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Adaptive Strategy and Sustainability in the National Fertilizer Industry under VUCA Conditions: A Systematic Literature Review and Bibliometric Analysis

Niera Feblidiyanti[1], Ahmad Syafrudidin Indrapriyatna[2*], Elita Amrina[3], Franka Hendra[4]
[1,2,3] Departemen Teknik Industri, Universitas Andalas, Indonesia
Jl. Limau Manis, Kecamatan Pauh, Padang, Kota Padang
Email: dosen02275@unpam.ac.id, ahmadsi@eng.unand.ac.id*, elita@eng.unand.ac.id
[1,4]Departemen Teknik Industri, Universitas Pamulang, Indonesia
Jl. Surya Kencana No.1 Pamulang barat
Email: 2530932008_niera@student.unand.ac.id , dosen01508@unpam.ac.id

ABSTRACT

The national fertilizer industry faces volatile energy and raw-material prices, global supply disruptions, policy uncertainty, subsidy pressures, and rising decarbonization expectations. This study reviews recent literature on adaptive strategy and sustainability in the fertilizer industry under volatile, uncertain, complex, and ambiguous (VUCA) conditions. A systematic literature review following PRISMA 2020 was combined with bibliometric analysis using bibliometrix/Biblioshiny. The final search was conducted on 10 December 2025 in Scopus and ScienceDirect for publications from 2020 to 2025. A total of 824 records were identified, 63 duplicates were removed, 761 titles and abstracts were screened, 173 records were retained for bibliometric mapping, and 23 full-text articles were selected for in-depth synthesis. An extended literature review matrix of 164 cleaned articles was used to triangulate themes, methods, and research gaps. The results show that sustainability, low-carbon fertilizer transformation, supply chain resilience, digital transformation, adaptive strategy, and VUCA-driven uncertainty dominate the literature, but their integration into a strategy-oriented framework remains limited. The novelty of this study lies in developing an integrative framework linking VUCA pressures, dynamic capabilities, supply chain resilience, adaptive strategic responses, and sustainability performance for national fertilizer industry transformation

***Keywords**:* adaptive strategy; bibliometric analysis; fertilizer industry; resilience; sustainability; VUCA.

Introduction

The fertilizer industry is a strategic sector because it supports agricultural productivity, food security, and economic stability. However, its operating environment is increasingly shaped by energy-price volatility, imported input dependency, global supply disruption, climate pressure, and stricter sustainability expectations. These pressures create a VUCA environment in which static efficiency-oriented strategies are no longer sufficient [1], [2], [3]

Recent studies on resilience, agility, dynamic capabilities, fertilizer-use efficiency, circular economy, and environmental assessment provide important insights, but they are still distributed across separate knowledge streams [4], [5], [6]. Resilience studies explain how supply chains absorb shocks; sustainability studies emphasize nutrient efficiency, emissions, and circularity; and strategy studies discuss agility and learning. What remains underdeveloped is an integrated explanation of how VUCA pressures are translated into adaptive strategic responses and sustainability outcomes in the fertilizer industry [7]

This article responds to that gap by combining systematic literature review and bibliometric analysis. It also integrates the results of a cleaned literature review matrix covering 164 supporting articles from 2020 to 2025. Unlike prior reviews that separately discuss fertilizer sustainability, supply chain resilience, or agronomic efficiency, this study synthesizes these streams into a strategy-oriented framework for national fertilizer industry transformation [8], [9], [10].

The study addresses four research questions: (RQ1) What themes dominate the literature on adaptive strategy and sustainability in the fertilizer industry under VUCA conditions? (RQ2) How is the knowledge structure among VUCA, resilience, adaptive strategy, sustainability, and fertilizer-related studies represented? (RQ3) What research gaps remain? (RQ4) What conceptual framework can be proposed for the national fertilizer industry?

VUCA refers to volatility, uncertainty, complexity, and ambiguity. In industrial systems, VUCA captures not only environmental turbulence but also the limits of conventional planning when firms face price shocks, policy shifts, disruptions, and unclear market signals [1],[2], [4], [5], [11], Dynamic capabilities explain how

organizations sense changes, seize opportunities, and reconfigure resources [4], [6]. Supply chain resilience describes the capacity to anticipate, absorb, recover from, and adapt to disruptions through visibility, flexibility, collaboration, and calibrated redundancy [8], [9], [10], [10],[12],[13]. Sustainability in fertilizer systems covers economic stability, emissions reduction, nutrient-use efficiency, circular inputs, and social contribution to food security.

