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The Impact of Energy Price Volatility on Industrial Performance: A Review of Energy Efficiency and Renewable-Energy Adoption

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Abstract

The increasing volatility of global energy markets has created significant challenges for industrial sectors by increasing production costs, reducing competitiveness, and threatening operational stability. This study investigates how energy price volatility influences industrial performance and examines the roles of energy efficiency and renewable-energy adoption as adaptation mechanisms. A systematic literature review (SLR) was conducted based on 298 peer-reviewed articles published between 2020 and 2026 from Scopus, Web of Science, ScienceDirect, and Google Scholar. The selected studies were analyzed using thematic synthesis to identify major research trends, causal mechanisms, and emerging research gaps. The findings reveal that energy price volatility represents a critical external shock affecting industrial performance through increased operational costs, supply-chain disruption, investment uncertainty, and reduced competitiveness. However, the literature also demonstrates that firms can reduce vulnerability through internal adaptation capabilities. Energy efficiency functions as a strategic capability by reducing energy intensity, improving operational flexibility, and mitigating cost pressures, while renewable-energy adoption provides a buffering mechanism by diversifying energy sources and reducing dependence on volatile fossil-fuel markets. The review integrates Resource Dependence Theory, Resource-Based View, Dynamic Capability Theory, and Natural Resource-Based View to explain how industrial firms transform energy uncertainty into resilience capabilities. The study highlights that future industrial competitiveness will depend not only on access to affordable energy but also on firms' ability to develop adaptive energy strategies, digital energy-management capabilities, and sustainable energy systems. This review provides a

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conceptual foundation for understanding industrial resilience under increasing global energy uncertainty.

Keywords: Energy price volatility, Industrial performance, Energy efficiency, Renewable-energy adoption, Industrial resilience.

1. Introduction

The global energy market has entered a period of unprecedented uncertainty, creating significant challenges for energy-intensive industries. Between 2021 and 2023, global energy prices experienced extreme fluctuations, with natural gas prices in Europe increasing by more than 400% compared with pre-crisis levels [1], [2], [3], while electricity prices in several industrial economies reached historical highs due to supply disruptions and geopolitical tensions. The International Energy Agency (IEA) reported that global energy investment reached approximately USD 3 trillion in 2024 [4], [5], [6], reflecting accelerated spending on both clean energy and energy-security measures. However, energy demand continues to rise, with global electricity consumption projected to grow by around 3.6% annually between 2026 and 2030 [7], [8], driven by industrial expansion, electrification, artificial intelligence infrastructure, and data-center development. This growing imbalance between energy demand, supply security, and price stability has increased uncertainty for industries that depend on reliable and affordable energy.

Industrial sectors are among the most vulnerable to energy-price volatility because energy costs represent a substantial portion of production expenses. In energy-intensive industries such as steel, cement, chemicals, ceramics, and food processing, energy-related costs can account for approximately 20–40% of total production costs, depending on technology and regional energy prices [9], [10]. Previous evidence indicates that sudden energy-price increases can reduce industrial competitiveness by increasing operational costs, decreasing profit margins, and forcing firms to reduce production or postpone investment [11]. For example, during the 2022 European energy crisis, several manufacturing industries reduced production capacity due to sharply increased electricity and natural-gas costs [12], [13]. These challenges demonstrate that energy-price volatility is not only an energy-market issue but also a major industrial-performance problem affecting productivity, profitability, and operational resilience.

To address increasing energy uncertainty, industrial firms are increasingly adopting energy-efficiency improvements and renewable-energy strategies as mechanisms to reduce vulnerability. Energy-efficiency measures can reduce industrial energy consumption by approximately 10–30% through improved equipment, process optimization, energy monitoring, and waste reduction, while renewable-energy adoption can decrease dependence on unstable fossil-fuel markets by diversifying energy sources [1], [14]. The International Renewable Energy Agency (IRENA) reported that global renewable-power capacity reached more than 4,400 GW by 2024 [15], [16], reflecting rapid expansion of alternative energy systems. However, existing studies provide fragmented evidence regarding whether energy efficiency and renewable-energy adoption effectively protect industrial performance during periods of energy-price instability. Therefore, this systematic literature review aims to synthesize current knowledge on how energy-price volatility influences industrial performance and how energy efficiency and renewable-energy adoption contribute to industrial resilience.

