.

A further boundary must be stated. Because HS 090421 and HS 090422 exclude sauces, pastes and mixed preparations, DES does not measure the whole Indonesian chilli-processing industry, and it carries no information about value added. Any claim about upgrading in the value-chain sense would require export values, unit values, HS 2001 and HS 2103 series and firm-level processing data. Those requirements are stated in Section 3.8 rather than assumed away.

Table 3. National production, recorded exports and diagnostic indicators, 2020-2024

Year	Production (t)	Fresh Exports (t)	Dried Exports (t)	PECR (%)	DES (%)
2020	1,264,190	418.973	n.a.	n.a.	n.a.
2021	1,360,571	246.753	1,915.630	0.1589	88.59
2022	1,475,821	106.035	1,112.620	0.0826	91.30
2023	1,554,498	291.189	516.164	0.0519	63.93
2024	1,469,325	439.577	270.167	0.0483	38.07

Notes: 1. Fresh exports correspond to HS 070960; dried exports to HS 090421 + HS 090422. 2. Dried-export data were unavailable for 2020 in the assembled panel and were retained as missing; PECR and DES are therefore not reported for that year. 3. PECR and DES follow Eqs. (1) and (2) and are computed from unrounded values.

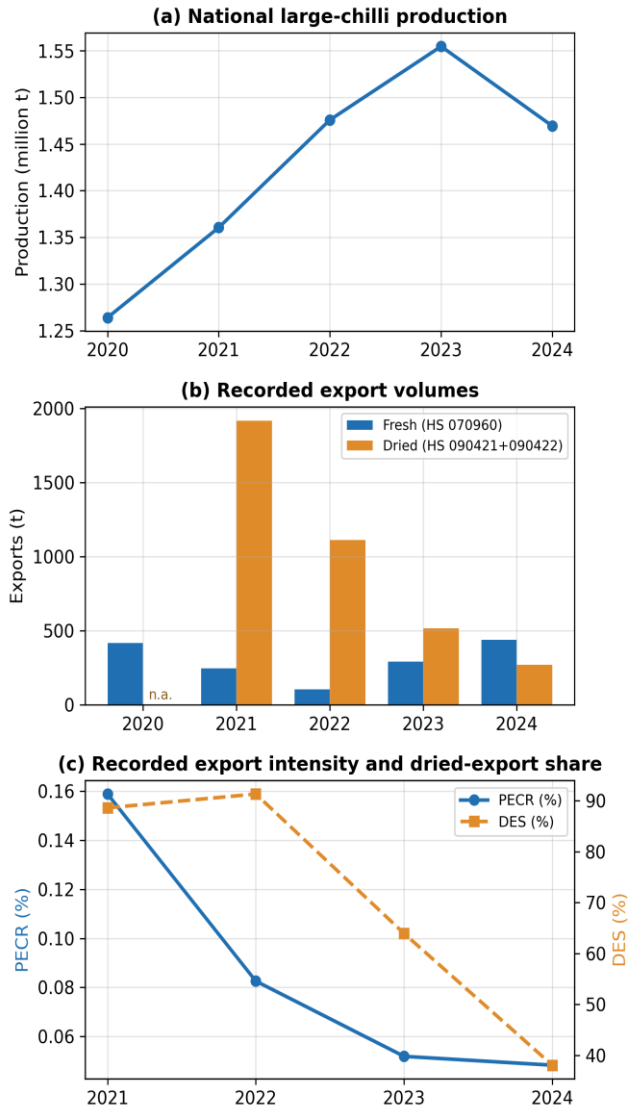


Figure 2. Production, recorded export volumes, export intensity and dried-export share (DES), 2020-2024

3.3 Regional concentration and the Jambi anomaly

Table 4 disaggregates the 2024 production base and reports both change measures explicitly. Two features dominate. First, concentration is high in 2024: the six leading provinces supplied 74.07% of national output, with West Java alone accounting for 22.07%. Second, the year-on-year and full-period changes tell materially different stories for the same provinces, which is precisely why both are now displayed. North Sumatra and Central Java are almost flat across 2020–2024, at +0.38% and +1.82% respectively, yet both contracted sharply between 2023 and 2024, at −10.70% and −28.55%. The apparent contradiction dissolves once the 2023 peak is shown: those provinces expanded strongly into 2023 and then gave back the gain. East Java's reported production is identical in 2023 and 2024, giving a 0.00% year-on-year change; its full-period change of +15.68% confirms that the province was not static over 2020–2024.

