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ORIGINAL ARTICLE

Integrated Risk Management for Energy Efficiency: A Case Study of Batam's Manufacturing Sector

Ayub Timba[1], Erkata Yandri[1,2,*], Omrie Ludji[1], Rendy Sidharta[1], Clizardo Amaral[1] and Ratna Ariati[1,2]

[1]Graduate School of Renewable Energy, Darma Persada University, Jl. Radin Inten 2, Pondok Kelapa, East Jakarta 13450, Indonesia; [2]Center of Renewable Energy Studies, School of Renewable Energy, Darma Persada University, Jl. Radin Inten 2, Pondok Kelapa, East Jakarta 13450, Indonesia

* Correspondence: erkata@gmail.com

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Abstract

The manufacturing sector in Batam faces increasing pressure from rising energy costs and operational inefficiencies. This study investigates how integrating risk management frameworks, specifically ISO 31000 and FMEA, can enhance energy efficiency in manufacturing operations. A mixed-methods approach was employed, combining quantitative analysis of energy consumption data from selected firms with qualitative insights from interviews with key industrial stakeholders. Baseline energy performance was established, and operational risks were assessed and prioritized. Findings show that outdated machinery, poor maintenance, and unplanned downtimes significantly contributed to energy inefficiency. Implementation of risk-based interventions led to measurable improvements in energy use and cost reduction. Firms adopting the integrated approach reported that 15% energy saving in PT X results in operational cost savings of $ 29.994, and 10% energy saving in PT Y results in operational cost savings of $ 23.952. The Return on Investment (ROI) from implementing an integrated energy risk management strategy is estimated to reach 18 months to 20 months, based on reduced energy consumption and increased productivity. The study underscores the importance of tailored risk-energy frameworks in industrial settings and suggests avenues for future research in broader contexts.

Introduction

Batam has emerged as one of Indonesia's key manufacturing centers, strategically positioned near major international shipping routes and supported by robust industrial infrastructure. This positioning has attracted domestic and multinational manufacturing enterprises, making Batam a critical node in Indonesia's economic development [1,2]. However, the region's rapid industrial growth has escalated energy consumption and operational costs, posing significant challenges to energy efficiency and sustainability [3,4]. At the same time, global sustainability agendas and stricter environmental regulations have elevated energy efficiency as a strategic priority, essential not only for cost reduction but also for ecological compliance and maintaining international competitiveness [5–7]. Over the past decade, researchers have explored the integration of risk management into energy efficiency strategies, particularly in the manufacturing sector [8–10].

Over the past decade, researchers have explored the integration of risk management into energy efficiency strategies, particularly in the manufacturing sector [9,11,12]. Studies from developed regions, such as those by Azevedo et al. in Europe and Zhang et al. in China, highlight the effectiveness of applying risk-based frameworks such as ISO 31000 and Failure Mode and Effects Analysis (FMEA) to reduce energy losses and production downtime [13-15]. These studies demonstrate that proactive risk identification and mitigation can improve energy performance and operational reliability, especially when managing critical equipment and process disruptions. However, much of the existing literature is concentrated in developed industrial settings with mature regulatory and technological ecosystems [16,17]. This finding underscores the critical role of risk identification, assessment, and mitigation in manufacturing. In contrast, there is limited understanding of how such frameworks perform in the developing manufacturing environments of Southeast Asia, including Batam. Industrial firms in Batam often face different structural challenges, such as fluctuating energy supply, reliance on aging machinery, and less formalized risk governance. These contextual factors raise essential questions about the adaptability and effectiveness of internationally recognized risk-energy integration strategies in such settings.

To address this gap, this study investigates how integrated risk management approaches specifically ISO 31000 and FMEA can enhance energy efficiency in Batam’s manufacturing sector [9,18,19]. The research combines international frameworks with local insights to assess their practical application, aiming to reduce operational costs and support sustainable industrial development. The study’s findings contribute to the evolving discourse on risk-informed energy management in emerging economies and offer actionable strategies for policy and practice.