2. Methods

2.1 Review Design

This study employed a systematic literature review (SLR) approach to examine the relationship between energy price volatility and industrial performance, focusing on the roles of energy efficiency and renewable-energy adoption (as shown in **Table 1**). The SLR approach was selected because research on energy crises, industrial competitiveness, and sustainability responses covers multiple disciplines, including energy economics, industrial management, and environmental studies [17].

Table 1. Literature Search Strategy and Database Sources

Component	Description
Review objective	To identify and synthesize studies examining the relationship between energy price volatility, industrial performance, energy efficiency, and renewable-energy adoption
Literature databases	Scopus, Web of Science, ScienceDirect, and Google Scholar
Publication period	2020–2026
Publication type	Peer-reviewed journal articles
Language restriction	English-language publications
Research fields	Energy economics, sustainability, industrial management, environmental research, and renewable-energy studies
Search approach	Keyword-based search using Boolean operators (AND, OR)
Main research concepts	1. Energy price volatility 2. Industrial performance 3. Energy efficiency 4. Renewable-energy adoption
Main search string	("energy price volatility" OR "energy price shock" OR "energy cost uncertainty") AND ("industrial performance" OR "manufacturing performance" OR "firm performance") AND ("energy efficiency" OR "renewable energy adoption")
Additional keywords	Energy-price instability, energy-market uncertainty, energy management, energy intensity, renewable integration, clean energy adoption, industrial resilience

Through systematic identification, selection, and synthesis of previous studies, this review aims to identify major research themes, existing knowledge, and research gaps related to industrial responses to energy uncertainty. The review process consisted of four main stages: literature identification, study selection, data extraction, and thematic synthesis. This approach was used to understand how energy-price fluctuations influence industrial outcomes and how firms develop adaptation strategies to improve resilience.

2.2 Literature Search Strategy

A structured literature search was conducted using four academic databases: Scopus, Web of Science, ScienceDirect, and Google Scholar. These databases were selected due to their broad coverage of peer-reviewed studies in energy, sustainability, industrial management, and environmental research [18]. The search period covered publications from 2020 to 2026 to capture recent developments related to energy-market uncertainty, energy crises, and the transition toward renewable-energy systems. The search strategy was developed around four main concepts: energy price volatility, industrial performance, energy efficiency, and renewable-energy adoption. Additional related keywords were applied to capture variations in terminology across different research fields.

Table 2. Inclusion and Exclusion Criteria for Study Selection

Criteria Category	Inclusion Criteria	Exclusion Criteria
Publication year	Studies published between 2015–2026	Studies published before 2015
Publication type	Peer-reviewed journal articles	Conference abstracts, editorials, book reviews, non-academic publications
Language	English-language publications	Non-English publications
Research context	Industrial, manufacturing, or firm-level studies	Household, residential, or individual consumer studies
Energy-related variables	Studies examining energy price volatility, energy efficiency, renewable-energy adoption, or energy-related risks	Studies unrelated to industrial energy issues
Performance outcomes	Studies discussing productivity, costs, profitability, competitiveness, investment, resilience, or operational performance	Studies without industrial performance outcomes
Methodological quality	Studies providing clear methods and findings	Studies lacking sufficient methodological information
Publication duplication	Original research articles	Duplicate records

2.3 Study Selection Criteria

The selection process followed predefined inclusion and exclusion criteria (as shown in **Table 2**) to ensure the relevance and reliability of reviewed studies [19]. Articles were included when they were published between 2020 and 2026, written in English, peer-reviewed, and focused on industrial, manufacturing, or firm-level contexts. Selected studies were required to examine relationships between energy-related factors and industrial outcomes, including energy price volatility, energy efficiency, renewable-energy adoption, or industrial performance [20].