Jambi is the outlier. Recorded production rose by 263.77% between 2020 and 2024, an increase of 124,324 t that is larger than the entire 2024 output of West Sumatra. Provincial statistics cannot separate the harvested-area effect from the yield effect, and this is not a data-cleaning problem that additional national aggregation can solve. The finding therefore identifies Jambi as a spatial-audit priority rather than demonstrating land expansion, and Section 3.5 implements the first stage of that audit.

Concentration of this degree creates a symmetrical planning problem. Clustered output justifies specialised packhouses, accredited laboratories and processing facilities, because throughput is sufficient to amortise fixed costs. The same clustering, however, means that infrastructure failure or climatic disturbance in a small number of territories transmits rapidly to national availability, a mechanism consistent with interregional evidence that agglomeration raises productivity while widening disparity [16]. Sustainable planning should therefore pair hub investment in high-volume clusters with the deliberate diversification of climate-resilient production zones and with contingency logistics, rather than treating concentration as an unambiguous efficiency gain.

Table 4. Production, year-on-year change, full-period change and 2024 share, principal provinces

Province	2020 (t)	2023 (t)	2024 (t)	Δ2023–24 (%)	Δ2020–24 (%)	2024 Share (%)
West Java	266,067	324,976	324,229	−0.23	+21.86	22.07
North Sumatra	193,862	217,909	194,593	−10.70	+0.38	13.24
Central Java	166,260	236,924	169,282	−28.55	+1.82	11.52
West Sumatra	133,190	127,450	114,170	−10.42	−14.28	7.77
East Java	99,110	114,653	114,653	0.00	+15.68	7.80
Jambi	47,133	157,850	171,457	+8.62	+263.77	11.67
Six-province subtotal	905,622	1,179,762	1,088,384	−7.75	+20.18	74.07
Other provinces	358,569	374,736	380,941	+1.66	+6.24	25.93
National total	1,264,190	1,554,498	1,469,325	−5.48	+16.23	100.00

Notes: 1. Year-on-year change follows $[(P_{2024} / P_{2023}) - 1] \times 100$; full-period change follows $[(P_{2024} / P_{2020}) - 1] \times 100$. 2. East Java's reported 2023 and 2024 values are identical, giving a 0.00% year-on-year change; the province is not static over the full period. 3. The 'other provinces' category is reconciled to the published national totals for 2023 and 2024, so column sums are exact. 4. Shares are computed from unrounded tonnage; the six displayed shares sum to 74.07%, identical to CR6 computed from raw tonnage (74.0737%).

Table 5. Cross-country benchmark of recorded 2024 exports and relative multiples

Country	Fresh Exports, HS 070960 (t)	Multiple of Indonesia	Dried Exports, HS 090421 + 090422 (t)	Multiple of Indonesia
Indonesia	439.577	1.0	270.167	1.0
China	198,011	≈450	355,985	≈1,318
Myanmar	≈ 12,300	≈28	≈ 23,500	≈87
Malaysia	≈ 5,300	≈12	≈ 3,800	≈14

Notes: 1. Multiples follow Eq. (4). 2. Values for Myanmar and Malaysia are reported to the precision supported by the assembled extract. 3. The comparison is an order-of-magnitude illustration; it is not normalised for production scale, population, domestic consumption or re-export function, and therefore carries no implication about relative efficiency or sustainability.