The national fertilizer industry context strengthens the relevance of this framework. In Indonesia and similar developing countries, fertilizer strategy is closely connected with imported raw materials, natural gas availability, energy-price volatility, fertilizer subsidy systems, logistics across archipelagic territories, farmer access, food security, decarbonization pressure, and the strategic role of state-owned fertilizer enterprises. Therefore, although the review corpus is global, its synthesis is directed toward national transformation needs: improving supply stability, building adaptive capability, and aligning industrial competitiveness with sustainability targets.

Research Method

This study used an SLR guided by PRISMA 2020 [18] and bibliometric analysis using bibliometrix/ Biblioshiny [14], [15]. The final database search was conducted on 10 December 2025. Scopus was used for high-quality indexed journal coverage, while ScienceDirect was used to strengthen access to full-text articles in operations, supply chain, sustainability, environmental management, agribusiness, and fertilizer-related domains. The search was limited to 2020–2025, peer-reviewed journal articles, English or Indonesian language, and topics related to VUCA/environmental uncertainty, adaptive strategy, resilience/agility/dynamic capabilities, sustainability/circular economy/LCA, fertilizer/agriculture, and supply chains

Table 1. Database-specific search strings and limits

Database	Search string / query logic	Limits
Scopus	TITLE-ABS-KEY((VUCA OR "volatile uncertain complex ambiguous" OR "environmental uncertainty") AND (fertilizer OR fertiliser OR pupuk OR agriculture OR "agri-food") AND (strategy OR "adaptive strategy" OR agility OR resilience OR "dynamic capabilities" OR sustainability OR "circular economy" OR "supply chain"))	Year 2020–2025; article; journal; English/Indonesian; title, abstract, and keywords.
ScienceDirect	Title, abstract, and keywords: (VUCA OR "environmental uncertainty") AND (fertilizer OR fertiliser OR agriculture) AND (adaptive strategy OR agility OR resilience OR sustainability OR circular economy OR supply chain)	Year 2020–2025; research/review articles; subject areas related to engineering, management, environmental science, agriculture, and energy.

Scopus metadata were exported in CSV/BibTeX format. ScienceDirect results were exported through the citation export menu in RIS/BibTeX format, with titles, abstracts, author keywords, source titles, years, and DOI information retained when available. The files were imported into Biblioshiny, converted into a unified bibliographic dataset, and checked manually for inconsistent titles and source fields. Duplicates were identified using DOI, title similarity, author-year matching, and manual inspection. Screening was performed by the author team: one reviewer screened the records, a second reviewer checked doubtful cases, and disagreements were resolved through consensus. A formal kappa statistic was not calculated; however, consistency was strengthened through a pilot screening of sample records and the use of explicit inclusion-exclusion criteria.

Table 2. Inclusion and exclusion criteria**.**

Aspect	Inclusion	Exclusion
Period	2020–2025 publications	Publications outside 2020–2025.
Document type	Peer-reviewed journal articles and review articles	Proceedings, editorials, books, reports, non-scholarly sources.
Topic	VUCA/environmental uncertainty, adaptive strategy, resilience, agility, dynamic capabilities, sustainability, fertilizer/agriculture/supply chain	Articles unrelated to the conceptual scope.
Eligibility for synthesis	Full text available and direct relevance to the framework	Inaccessible full text or weak conceptual relevance.