Table 3. Data Extraction Framework

Data Category	Extracted Information	Purpose
Bibliographic information	Author, publication year, journal name	Identify publication characteristics and research development trends
Geographic characteristics	Country/region of study	Analyze geographical distribution of evidence
Industrial characteristics	Industrial sector, manufacturing category	Identify industries most affected by energy uncertainty
Research methodology	Quantitative, qualitative, case study, modelling, review approach	Compare methodological approaches across studies
Energy-price characteristics	Energy type, volatility measure, energy shock indicator	Understand how energy uncertainty is measured
Industrial performance indicators	Productivity, production cost, profitability, competitiveness, investment, resilience	Identify consequences of energy volatility
Energy-efficiency mechanisms	Energy management, efficiency technology, energy intensity reduction, process optimization	Evaluate efficiency as an adaptation mechanism
Renewable-energy mechanisms	Renewable integration, solar adoption, alternative energy sources, energy diversification	Assess renewable energy as risk mitigation
Main findings	Key conclusions, theoretical contribution, practical implications	Synthesize evidence and identify research patterns

Studies were excluded when they focused on household energy consumption, individual behavior, transportation or residential energy systems without industrial relevance, non-academic publications, duplicate records, or studies without sufficient methodological and empirical information. The selection process involved three stages: title and abstract screening, full-text evaluation, and final inclusion of studies that directly addressed the research objectives.

2.4 Data Extraction and Analysis

A structured data extraction framework was applied to collect relevant information from each selected article [21]. The extracted data included publication characteristics, geographical context, industrial sector, research methodology, studied variables, measurement approaches, and key findings (as shown in **Table 3**). Particular attention was given to how studies measured energy price volatility, industrial performance, energy efficiency, and renewable-energy adoption. Industrial performance indicators included productivity, production costs, profitability, competitiveness, investment, and operational resilience. Due to differences in research designs and analytical approaches among studies, the extracted data were analyzed using thematic synthesis to identify recurring patterns, relationships, and research trends.

Table 4. Thematic Analysis Framework

Research Theme	Analytical Focus	Key Variables Examined	Expected Contribution
Theme 1: Energy price volatility and industrial performance	Examining how energy-market instability affects industrial outcomes	Production costs, operational expenses, profitability, productivity, competitiveness, investment decisions, resilience	Identifies the direct consequences of energy-price uncertainty on industrial systems
Theme 2: Energy efficiency as an adaptation strategy	Investigating how firms reduce vulnerability through efficiency improvements	Energy management systems, process optimization, efficient equipment, energy monitoring, energy intensity reduction, technology improvement	Explains whether energy efficiency acts as a capability that mitigates negative energy shocks
Theme 3: Renewable-energy adoption as risk mitigation	Evaluating whether renewable energy reduces dependence on volatile energy markets	Renewable investment, renewable electricity integration, energy diversification, cost stabilization, energy security	Determines whether renewable energy provides protection against energy-price instability

2.5 Thematic Analysis Framework

The thematic analysis organized the literature into three main themes based on the relationship between energy uncertainty, industrial impacts, and adaptation strategies [22]. The first theme, Energy Price Volatility and Industrial Performance, examined the effects of energy-price fluctuations on production costs, operational expenses, profitability, productivity, investment decisions, competitiveness, and industrial resilience (as seen in **Table 4**). This theme identifies the direct consequences of energy-market instability on industrial activities.

The second theme, Energy Efficiency as an Industrial Adaptation Strategy, analyzed how firms respond to energy uncertainty through energy-management systems, process optimization, efficient equipment, energy monitoring, reduced energy intensity, and technological improvements. This theme evaluates whether energy efficiency functions as a strategic capability for reducing vulnerability to energy-price fluctuations.

The third theme, Renewable-Energy Adoption as a Risk-Mitigation Strategy, examined the role of renewable-energy integration in reducing dependence on volatile conventional energy sources. The analysis focused on renewable-energy investment, renewable electricity integration, energy diversification, cost stabilization, and industrial energy resilience.