3.4 International benchmark and its interpretive limits

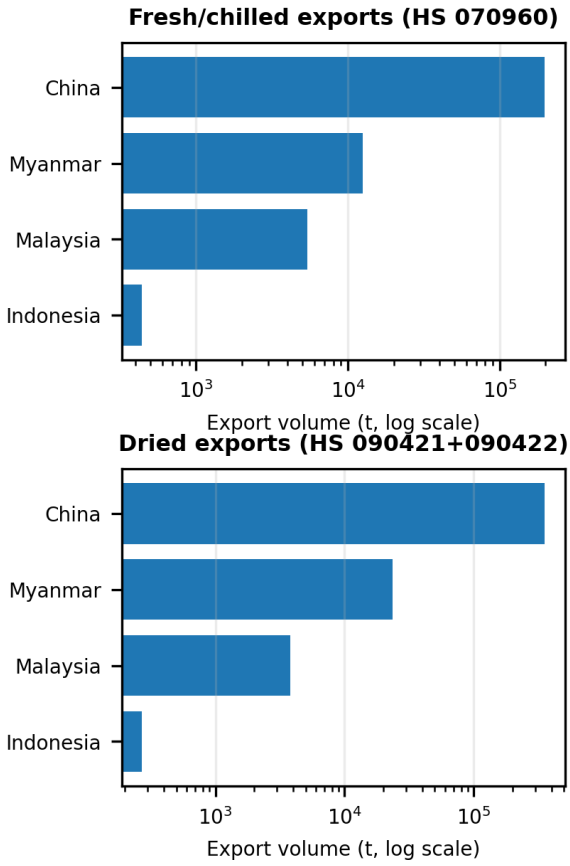


Figure 3. Recorded fresh and dried Capsicum/Pimenta export volumes, 2024 (logarithmic scale)

Table 5 and Figure 3 present the 2024 cross-section. China exported 198,011 t of fresh product and 355,985 t of dried product, approximately 450 and 1,318 times Indonesia's respective recorded volumes. Myanmar exceeded Indonesia by roughly 28 times in fresh and 87 times in dried exports, and Malaysia by roughly 12 and 14 times.

These absolute gaps must be read with discipline. They are not normalised for production scale, population, domestic consumption or re-export function, and they therefore establish only that substantially larger recorded export channels exist under different national structures. They do not establish that the comparator countries are more efficient, more competitive or more sustainable, and they do not license uncritical imitation of any comparator's policy model. The selection bias documented in Section 2.5 operates in the direction of widening the apparent gap, which reinforces rather than weakens this restriction.

What the benchmark does support is a structural rather than a volumetric reading. Exporters require aggregated consignments, repeatable quality, residue documentation consistent with importing-country maximum residue limits [24], phytosanitary clearance, appropriate packaging, traceability and reliable shipment schedules [5, 6]. Where smallholders sell through long spot-market chains, buyer specifications reach the farm late and the incentive to invest in farm-level compliance is correspondingly weak [7, 9]. Standards can therefore exclude farmers when compliance costs are individualised, but the same standards can enable upgrading when cooperatives, lead firms, accredited laboratories and public infrastructure distribute those costs and stabilise market relationships [5, 25]. These are policy hypotheses consistent with the observed pattern; the present design does not estimate their effects.

Indonesia's prevailing policy orientation is also material to the interpretation. Because chilli is governed principally as an inflation commodity, the instruments applied are short-run distribution measures triggered by retail-price movements [13, 15]. Indonesia's rice-policy literature likewise documents the persistent policy tension among domestic availability, producer incentives and trade decisions [26]. A balanced strategy would protect domestic availability while constructing segregated export clusters with contract production, auditable input use, pre-cooling, packhouse grading and processor off-take. Sustainability-adjusted trade

analysis for Indonesian commodities supports precisely this subordination of volume targets to sustainability and capability objectives [20].

3.5 Proof-of-concept eco-spatial screening: Jambi

Figure 4 presents the screening overlay. Jambi was selected because its recorded production increased by 263.77% between 2020 and 2024, the largest relative change in the panel by a wide margin. The overlay clips ESA WorldCover 2021 v200 classes to the GADM 4.1 provincial boundary and displays them at approximately 100 m for legibility, with nearest-neighbour resampling preserving categorical integrity [21, 22].