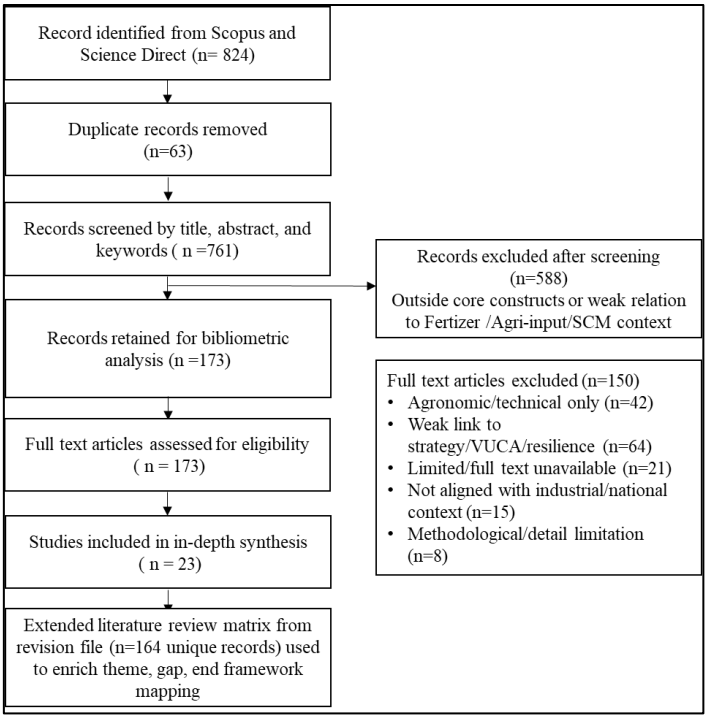

Figure 1. PRISMA flow diagram showing identification, deduplication, screening, eligibility assessment, and inclusion.

The reduction from 173 bibliometric records to 23 in-depth synthesis articles was intentional. The 173 records were sufficient for science mapping, whereas the final 23 were selected because they were full-text articles with the strongest direct relevance to VUCA, fertilizer-related systems, adaptive strategy, resilience, and sustainability, and because they represented the main thematic streams required to build the proposed framework

Result and Discussion

Bibliometric and Quantitative Results

The bibliometric dataset contained 173 records, while the extended literature review matrix contained 164 cleaned supporting articles from 2020 to 2025. The matrix confirms strong growth of the topic after 2021, with the largest number of supporting articles in 2022 and 2025. The year distribution in the matrix was: 2020 = 5, 2021 = 13, 2022 = 45, 2023 = 35, 2024 = 22, and 2025 = 44. This pattern indicates that the topic became more visible after the recent period of supply chain shocks, energy-price instability, and sustainability transition.

Table 3. Quantitative theme evidence from the integrated literature review matrix.

Theme / cluster in integrated matrix	Frequency (n=164)
Digital transformation	142
Sustainability/low-carbon	111
Supply chain resilience	72
Industri pupuk/amonia/nitrogen	65
Strategi adaptif/agility	31
VUCA & ketidakpastian	18
Pendukung umum strategi/operasi	3

Table 4. Method distribution in the integrated literature review matrix

Method category	Frequency
Kuantitatif / modeling	58
Perlu cek metode full paper	43
Literature review / SLR	38
Kualitatif / studi kasus	20
Optimasi / simulasi	5
Optimasi / simulasi	5

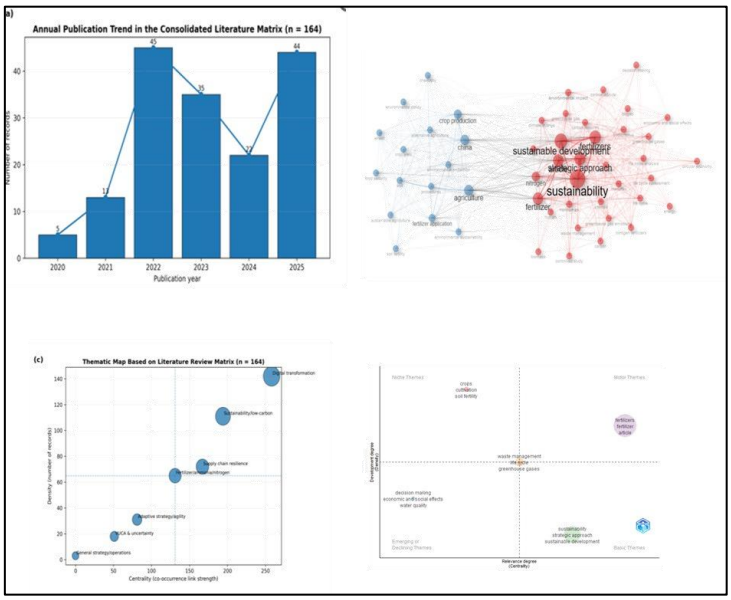

Figure 2. Bibliometric evidence panel: (a) annual publication trend, (b) keyword/theme co-occurrence network, (c) thematic map, and (d) conceptual structure map.