3.Results and Discussion

3.1 Overview of Literature Characteristics and Research Development

The systematic review identified 298 articles examining the relationship between energy uncertainty, industrial performance, and sustainability transformation (in Table 5). The literature distribution indicates that research attention has mainly focused on the industrial consequences of energy instability and the transition toward sustainable energy systems. The largest research theme was industrial performance and manufacturing impact, accounting for 93 studies (31.21%), demonstrating that energy-related challenges are increasingly recognized as important determinants of productivity, production costs, operational efficiency, and competitiveness. The strong concentration of studies in this area reflects growing concerns that unstable energy markets can directly affect firms' ability to maintain production continuity and competitive advantage.

Table 5. Overall Research Focus Distribution

Research Theme	Number of Articles	Percentage	Interpretation
Industrial performance / manufacturing impact	93	31.21%	Many studies discuss industrial productivity, production systems, costs, and competitiveness
Energy transition & sustainability	87	29.19%	Strong focus on decarbonization, emissions reduction, and sustainable industrial development
Energy security & policy	49	16.44%	Studies examine energy supply risks, policy responses, and governance
Energy price volatility / energy shocks	31	10.40%	Direct studies discussing energy-price instability, shocks, or energy-cost uncertainty
Energy efficiency	19	6.38%	Studies focusing on reducing energy consumption, energy intensity, and efficiency improvement
Renewable-energy adoption	19	6.38%	Studies discussing renewable integration, solar, clean energy, and alternative energy sources

The second dominant theme was energy transition and sustainability, represented by 87 studies (29.19%), highlighting increasing research interest in decarbonization, renewable-energy integration, and transformation of industrial energy systems. Meanwhile, energy security and policy studies accounted for 49 articles (16.44%), indicating that supply reliability, geopolitical risks, and regulatory responses have become important factors influencing industrial resilience. Recent energy disruptions demonstrate that industrial problems and energy crises are interconnected, where supply constraints and high energy prices increase production costs while industrial demand pressures further intensify energy-system challenges.

However, fewer studies directly investigate adaptation mechanisms. Only 31 studies (10.40%) focused specifically on energy price volatility and energy shocks, while 19 studies (6.38%) examined energy efficiency and 19 studies (6.38%) investigated renewable-energy adoption. This imbalance indicates that existing research has extensively explained the negative consequences of energy instability but provides limited understanding of how firms develop internal capabilities to reduce vulnerability.

From a theoretical perspective, this trend represents a shift from a risk-impact perspective toward a resilience-based perspective [23]. Based on Dynamic Capability Theory, energy crises represent environmental turbulence that encourages firms to sense emerging risks, adapt resources, and transform operational strategies. Therefore, future industrial competitiveness will depend not only on accessing affordable energy but also on developing capabilities that enable firms to respond effectively to continuous energy uncertainty.

3.2 Energy Price Volatility as an External Shock to Industrial Performance

The systematic review indicates that energy price volatility has become a major external shock affecting industrial performance through rising production costs, operational uncertainty, and declining competitiveness [24]. Among the reviewed studies, energy-intensive industries such as chemicals, metals, mining, manufacturing, and logistics are consistently identified as the most vulnerable sectors because their production processes depend heavily on stable and affordable energy supplies. Energy-price fluctuations directly increase electricity, fuel, and raw-material costs, which subsequently reduce profit margins, increase product prices, and weaken industrial competitiveness.

The current 2026 global energy crisis provides further evidence of this relationship, demonstrating how geopolitical instability and supply disruptions can rapidly transmit energy shocks into industrial systems [25], [26]. Recent disruptions in global oil and gas markets, including instability around major energy transportation routes such as the Strait of Hormuz, have reduced energy supply availability and contributed to elevated oil, gas, and electricity prices. These conditions have created a broader industrial cost shock rather than a limited energy-market problem, affecting manufacturing, petrochemicals, mining, semiconductors, and logistics sectors.