Materials and Methods

This study adopts a mixed methods approach, integrating quantitative and qualitative techniques to develop a comprehensive understanding of how integrated risk management frameworks influence energy efficiency within the manufacturing sector in Batam, Indonesia [20]. The quantitative component analyzes operational data and energy performance metrics, while the qualitative component explores stakeholder perspectives through in-depth interviews and structured surveys. The rationale for using a mixed methods design lies in its ability to triangulate findings, where numerical evidence is complemented by contextual insights, enabling a more holistic exploration of both technical and managerial aspects of energy efficiency [9,21].

Data were collected from a combination of primary and secondary sources. Quantitative data included Energy usage records, Energy cost statistics, Production output data, and Carbon footprint metrics. These were obtained from internal company reports and verified against public databases. Qualitative data were collected through Semi-structured interviews with key personnel such as operations managers, energy supervisors, maintenance engineers, and sustainability officers. Structured surveys were designed to capture perceptions of energy-related risks, decision-making behavior, and organizational readiness for adopting energy-saving technologies [21,22].

In addition, comparative case studies were conducted with large-scale manufacturing companies in Batam that had implemented energy conservation measures or renewable energy solutions. These case studies enriched the analysis with contextual examples and strategic variations across industries.

The risk management approach applied in this study is primarily based on the ISO 31000:2018 standard, supported by technical diagnostics using Failure Mode and Effects Analysis (FMEA) and risk classification through a Risk Matrix [23,24]. FMEA was used to systematically identify and evaluate potential failure modes in energy-intensive processes that could lead to inefficiencies or excessive energy consumption. Each mode was assessed based on severity, occurrence, and detection, generating a Risk Priority Number (RPN) for prioritization. A Risk Matrix was applied to visualize and classify risks based on probability and impact, guiding mitigation strategies. SWOT analysis was used to contextualize energy risk responses, identifying internal strengths and weaknesses alongside external opportunities and threats affecting implementation [25-27]. This framework, partially adapted from ISO 55000 (Asset Management Standard), follows a structured multi-stage process: Risk Identification through energy audits and operational diagnostics; Risk Assessment, using severity, likelihood scoring, and asset criticality evaluation; Risk Prioritization, based on process impact, energy usage profiles, and downtime risks; Risk Mitigation, including predictive maintenance, equipment modernization, automation, and energy optimization interventions [28]. The entire process is visualized in Figure 1, which outlines the sequential flow of the risk-based energy management strategy implemented in selected case companies.

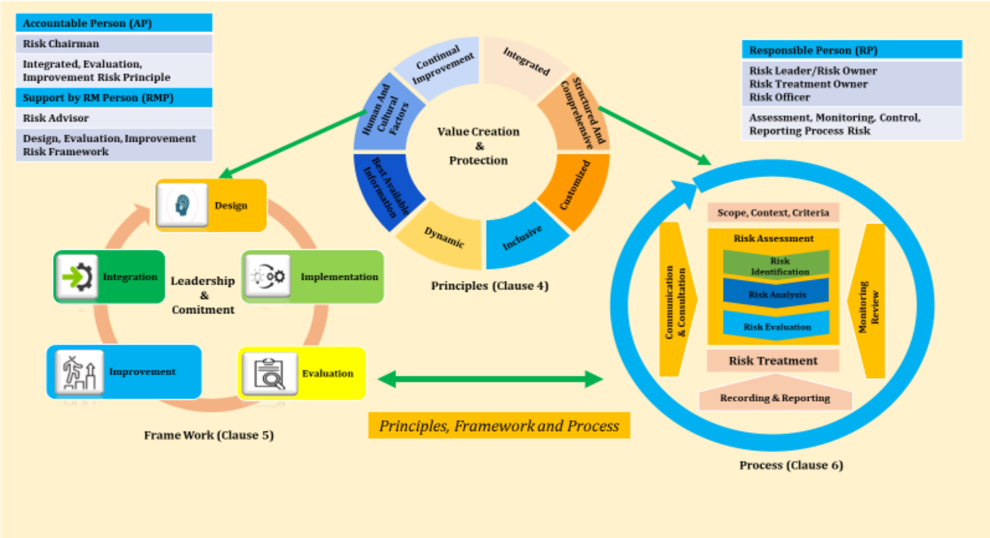

Figure 1. Risk management concept framework (ISO 31000; ISO 55000).

To evaluate the effectiveness of the proposed risk-based energy strategy, a set of Key Performance Indicators (KPIs) was used, including Energy consumption per unit of output (kWh/unit), Energy cost per unit of production (USD/unit), Percentage reduction in total energy use post-intervention (%) [27]. A comparative analysis was conducted between baseline (pre-intervention) and post-implementation performance data to assess energy efficiency improvements.