The overlay distinguishes tree cover, cropland, grassland, shrubland, built-up land, permanent water, herbaceous wetland and mangroves. Three readings are supported. First, cropland and mixed agricultural mosaics are visibly concentrated in parts of the western portion and near mapped permanent-water and built-up features. These patterns identify candidate areas for subsequent logistics screening; efficiency itself cannot be established without road travel-time, energy and facility data. Second, extensive tree-cover classes dominate the interior, and because that class does not separate natural forest from oil palm or rubber, the map cannot be used to characterise the land-use status of any candidate expansion area. Third, wetland and mangrove classes along the eastern coastal margin identify ecologically sensitive screening areas; any expansion proposal there would require additional validation against statutory protection, peat and hazard layers before a risk conclusion could be made.

What the overlay cannot do is equally important. It is a single-date screen and not a change model; it cannot attribute any land-cover class to chilli cultivation; and it cannot substitute for statutory spatial-planning instruments. A decision-grade extension would integrate district or village production, harvested area and yield with annual land-cover transitions, statutory protected-area boundaries, peat depth, slope, watershed function, fire exposure, road travel time, electricity reliability and the locations of packhouses and processing facilities [27]. Under that architecture, candidate intensification zones would require evidence of existing agricultural use and acceptable environmental risk; exclusion zones would be defined by statutory protected-area, peat and hazard regulation rather than by WorldCover alone; and aggregation or processing nodes would be evaluated against network accessibility and infrastructure-service criteria.

The policy implication is precautionary rather than causal. Public support should prioritise yield reliability, loss reduction and value capture on verified existing agricultural land. Expansion should be excluded from protected ecosystems, peatlands, steep slopes and disaster-prone areas following validation against statutory spatial plans and relevant peat, slope and hazard datasets. This posture is consistent with evidence that Indonesian land-use transitions are spatially heterogeneous and cannot be inferred from commodity trends [18], and with the documented interaction between extractive dependence and environmental degradation in Jambi specifically [17].

3.6 Conditional scenarios and sensitivity to 2029

Table 6 reports the four scenario definitions and their baseline implications; Table 7 reports the full sensitivity grid; Figure 5 displays both the pathways and the resulting volume band. Under the baseline denominator of 1,773,168 t, the transformation scenario implies approximately 4,433 t of recorded exports in 2029.