The industrial impact occurs through several interconnected mechanisms. First, higher energy prices increase unit production costs, particularly for energy-intensive industries where energy represents a significant operational input. Second, supply uncertainty disrupts production planning and encourages firms to delay investment decisions due to unpredictable future costs. Third, energy shocks create cascading effects throughout industrial supply chains. For example, higher natural gas and petroleum-based feedstock prices increase costs in chemical and fertilizer industries, which subsequently influence downstream manufacturing and agricultural sectors [27], [28]. Similarly, increased fuel prices raise logistics and transportation costs, creating additional pressure on global supply networks.

This relationship can be explained through Resource Dependence Theory, which argues that organizations become vulnerable when they rely heavily on external resources that are uncertain or difficult to control [29]. Energy represents a critical strategic resource for industrial firms; therefore, companies with high energy dependence have limited flexibility when energy markets experience sudden disruptions. The severity of the impact depends on several firm characteristics, including energy intensity, technological capability, financial capacity, and access to alternative energy sources.

However, the literature and recent energy crisis evidence also indicate that energy volatility produces a dual effect. While short-term consequences are mainly negative, prolonged energy uncertainty can stimulate industrial transformation by forcing firms to improve energy management, adopt efficient technologies, and diversify energy sources. The 2026 crisis demonstrates that industrial problems can also reinforce energy-system vulnerability, as rising production costs and financial pressure may delay investments in renewable energy, energy efficiency, and alternative infrastructure, potentially prolonging future energy insecurity [30], [31].

Therefore, from the perspective of Dynamic Capability Theory, energy crises should not only be viewed as external threats but also as environmental pressures that encourage firms to develop adaptive capabilities [32]. Future industrial competitiveness will depend less on avoiding energy shocks and more on the ability of firms to sense risks, restructure energy strategies, and build long-term resilience.

3.3 Energy Efficiency as a Strategic Capability for Industrial Adaptation

The reviewed studies indicate that energy efficiency represents a key mechanism through which industrial firms respond to energy uncertainty. Rather than functioning only as an energy-saving practice, efficiency improvement increasingly represents a strategic capability that enables firms to reduce energy intensity, control production costs, and maintain competitiveness during periods of energy-price instability [1]. This relationship is supported by the **Resource-Based View (RBV)**, which suggests that competitive advantages emerge from valuable and difficult-to-replicate internal capabilities [33]. Energy efficiency requires not only advanced technology but also organizational knowledge, managerial commitment, energy-monitoring systems, and continuous improvement practices [34]. Firms capable of integrating efficient equipment, digital monitoring, and optimized production processes can reduce exposure to energy-price shocks and improve operational resilience. The literature therefore supports the role of energy efficiency as a mediating mechanism:

Energy Price Volatility → Energy Efficiency → Industrial Performance

However, existing research still emphasizes technical efficiency outcomes, while organizational factors enabling efficiency implementation remain less explored. Future studies should examine energy efficiency as a dynamic capability involving digitalization, managerial decision-making, employee involvement, and smart manufacturing technologies.

3.4 Renewable-Energy Adoption as a Buffer Against Energy Volatility

Renewable-energy adoption has increasingly emerged as a strategic response to energy-price instability [35]. Industrial firms adopting renewable-energy technologies, including solar photovoltaic systems, renewable electricity contracts, biomass, and hybrid energy systems, aim to reduce dependence on volatile fossil-fuel markets and improve long-term energy security. Renewable integration allows firms to diversify energy sources, stabilize energy costs, and reduce vulnerability to external supply disruptions.

This mechanism aligns with the Natural Resource-Based View (NRBV), which explains how environmental capabilities can generate competitive advantages [36]. Renewable-energy adoption provides firms with both environmental and strategic benefits by improving sustainability performance while strengthening operational resilience. Through energy diversification, firms can reduce resource dependency and improve their ability to manage future energy uncertainty.

Nevertheless, renewable-energy adoption remains constrained by financial capability, technological readiness, and institutional support [37], [38]. Large corporations often have greater capacity to invest due to stronger financial resources, while small and medium enterprises face barriers related to investment costs and technical limitations. Therefore, renewable energy should be considered a capability influenced by organizational resources and policy environments rather than a universal solution.