The statistical analysis was complemented by operational feedback from stakeholders to validate observed changes. IoT-based energy management systems and real-time monitoring software were deployed to support continuous data acquisition and performance tracking. These tools enabled Continuous monitoring of energy consumption across production lines, Early detection of abnormal usage patterns, Real-time visualization of KPI trends, and Enhanced decision-making through data-driven diagnostics and predictive alerts [28,29]. These digital systems provided operational transparency and accountability, ensuring corrective actions were effectively implemented and monitored over time.

Results and Discussion

The integration of risk management into energy efficiency strategies in Batam's manufacturing sector was operationalized through a structured, technology-based approach supported by comprehensive risk evaluation, as visualized in Figure 2. Specialized software tools and energy management systems were deployed to link risk indicators with energy performance metrics, enabling companies to identify critical inefficiencies and implement targeted mitigation strategies [29]. The effectiveness of these interventions was assessed through a comparative analysis of energy consumption, operational costs, and productivity before and after implementation [30].

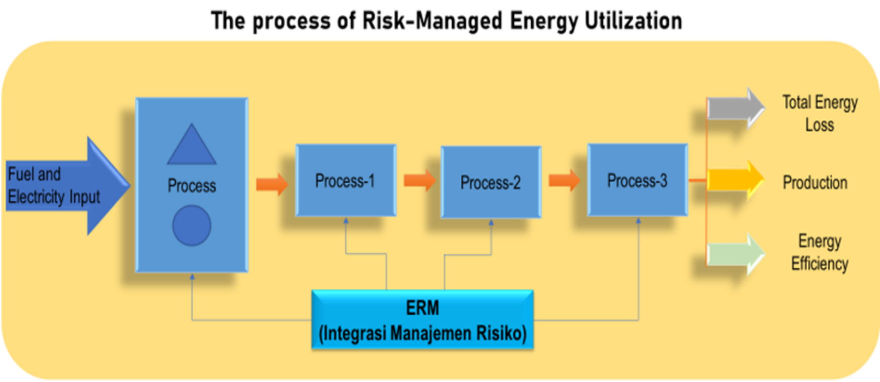

Figure 2. Concept of risk management integration into industrial processes.

Given that Batam's unique industrial ecosystem has developed since the 1970s as a special economic zone (SEZ), the strategic integration of energy risk management is timely and essential. With fiscal incentives, modern infrastructure, and proximity to international trade routes, Batam houses various energy-intensive industries such as electronics, shipbuilding, and oil and gas. As Shown in Table 1 provides an overview of Batam's major industrial sectors, associated energy challenges, and strategic opportunities.

Table 1. Overview of industry in Batam.

Industrial Sector	Description	Challenge	Opportunity	Amount
Manufacturing	Producing electronic components, telecommunications equipment, automotive, and household appliances. Many international companies have established factories in Batam.	Rising operating costs, especially energy. Competition with neighboring countries such as Vietnam and Thailand.	Adopting green technology and automation to improve efficiency. Global demand for electronic products is growing.	375
Oil and Gas	Focus on the construction and maintenance of oil drilling vessels and offshore platforms. The oil and gas industry involves global operating companies.	Global investment decline in the oil and gas sector due to the energy transition to renewable sources	Development of renewable energy technology and oil exploration in the Southeast Asia region.	58
Shipping and Maritime	Shipbuilding, repair and maintenance center for commercial and industrial vessels. Logistic services for the offshore oil and gas industry.	Global economic fluctuations affect demand in the maritime industry. Competition from countries with lower labor costs.	Batam's strategic position on international shipping routes increases demand for maritime and shipping services.	80
Technology and Communication	Growing as a base for high-tech companies and information and communication services. Focus on IT outsourcing and electronics production for export.	Technological competition with Singapore and other neighboring countries. Limited workforce with high technology skills.	Taking advantage of global outsourcing trends and Southeast Asia's rapidly growing technology market.	60
				220