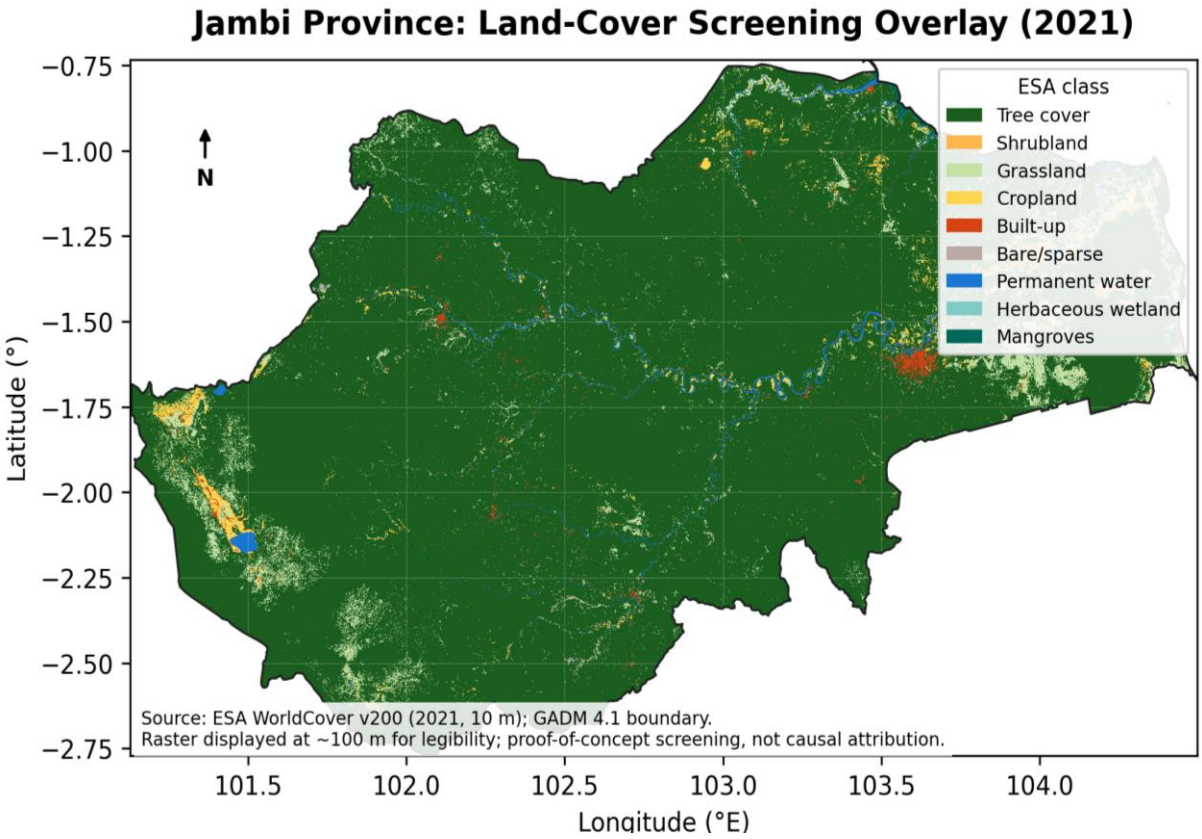


Figure 4. Proof-of-concept land-cover screening overlay for Jambi Province, 2021

Table 6. Conditional 2029 scenario definitions and baseline implications

Scenario	PECR 2029 (%)	Basis of the Value	Implied 2029 Exports (t)	Planning Meaning
Deterioration	0.0300	Continuation of the observed downward path	532	Recorded conversion weakens further; seasonal surplus and price-volatility exposure persist.
Stabilisation	0.0483	Observed 2024 ratio	856	Arrests decline but leaves the structural disparity intact.
Recovery	0.1589	Observed 2021 ratio	2,818	Restores the earlier conversion level through coordinated infrastructure and market access.
Transformation	0.2500	Normative planning threshold, ≈ 5.2 × the 2024 ratio	4,433	Requires dedicated export clusters, processing capacity and verified compliance systems.

Notes: 1. The baseline 2029 production denominator is 1,773,168 t, obtained from Eq. (5) using the unrounded observed 2020–2024 CAGR of 3.8308% (3.83% when displayed). 2. Values are conditional planning targets derived from Eq. (6); they are not statistical forecasts and carry no probability interpretation. 3. Production-to-export conversion ratio (PECR).

Table 7. Sensitivity of implied 2029 export volumes to production-growth assumptions

Growth Assumption	2029 Production (t)	Deterioration 0.0300% (t)	Stabilisation 0.0483% (t)	Recovery 0.1589% (t)
Low bound, g = 0.00%	1,469,325	441	710	2,335
Baseline, g = 3.83%	1,773,168	532	856	2,818
High bound, g = 6.00%	1,966,288	590	950	3,124

Notes: 1. Under the transformation pathway (PECR = 0.2500%), implied 2029 exports are 3,673 t, 4,433 t and 4,916 t under the low, baseline and high growth assumptions respectively. 2. The low bound reflects the possibility that the 2023–24 contraction of 5.48% persists or offsets later recovery; the high bound is a transparent upward stress test. 3. Because the denominator enters Eq. (6) multiplicatively, the proportional effect of the growth assumption is identical across all four pathways: the high-growth case is 33.8% above the low-growth case (equivalently, the full low-to-high spread is about 28.0% of the baseline value).