3.5 Integrated Framework: Toward Industrial Energy Resilience

The reviewed evidence suggests that industrial resilience emerges from the interaction between external energy pressures and internal organizational capabilities (as shown in **Figure 1**). Energy price volatility represents an external disruption that threatens industrial stability, while energy efficiency and renewable-energy adoption function as strategic mechanisms that allow firms to absorb and adapt to these shocks. The 2026 energy crisis illustrates the importance of this resilience perspective. Industrial disruptions caused by energy shortages and price increases have created cascading effects across multiple sectors, including chemicals, mining, semiconductors, and logistics [39]. These disruptions demonstrate that modern industrial systems are highly interconnected, where energy instability in one sector can propagate through supply chains and amplify broader economic impacts.

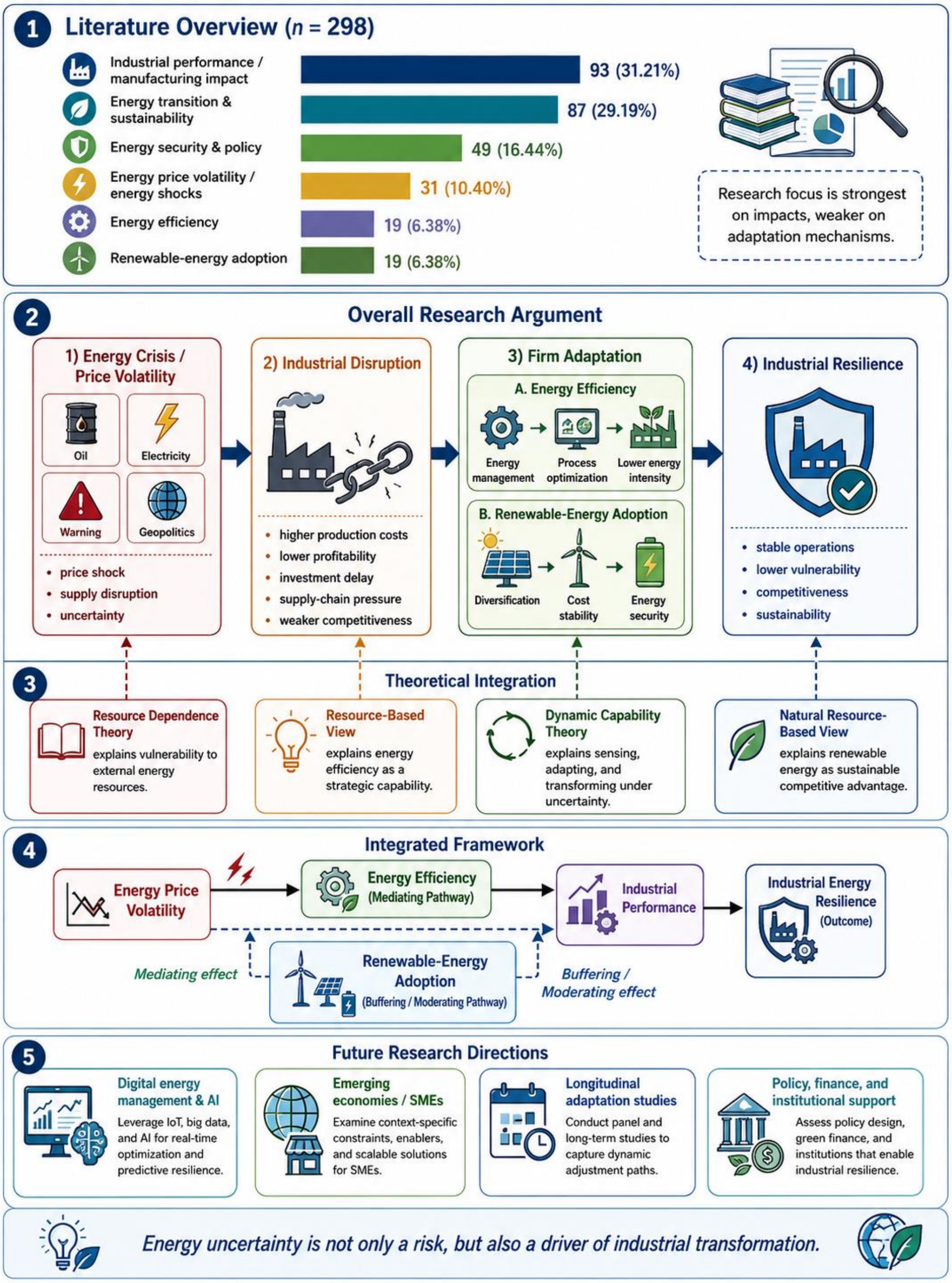

Figure 1. Infographic of overall research argument and theoretical integration

The integrated framework developed in this review combines insights from Resource Dependence Theory, Resource-Based View, Dynamic Capability Theory, and Natural Resource-Based View [40]. Resource Dependence Theory explains why firms are vulnerable because of dependence on external energy resources. Resource-Based View explains why capabilities such as energy efficiency provide competitive advantages. Dynamic Capability Theory explains how firms transform their strategies under changing environments. Meanwhile, Natural Resource-Based View explains how renewable-energy adoption supports sustainable competitiveness.

Therefore, industrial energy resilience should not be understood simply as the ability to reduce energy consumption [1]. Instead, it represents the capability to anticipate energy risks, diversify energy sources, improve operational efficiency, and continuously adapt to changing energy conditions. The current energy crisis demonstrates that firms lacking these capabilities face greater exposure to production disruption, while firms with stronger adaptive capabilities are better positioned to maintain competitiveness during periods of energy uncertainty.

3.6 Future Research Directions

Although existing studies provide substantial evidence regarding the negative effects of energy instability, several important research gaps remain. First, most studies focus on the direct impact of energy prices on industrial outcomes, while fewer studies investigate how firms adapt to energy uncertainty. Future research should therefore shift from measuring the damage caused by energy volatility toward identifying the capabilities that enable firms to remain competitive.