Industrial Sector	Description	Challenge	Opportunity	Amount
Tourism and Hospitality	A tourist destination with a focus on resorts, golf courses and shopping malls. Attracts tourists from Singapore and Malaysia.	Dependence on foreign tourists and vulnerability to changes in international travel policies. The global pandemic has reduced tourist volumes.	Recovery of the tourism sector post-pandemic and diversification of tourist attractions to attract domestic and international tourists.	
Logistics and Distribution	Logistics and distribution center for international trade, especially between Indonesia and Singapore. Ports and airports that support regional trade.	Congestion of port and airport infrastructure, and increased logistics costs due to changes in regional policies.	Expanding logistics capacity and taking advantage of the ever-increasing international trade routes, especially with the existence of Special Economic Zones.	115
Supporting Infrastructure	Batu Ampar Port, Hang Nadim International Airport, and Batamindo and Sekupang industrial areas. Infrastructure supports connectivity and efficiency	Infrastructure capacity constraints face increasing industrial demand. Need for improved transportation and logistics facilities.	The development of new infrastructure and improving the quality of services will open up more investment opportunities in the future.	31

The study found that companies applying integrated risk-energy strategies achieved significant efficiency gains. For instance, a major electronics manufacturer in Batam reported an 18% reduction in energy consumption over the past three years through regular energy audits, predictive maintenance, and installing renewable energy systems such as solar PV and biomass [14,32].

The implementation of Enterprise Risk Management (ERM), including measures like energy supply diversification and long-term contracts with suppliers, helped stabilize operational costs [27]. As show in Table 2 highlights key sectors at high risk of energy inefficiencies, particularly electronics manufacturing and oil and gas, where energy losses are most pronounced. Tourism-related industries, including hospitality and recreation, also face significant risks due to high energy demand.

Table 2. Implementation of Risk Management in energy saving in the industrial sector in Batam.

Industrial Sector	Energy Loss Risk Factors	Potential Impact	Mitigation Mechanism
Electronics Manufacturing	Production machines are worn out or inefficient.	Increase in operating costs.	Regular energy audits
	Large dependence on electrical energy.	*downtime* due to system failure.	Use of energy-saving technologies such as automatic machines.
			The use of green technologies such as solar and wind or other green alternative energy.
Oil and Gas	Offshore platform operations require large amounts of energy.	Oil and gas production losses.	Backup power plant.
	Power outages or disruptions to energy supply.	Safety and security risks at drilling facilities.	The use of green technologies such as solar

Industrial Sector	Energy Loss Risk Factors	Potential Impact	Mitigation Mechanism
			and wind or other green alternative energy.
			IoT based energy management.
Shipping and Maritime	Inefficient use of ship fuel.	High fuel costs.	Optimization of ship routes.
	Energy-intensive port infrastructure.	Increased pollution from carbon emissions.	Implementation of renewable energy in Port facilities (solar panels, wind, or other green energy).
Technology and Communication	Data Centers and servers require large amounts of electrical power.	Increase in operating costs.	Implementation of energy-efficient cooling systems.
	IT infrastructure is less efficient.	*Downtime* affecting IT and communications services.	Transition to more efficient servers (Green Data Centers).
			Use of green energy sources such as solar panels or other green energy.
Tourism and Hospitality	High electricity consumption from hotels, resorts and recreational facilities.	Energy costs are rising.	Installation of energy sensors for power management.
	Dependence on air conditioning and large appliances.	Disruption of services for tourists in the event of a blackout.	Use of green technology, such as solar panels or other green energy.
Logistics and Distribution	Warehouses and storage facilities are energy intensive.	Transportation costs are increasing.	Implementation of IT-based logistics management.
	Inefficient transportation system.	Increased carbon emissions due to inefficient fuel use.	Replacing logistics vehicles with electric fleets.
Supporting Infrastructure	Excessive electricity usage in factory facilities.	Rising energy costs.	Real-time energy monitoring.
	Inability to control energy usage per machine.	Decreased productivity due to energy failure.	Implementation of automatic control systems throughout industrial facilities.
			Use of green energy such as solar panels, or other green energy.

Several large-scale firms in Batam have adopted ERM frameworks aligned with ISO 31000 and COSO. ERM provides a structured mechanism to identify, assess, and respond to risks impacting energy use, cost, and compliance [22,31]. This section outlines the step-by-step tools and methods used to quantify energy optimization, including energy audits, downtime analysis, and Failure Mode and Effects Analysis (FMEA), in accordance with Table 3.