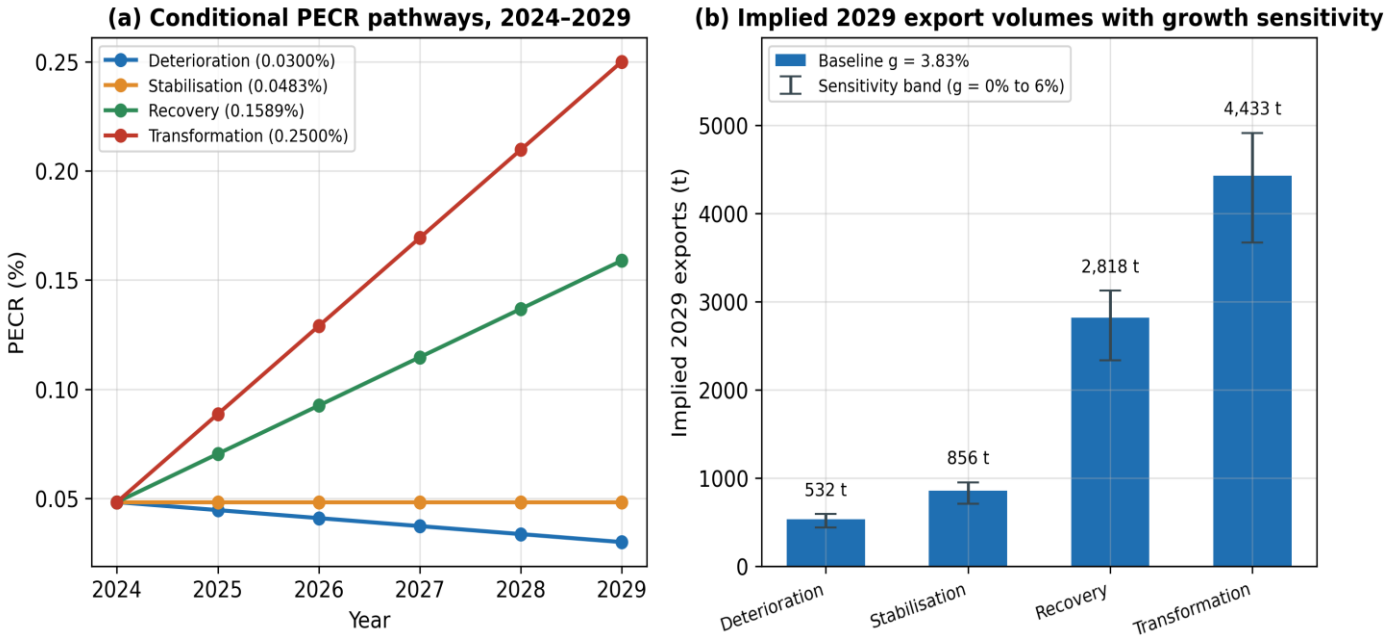


Figure 5. Conditional production-to-export conversion ratio (PECR) pathways and implied 2029 export volumes with growth sensitivity

Two readings of these magnitudes must be held simultaneously, and conflating them was a weakness of the earlier draft. Relative to projected national production, 4,433 t is trivial: it is one quarter of one percent of output, and achieving it would divert a negligible quantity from domestic consumers. Relative to the 2024 export base of 709.744 t, the same figure is highly demanding, because it implies a 6.25-fold increase in five years under the baseline denominator, and between 5.2- and 6.9-fold across the sensitivity band. The transformation scenario should therefore be read as a capability-building threshold, not as an easy reallocation of surplus output. Within the imposed sensitivity bounds, the high-growth case yields implied export volumes 33.8% above the low-growth case, whereas moving from stabilisation to transformation raises the PECR target by approximately 418%. Thus, within this deterministic scenario design, implied export volume is more sensitive to the PECR pathway than to the production-growth assumption.