Figure 2 shows that sustainability, digital transformation, supply chain resilience, fertilizer/ammonia/nitrogen, adaptive strategy, and VUCA-related uncertainty form the main knowledge clusters. The keyword network indicates that sustainability and supply chain resilience function as bridging themes, while the thematic map suggests that low-carbon and digital transformation themes are more developed than firm-level adaptive strategy. The conceptual structure map shows a persistent separation between agronomic productivity, environmental assessment, and strategic transformation.

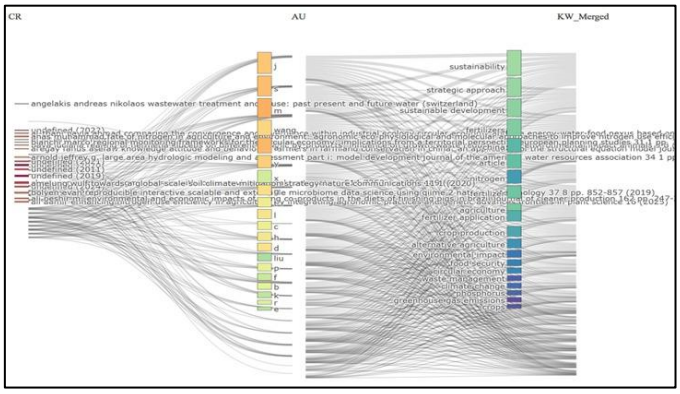

Figure 3. Knowledge linkage and proposed framework panel: three-fields plot linking theory, theme, and method

The three-fields plot supports the interpretation that the literature links theories of sustainability, supply chain resilience, digital transformation, and dynamic capabilities with quantitative modeling, SLR, and case-based approaches. However, the connection between these theories and a national fertilizer strategy remains underdeveloped. Figure 3b therefore synthesizes the evidence into a sequential framework: VUCA pressures trigger the need for dynamic capabilities, dynamic capabilities strengthen supply chain resilience, resilience enables adaptive strategic responses, and adaptive responses improve sustainability performance

Thematic Synthesis and Research Gaps

Table 5. Systematic thematic synthesis of the in-depth articles and integrated literature matrix.

Theme	Representative articles	Main findings	Research gap

Resilience and agility	[1],[2], [4], [5], [11]	Visibility, flexibility, learning, coordination, and calibrated redundancy help firms absorb disruptions and recover faster.	Limited integration with fertilizer-specific subsidy, energy, and raw-material constraints.
Sustainability and environmental assessment	[8],[9],[10],[12], [13]	Fertilizer studies increasingly emphasize nutrient efficiency, emissions, life cycle assessment, and circular resource use.	Operational strategy is not always linked with measurable sustainability outcomes.
Supply chain and market shocks	[3], [11], [16], [5], [17], [18] [17], [19], [20], [7],	Fertilizer price shocks, market concentration, and supply uncertainty affect farm profitability and food security.	Few studies translate market shocks into adaptive industrial strategy.
Digitalization and decision support	[4], [11], [21]	Digital capability improves information visibility, responsiveness, and decision quality under uncertainty.	Digitalization is often discussed generally, not as an integrated control mechanism for fertilizer resilience.
National transformation context	Integrated matrix; [5], [11], [21]	The national industry faces imported input dependency, energy volatility, logistics complexity, subsidy policy, and decarbonization pressure.	Empirical testing in national fertilizer companies remains limited.

The synthesis reveals four main gaps. First, macro-level sustainability objectives are weakly connected with micro-level operational decisions such as sourcing, distribution, inventory, technology selection, and emissions tracking. Second, trade-off models that jointly consider productivity, cost, resilience, and environmental impact remain limited. Third, dynamic capabilities are rarely tested as a mechanism linking uncertainty and sustainability performance in fertilizer systems. Fourth, the national or developing-country context remains underdeveloped despite its distinctive characteristics: subsidy governance, logistics constraints, import dependency, and state-owned enterprise roles.