Table 3. Energy optimization measurement steps through the application of risk management.

Step	Measurement	Tools/Methodology	Objective
Implementation of energy performance indicators	Energy consumption per unit of production (kWh/ton)	Historical energy consumption analysis	Identifying energy baselines for efficiency measurement
	Total energy used (kWh)	Energy Management System (EnMS)	
	Carbon emissions (CO2 per unit of energy)		

Step	Measurement	Tools/Methodology	Objective
Energy risk identification	Risk of equipment failure Energy Costs Fluctuate Environmental regulatory risks	*Failure Modes and Effects Analysis* (FMEA) SWOT Analysis	Identifying sources of risk that affect energy efficiency
Risk assessment and its impact	Probability of risk Impact on energy consumption and operating costs	Company Risk Profile equipped with risk matrix	Prioritize the most significant energy for mitigation
Implementation of mitigation strategies	Preventive maintenance Adoption of energy-saving technologies	Predictive maintenance system IoT for real-time monitoring	Reduce downtime and prevent energy waste due to breakdowns
Monitoring and re-measurement	Changes in energy consumption Energy efficiency after risk mitigation	Energy per unit output compared to baseline	Evaluate the success of mitigation strategies and adjust actions

In the manufacturing industry in Batam, ERM can provide many benefits, especially considering the operational complexity and challenges faced, such as energy cost fluctuations, market competition, and strict environmental regulations [32]. Details companies that have successfully implemented ERM, showing a maturity trend among large industrial players. These companies exhibited more robust documentation of risk profiles and demonstrated higher awareness of how risk factors such as equipment failure or energy market volatility impact performance Table 4. Furthermore, these general parameters will be identified and assessed in a document containing risk profile results or risk studies and an assessment of the company's maturity index. The focus of the discussion is how the implementation of ERM has been carried out by Large-Scale Manufacturing Companies in Batam.

Table 4. ERM implementation and main focus industrial sector in Batam.

Industrial Sector	Energy Loss Risk Factors	Mitigation Mechanism
Electronics and Energy	ERM implementation to manage operational risk, energy efficiency and regulatory compliance	Energy risk management, machine maintenance, and downtime risk mitigation in the production process
Electronic	Implementing ERM to reduce operational risks and manage supply chains efficiently	Supply chain risks, energy efficiency, compliance with environmental regulations and occupational health
Oil & Gas, Shipping	Application of ERM for risk management of large projects in the energy and shipping sectors	Project risk management, environmental compliance and energy management in shipyard and fabrication operations
Oil & Gas (Pipe Fabrication)	ERM is implemented to manage financial, operational and compliance risks to international safety standards.	Operational risk management, safety regulatory compliance, and energy efficiency in the fabrication process.
Electronics and Components	Application of ERM in risk management related to global supply chains and electronics manufacturing operations	Supply chain risk, production optimization, energy management, and crisis management.
Industrial & Manufacturing Area	ERM is used to manage operational and financial risks in the Batmindo industrial area which includes many factories.	Infrastructure risks, energy services and efficiency in industrial area management

Industrial Sector	Energy Loss Risk Factors	Mitigation Mechanism
Electronics and Technology	Using ERM to manage production risks, energy efficiency, and compliance with global standards	Energy risk management, production optimization and electronic component supply chain efficiency
Shipping and Oil & Gas	ERM is applied to manage operational, safety and sustainability risks in shipyard facilities.	Project safety risks, energy efficiency in production facilities, and compliance with environmental standards

Based on energy consumption data collected from several factories in Batam, energy consumption patterns in the manufacturing sector show varying trends depending on the type of industry and technology used [13,33]. In this study, energy consumption is monitored through an energy management system that measures energy use per unit of output in various factories, including electronics, shipyards, and assembly [21]. The result (Table 5) presents average energy consumption levels across different industrial sectors, highlighting the energy intensity of electronics and shipyard operations.

Table 5. Energy consumption in Batam manufacturing sector.