The recovery and transformation pathways both require sequenced rather than simultaneous investment, and sequencing errors are the most common source of stranded agro-industrial assets. Farm protocols and traceability must precede certification, because certification of an undocumented process yields no verifiable claim. Aggregation centres must be linked to confirmed buyers before construction, because throughput assumptions drive their entire cost structure. Drying and milling capacity must be matched to energy availability, moisture control and contamination management, since the technical conditions governing dried-product quality are exacting. Port logistics

must be designed around product shelf life rather than around generic freight economics. Export diplomacy conducted in the absence of these domestic capabilities will not deliver consistent contracts; conversely, processing investment undertaken without market agreements produces under-utilised assets and discredits the strategy.

3.7 Integrated policy architecture

Table 8 converts the diagnosis into an implementation sequence with measurable planning signals, so that each intervention is paired with an indicator that can be monitored rather than asserted.

The immediate priority is data integrity. Production, harvested area, prices, losses, domestic processing volumes and product-level trade codes must be reconciled within a single statistical architecture before any target is set, because every indicator in this study is constrained by concordance problems that better administrative data would resolve. The second priority is selective concentration of effort: a small number of export-ready clusters in which farmer groups, processors, accredited laboratories and confirmed buyers can be contractually aligned will generate more learning than dispersed support. Public funding should target shared infrastructure, verification systems and spatial screening rather than subsidising area expansion. Evidence from Vietnam's vegetable sector shows that effective supply-chain collaboration depends on both farmer engagement and robust coordination mechanisms, reinforcing the case for integration rather than dispersed production support [28].

Performance should be monitored through a balanced dashboard rather than a single export target: marketable yield, postharvest loss, rejection rate, PECR, DES, export unit value, the farmer share of final value, energy use per processed tonne, and the proportion of supported production located on verified suitable land. A balanced dashboard prevents a narrow export objective from displacing domestic affordability, farmer welfare or ecological safeguards. Loss reduction deserves particular emphasis. Indonesian household evidence shows that spoilage, short shelf life, over-preparation and plate leftovers are important food-waste drivers, indicating that infrastructure measures should be complemented by handling and behavioural interventions [29]. Circular use of rejected fruit and processing residues should be developed where technically and economically feasible. Finally, Indonesian land-allocation research shows that agricultural, climate, forestry and other sectoral goals need to be reconciled within a common land-allocation framework and reference database to avoid policy overlap and hidden trade-offs [30].

Table 8. Integrated policy architecture and measurable planning signals

Domain	Priority Intervention	Measurable Planning Signal	Horizon
Production	Good agricultural practice protocols, climate-resilient planting calendars and yield-led intensification on verified existing farmland.	Marketable yield per hectare rises without any expansion into screened exclusion zones.	1–3 y
Postharvest	Cluster packhouses, pre-cooling, grading lines, reusable crates and systematic loss monitoring.	Rejection rate, damage rate and elapsed time from harvest to cooling all decline.	1–3 y
Processing	Modular dryers, hygienic milling, moisture and contamination control, and off-take contracts.	Recorded dried-export volume and DES recover; energy use per processed tonne falls.	2–5 y
Institutions	Farmer aggregation, written contract specifications, accredited laboratories and digital traceability.	Repeatable lots meet residue and phytosanitary requirements on first inspection.	2–5 y
Spatial planning	Integration of production clusters with RTRW/RDTR, land cover, peat depth, slope and protected-area layers.	Public investment is located only in screened suitable zones; no incentive reaches a high-risk ecosystem.	1–5 y
Trade resilience	Buyer diversification, port-route optimisation and management of energy and freight exposure.	Buyer concentration falls; on-time delivery performance improves.	3–5 y

Note: Horizons are indicative planning ranges derived from the sequencing logic in Section 3.6, not from estimated implementation functions.