Second, future studies should investigate the role of digital technologies, including artificial intelligence, smart manufacturing, and real-time energy management systems. These technologies may improve firms' ability to forecast energy demand, optimize consumption, and respond dynamically to energy-market changes.

Third, current evidence remains concentrated in developed economies, while emerging industrial economies remain underrepresented. Countries with high energy-import dependence face stronger vulnerability due to infrastructure limitations and financing constraints. Future research should examine how institutional support, government policy, and financial mechanisms influence industrial adaptation.

Finally, more longitudinal studies are needed to understand how firms respond over time. Energy crises are not isolated events but part of a broader transformation of global energy systems. Understanding long-term adaptation pathways will provide deeper insights into how industries can maintain competitiveness while transitioning toward secure and sustainable energy systems.

4. Conclusion

This systematic literature review demonstrates that energy price volatility has evolved from a temporary market disruption into a long-term strategic challenge affecting industrial performance, competitiveness, and operational resilience. Analysis of 298 studies shows that energy uncertainty primarily influences industries through increased production costs, supply-chain disruptions, investment uncertainty, and reduced operational stability, particularly in energy-intensive sectors. However, the findings also indicate that firms are not passive recipients of energy shocks but can develop adaptive capabilities through energy-efficiency improvement and renewable-energy adoption. Energy efficiency acts as a strategic internal capability that reduces energy intensity and improves operational flexibility, while renewable-energy adoption provides a risk-mitigation mechanism by increasing energy diversification and reducing dependence on volatile conventional energy sources. By integrating Resource Dependence Theory, Resource-Based View, Dynamic Capability Theory, and Natural Resource-Based View, this review highlights that industrial resilience depends on the combination of technological innovation, organizational capability, and sustainable energy strategies. Future research should further investigate firm-level adaptation mechanisms, digital energy-management technologies, emerging-economy contexts, and longitudinal responses to energy disruptions to better understand how industries can maintain competitiveness during the transition toward more secure and sustainable energy systems.

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Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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