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SUPPLY CHAIN MANAGEMENT IN A CPEC COAL-FIRED POWER PROJECT: A BIBLIOMETRIC ANALYSIS AND DOCUMENT-BASED CASE STUDY OF THE SAHIWAL POWER PLANT

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ABSTRACT

The China-Pakistan Economic Corridor has played an important role in strengthening energy infrastructure and economic cooperation between China and Pakistan. Among its major energy projects, the Sahiwal Coal-Fired Power Plant is strategically significant because of its contribution to addressing Pakistan's electricity shortages and supporting industrial development. However, the supply chain management of imported-coal power plants remains an underexplored area, particularly in relation to how broader research trends can be connected to plant-level operational practices. This study examines supply chain management in the power generation sector by integrating bibliometric analysis with a document-based case study of the Sahiwal Coal-Fired Power Plant. The bibliometric analysis was conducted using publications from IEEE Xplore, ScienceDirect, Wiley, and Emerald covering the period from 2014 to 2024. VOSviewer was used to analyse publication trends, journal distribution, keyword co-occurrence, and author collaboration patterns. The case study component draws on publicly available project and industry documentation to examine supply chain management practices related to procurement, inventory management, transportation logistics, supplier relationships, performance monitoring, risk management, and sustainability. The bibliometric findings identify major research themes, including reliability and monitoring, decarbonisation, optimization under uncertainty, demand response, coal-fired technology, and smart grid systems. The case analysis indicates that the Sahiwal plant reflects several of these themes through its strategic supplier partnerships, multimodal coal transportation, inventory planning, performance monitoring, and coal-ash management practices. The study contributes by linking macro-level supply chain management research patterns with micro-level operational practices in a coal-fired power project. The findings provide practical implications for improving supply chain resilience, operational efficiency, and sustainability in power generation supply chains.

Keywords: Bibliometric analysis, coal-fired power plant, CPEC, energy supply chain, supply chain management

INTRODUCTION

The China-Pakistan Economic Corridor (CPEC) is the centerpiece of China's Belt and Road Initiative (BRI), which aims to improve accessibility and economic ties between the two nations (Naithani & Agarwal, 2023). CPEC became operational in 2015 after China and Pakistan signed 51 contracts and Memorandums of Understanding for USD 46 billion, covering energy initiatives, railway lines, road networks, and Special Economic Zones intended to stimulate trade and development (Qazi, 2022; Sharif, 2023). Among these, the energy projects are the most consequential for Pakistan, which has experienced severe power shortages that hampered industrial growth and everyday life (Yasmin & Qamar, 2013). This study concentrates on the energy dimension of CPEC rather than its wider geopolitics, because the corridor's coal-fired power plants are where supply chain management decisions most directly determine whether electricity is delivered reliably.

The Sahiwal Coal-Fired Power Plant is a flagship CPEC project comprising 2 × 660 MW coal-fired units, sponsored by Huaneng Shandong Ruyi (Pakistan) Energy and supervised by the Private Power & Infrastructure Board (PPIB) and Punjab Power Development Board (PPDB). It was completed in record time and began commercial operations in October 2017, and by January 2023 it had injected more than 41 billion units of electricity into the national grid (Sahiwal Coal Power Project, n.d.). The Sahiwal plant has been chosen for this study for three reasons. Firstly, it is the first, largest and most advanced coal fired plant of the CPEC "Early Harvest" projects and therefore is analytically interesting; secondly, it is the first coal fired plant that uses imported coal, making its supply chain unusually long and vulnerable to risks; and thirdly, detailed public documentation of the sponsors, contractors, and operations is available, which allows a credible operational history.

Supply Chain Management (SCM) plays a crucial role in coal-fired power plants because electricity generation depends on the reliable supply of coal, equipment, spare parts, logistics support, and maintenance coordination. In imported-coal power plants, SCM is particularly important because procurement, transportation, inventory planning, supplier reliability, and risk management directly influence operational continuity. However, existing SCM research in the power generation sector remains fragmented, with limited studies connecting broader research trends to the operational realities of specific imported-coal power plants.

Bibliometric studies provide useful insights into publication trends, research themes, keyword structures, and collaboration patterns, but they often do not explain how these themes are reflected in actual power plant operations. Conversely, plant-level case discussions tend to focus on operational practices without connecting them to broader research development in the field. This creates a gap between macro-level knowledge structures and micro-level supply chain practices, particularly in imported-coal power projects operating in developing economies.

Therefore, this study integrates bibliometric analysis with a document-based case study of the Sahiwal Coal-Fired Power Plant. The bibliometric component maps the development of SCM research in the power generation sector, while the case study component examines how key SCM themes are reflected in the plant's procurement, inventory management, logistics, supplier relationships, performance monitoring, risk management, and sustainability practices.