3.8 Limitations and research agenda

The limitations of this study are specific and bounded. Commodity concordance does not isolate red chilli perfectly, because the HS aggregates are broader than the BPS production definition. Fresh and dried masses were not converted to fresh-weight equivalents, since no defensible Indonesia-specific coefficient was available. Domestic consumption, industrial utilisation, losses and stock changes were unobserved, which prevents any welfare interpretation of the disparity. Export values and unit values were not modelled, so no statement about value capture is made. The country benchmark is not normalised and is subject to the selection bias documented in Section 2.5. The Jambi overlay is cross-sectional, cannot separate natural forest from plantation tree cover, and cannot attribute land-cover status to chilli cultivation. Finally, the scenarios are deterministic planning envelopes and carry no probability interpretation.

These limitations narrow the claims but do not undermine the central diagnostic. The simultaneous decline in recorded export intensity and in DES, occurring alongside persistently high production concentration, is a robust signal that value-chain and territorial capabilities require policy attention. Four research extensions would convert the diagnostic into an explanatory model. First, a district-level panel combining harvested area, yield, farm-gate price and loss estimates would allow the area and yield components of provincial change to be separated, which is the precondition for any credible land-use claim. Second, incorporation of HS 2001 and HS 2103 series together with export values and unit values would allow genuine upgrading-as opposed to composition-to be measured. Third, a normalised international benchmark using harmonised production denominators, population and apparent domestic consumption would replace the order-of-magnitude comparison with an interpretable ratio. Fourth, integration of annual land-cover transition data with statutory spatial plans, peat and slope layers would upgrade the screening overlay to a decision-grade instrument. Together these extensions would permit estimation of whether upgrading raises export unit value and farmer income without increasing domestic price risk or transferring environmental costs to vulnerable landscapes.

4. CONCLUSIONS

Indonesia's red-chilli challenge cannot be reduced to a production deficit. In 2024, a production base of 1,469,325 t was accompanied by 709.744 t of recorded fresh and dried exports, a PECR of 0.0483%, while the DES fell from 88.59% in 2021 to 38.07% in 2024. The second movement is a compositional shift within the observed HS categories and not an economy-wide processing downgrade; several alternative mechanisms remain consistent with the evidence and cannot be discriminated without product-level value data. Six provinces supplied 74.07% of national output, creating genuine cluster economies alongside correlated territorial risk that justifies systematic screening.

The international benchmark demonstrates that substantially larger recorded export channels exist under different national structures, but it cannot establish superior efficiency or sustainability without harmonised production, population, consumption and re-export controls, and the comparator screen is itself subject to documented selection bias. The Jambi overlay demonstrates how public land-cover data can initiate spatial screening while simultaneously exposing the additional layers-district harvested area, protected-area boundaries, peat depth, slope, road access and processing locations-that any expansion decision would require.

Under the sensitivity bounds applied here, a 0.25% PECR in 2029 implies between 3,673 t and 4,916 t of recorded exports. That range is negligible relative to projected national production yet demanding relative to the current export base, requiring a 5.2- to 6.9-fold increase within five years. Achieving it would depend on coordinated aggregation, postharvest control, traceability, processing capacity and durable buyer relationships, supported by verified spatial safeguards and monitored through a balanced dashboard rather than a single volume target. The policy leverage identified by the sensitivity analysis lies in the conversion pathway rather than in the production denominator, which reframes the strategic question from how much Indonesia grows to how reliably what it already grows can be graded, preserved, verified and delivered.

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NOMENCLATURE

CR6	six-province concentration ratio, %
DES	dried-export share, %
g	assumed annual growth rate of national production, dimensionless
M_j	benchmark multiple of comparator country j, dimensionless
$P_{i,t}$	large-chilli production of province i in year t, t
PECR	production-to-export conversion ratio, %
$X_dried_{,t}$	recorded dried exports (HS 090421 + HS 090422) in year t, t
$X_fresh_{,t}$	recorded fresh exports (HS 070960) in year t, t
GADM	Database of Global Administrative Areas
RDTR	Rencana Detail Tata Ruang (detailed spatial plan)
RTRW	Rencana Tata Ruang Wilayah (regional spatial plan)
SPTS	Sustainable Production–Trade–Space diagnostic framework
WITS	World Integrated Trade Solution