Manufacturing Sector	Energy Consumption (kWh/year)	Unit Output Per Year	Energy Consumption per Unit (kWh/Unit)
Electronic	1.200.000	15	8
Shipyard	950	85	11
Machine Assembly	750	90	8.33

Some of the key areas of energy inefficiency in these factories include using old technology machines, poor equipment maintenance, and high operational downtime due to emergency repairs [18,29]. The percentage on Table 6, to view of downtime that directly impacts energy performance. In the electronics and shipbuilding sectors, downtime due to unplanned maintenance and machine failure remains a major contributor to inefficiency.

Table 6. Percentage of energy inefficiency findings.

Inefficiency Area	Percentage Downtime
Poor maintenance	25%
Equipment Failure	35%
Operational Error	20%

The results (Table 7) Risk assessments conducted through FMEA revealed that equipment failure (35%), scheduled technical downtime (30%), and operational errors (20%) were primary contributors to energy inefficiency. These factors disrupt production and increase baseline energy consumption, particularly in high-load systems.

Table 7. Indentified risk.

Risk Factors	Impact on Energy Consumption (%)
Equipment Failure	35%
Unplanned Downtime	30%
Operational Error	20%

Two companies' case studies illustrate the measurable impact of applying structured risk management: PT X implemented FMEA and predictive maintenance, reducing downtime and achieving a 15% increase in energy efficiency; PT Y, using COSO-based ERM, improved coordination between departments and reduced energy use by 10% through enhanced maintenance practices [18,31,34]. According to Table 8 shows before-and-after energy consumption values, with PT X reducing energy use from 8 kWh to 6.8 kWh per unit, a 15% savings.

Table 8. Impact of risk management on energy efficiency.

Period	Energy Consumption per Unit Output (kWH)	Subtraction (%)
Before implementing risk management	8	-
After the implementation of risk management	6,8	15%

Comparative analysis (Table 9) shows that firms adopting integrated risk frameworks reduced energy use by an average of 12%, versus just 5% in firms relying on conventional energy-saving programs [18,35].

Table 9. Factory with and without integrated risk management.

Factory Type	Energy Savings (%)
With integrated risk management	12%
Without risk management	5%

Energy efficiency improvements translated into substantial cost savings. At PT X, a 15% reduction in energy usage led to operational savings of USD 29,994, while PT Y's 10% reduction yielded USD 23,952 (Table 10) [36,37]. These savings resulted in a Return on Investment (ROI) of approximately 18–20 months, indicating that integrated energy-risk strategies offer technical and environmental benefits and strong economic justification.

Table 10. Energy savings at PT X and PT Y.

Manufacturing	Energy Savings (%)	Cost Savings ($)	Energy Savings (%)
PT. X	15%	29.994	12%
PT. Y	10%	23.952	5%

Despite demonstrated benefits, several barriers to widespread implementation remain: Technological limitations: Many firms, particularly SMEs, rely on legacy systems with low energy performance [38,39]. Capital constraints and high upfront costs for energy-efficient technology deter investment, especially in sectors with thin margins; Organizational resistance, Lack of awareness, and weak coordination among departments operations, finance, and maintenance impede risk-energy integration; Regulatory compliance, Firms face increasingly stringent environmental standards but lack consistent technical or financial support to meet them [40,41]. These findings underscore the need for enhanced policy support, targeted subsidies for energy-efficient upgrades, and structured training in risk management for industry personnel.

This study demonstrates that integrated risk management frameworks significantly improve Batam's manufacturing sector's energy efficiency and cost savings. The findings support the hypothesis that structured, technology-enhanced ERM can optimize operational energy performance. Future research should focus on expanding this approach to small and medium-sized enterprises (SMEs), which represent a large segment of Indonesia's manufacturing base, and on longitudinal studies tracking ROI and sustainability impact over multiple fiscal cycles.

Conclusions

This study concludes that energy inefficiency in manufacturing companies is largely driven by operational factors such as equipment failure, unplanned downtime, and human error, especially in facilities with outdated technology or poor maintenance. Integrating risk management tools like FMEA and Risk Matrix with energy-saving strategies has proven effective, as demonstrated by PT X and PT Y, which achieved 15% and 10% energy savings respectively, resulting in notable cost reductions and an estimated ROI of 18 to 20 months. This integrated approach not only improves energy use and reduces operational costs but also supports environmental sustainability. Its wider adoption in Batam's manufacturing sector is recommended to enhance competitiveness and regulatory compliance. Future research should expand to include small and medium enterprises and other industrial regions for a more comprehensive understanding.

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