Proposed Framework and Propositions

The proposed framework has five main components. VUCA conditions represent external pressure generated by energy volatility, raw-material uncertainty, policy ambiguity, climate risks, market shocks, and sustainability requirements. Dynamic capabilities represent sensing, seizing, learning, and resource reconfiguration. Supply chain resilience represents visibility, flexibility, coordination, preparedness, and recovery capability. Adaptive strategy represents the portfolio of strategic responses, including supplier diversification, digital control towers, flexible production planning, circular input innovation, low-carbon transition, and distribution redesign. Sustainability performance covers supply stability, resource efficiency, emissions reduction, economic viability, and legitimacy.

Table 6. Conceptual propositions derived from the framework.

Proposition	Statement
P1	VUCA conditions increase the need for dynamic capabilities in the fertilizer industry.
P2	Dynamic capabilities strengthen supply chain resilience through sensing, coordination, learning, and resource reconfiguration.
P3	Supply chain resilience enables adaptive strategy by improving visibility, flexibility, and response speed under disruption.
P4	Adaptive strategy improves sustainability performance through resource efficiency, emissions reduction, and supply stability.
P5	Supply chain resilience mediates the relationship between dynamic capabilities and adaptive strategic responses.
P6	National context factors such as subsidy policy, energy dependency, logistics complexity, and state-owned enterprise roles moderate the implementation of adaptive strategy.

Table 7. Operationalization of framework constructs.

Construct	Core dimensions	Illustrative indicators

VUCA condition	Volatility, uncertainty, complexity, ambiguity	Energy price volatility; raw-material uncertainty; policy ambiguity; market disruption.
Dynamic capabilities	Sensing, seizing, learning, reconfiguration	Scenario planning; rapid decision-making; capability renewal; cross-functional learning.
Supply chain resilience	Visibility, flexibility, coordination, recovery	Supplier diversification; buffer policy; digital monitoring; logistics collaboration.
Adaptive strategy	Strategic portfolio for adjustment and transformation	Multi-sourcing; production flexibility; digital control tower; low-carbon fertilizer portfolio.
Sustainability performance	Economic, environmental, and social outcomes	Supply stability; resource efficiency; emissions intensity; farmer access; legitimacy.

Managerial Implications

For national fertilizer companies, adaptive strategy should be designed as an integrated portfolio rather than as isolated initiatives. Multi-sourcing without data visibility may increase complexity; digital systems without organizational learning may improve data availability but not decision quality; and sustainability programs without resilient supply configuration may fail when shocks occur. Managers should therefore prioritize: (1) end-to-end visibility across raw materials, production, inventory, distribution, and sustainability indicators; (2) disruption-response mechanisms for energy and input supply; (3) fertilizer portfolio innovation using circular and low-carbon pathways; and (4) traceable metrics such as emissions per ton, energy intensity, supply stability, distribution service level, and nutrient-use efficiency

Reference Checking and Scope Control

The reference list was checked to align the review scope with 2020–2025 publications. Future-dated items were removed or corrected where publication metadata showed a valid year within the scope. DOI formatting, journal title consistency, and citation numbering should be checked once again against the target journal template before submission.

Conclusion

This study maps the literature on adaptive strategy and sustainability in the fertilizer industry under VUCA conditions using PRISMA-based SLR, Biblioshiny-assisted bibliometric analysis, and an integrated literature review matrix. The evidence indicates that sustainability, digital transformation, supply chain resilience, fertilizer/ammonia/nitrogen, adaptive strategy, and VUCA uncertainty dominate the field. However, the literature remains insufficiently integrated at the strategy level, particularly for national fertilizer industries facing imported input dependency, energy volatility, subsidy governance, logistics challenges, and decarbonization pressure.

The main contribution is an integrative framework connecting VUCA-driven pressures, dynamic capabilities, supply chain resilience, adaptive strategic responses, and sustainability performance. Future studies should empirically test the propositions in national fertilizer companies and develop decision models that jointly evaluate productivity, cost, emissions, resilience, and supply stability

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