The objectives of this study are as follows:

1. To identify the dominant themes and intellectual structure of supply chain management research in the power generation sector.

2. To examine the supply chain management practices of the Sahiwal Coal-Fired Power Plant in terms of procurement, inventory management, logistics management, supplier relationships, and performance evaluation.
3. To link the bibliometric themes with the Sahiwal case in order to identify key challenges, best practices, and improvement opportunities for supply chain management in coal-fired power generation.

Case Background: Sahiwal Coal-Fired Power Plant

The Sahiwal Coal-Fired Power Plant is a major CPEC energy project located in Qadarabad, Sahiwal, Punjab. The plant has a generation capacity of 1320 MW and relies on imported coal as its main energy source, making supply chain management central to its operational reliability. The project was financed under an Independent Power Producer (IPP) arrangement and developed by Huaneng Shandong Ruyi Energy (Pakistan), a subsidiary of Huaneng Shandong Ruyi Group.

The project involved multiple stakeholders across policy, ownership, regulation, construction, operation, and local community engagement. The Government of Pakistan provided policy support, while regulatory and facilitation roles were undertaken by the Ministry of Energy (Power Division), the Private Power and Infrastructure Board, and the Punjab Power Development Board. Engineering, procurement, and construction activities involved SEPCOI Electric Power Construction, with contributions from Shanghai Electric Group, Harbin Boiler, and local construction partners. These stakeholder arrangements illustrate the complexity of supply chain coordination in large-scale CPEC energy infrastructure projects.

LITERATURE REVIEW

Supply Chain Management in Power Generation

Supply chain management (SCM) plays an important role in the power generation sector because electricity production depends on the continuous availability of fuel, equipment, spare parts, logistics support, and operational coordination. In coal-fired power plants, SCM is particularly important because the reliability of electricity generation depends on the timely sourcing, transportation, storage, and quality control of coal. Previous studies have shown that coal quality, supplier reliability, transportation infrastructure, inventory planning, and procurement coordination are key issues affecting the efficiency and continuity of thermal power operations.

In the power generation context, SCM extends beyond traditional procurement and logistics activities. It also involves risk management, performance monitoring, sustainability practices, supplier relationship management, and technology-supported decision-making. Studies on power plant supply chains have highlighted the importance of maintaining reliable supply networks, reducing lead-time uncertainty, improving inventory control, and ensuring that operational decisions are aligned with environmental and regulatory requirements. These issues are especially relevant for imported-coal power plants, where supply chains are exposed to international sourcing risks, port dependency, transportation delays, price volatility, and policy changes.

Supply Chain Risk, Sustainability, and Technology Adoption

Risk management is a central issue in power generation supply chains. Disruptions may arise from supplier failure, transportation delays, weather conditions, port congestion, regulatory changes, infrastructure limitations, and fluctuations in fuel prices. Since power plants operate continuously, such disruptions may affect electricity generation and increase operational cost. Therefore, supply chain resilience requires supplier diversification, strategic inventory, contingency planning, and continuous performance monitoring.

Sustainability has also become an important concern in power generation SCM. Coal-fired power plants face increasing pressure to reduce emissions, manage coal ash, improve waste disposal, and comply with environmental regulations. As a result, SCM decisions must consider not only cost and efficiency, but also environmental responsibility and long-term operational legitimacy. Previous studies have also discussed the role of green supply chain management, renewable energy integration, carbon reduction, and sustainable logistics in improving the environmental performance of the power sector.

Technology adoption is another major theme in the literature. Digital technologies such as Enterprise Resource Planning (ERP), Internet of Things (IoT), blockchain, artificial intelligence, predictive analytics, and transport management systems can improve supply chain visibility, coordination, forecasting, risk detection, and decision-making. These technologies support procurement planning, inventory control, supplier evaluation, shipment tracking, predictive maintenance, and performance monitoring. In this respect, digitalisation is increasingly viewed as an important enabler of supply chain resilience and operational efficiency in power generation.

Synthesis of Prior Studies and Research Gap

Overall, the literature shows that SCM research in power generation is shaped by several recurring themes, including supply reliability, optimization, sustainability, risk management, digital technology, and performance monitoring. However, prior studies remain fragmented. Some studies focus on bibliometric trends and publication patterns, while others examine specific supply chain practices, optimization models, or sustainability issues. Limited research has integrated bibliometric mapping with a plant-level case analysis to explain how broader research themes are reflected in the operational practices of a specific power generation project.

This gap is particularly relevant to the Sahiwal Coal-Fired Power Plant because it is an imported-coal CPEC power project with a long and complex supply chain. The plant depends on international coal sourcing, multimodal transportation, inventory planning, supplier coordination, performance monitoring, and environmental management. Therefore, this study integrates bibliometric analysis with a document-based case study to connect macro-level research trends with micro-level supply chain practices in a coal-fired power generation context.

Table 1 summarises selected prior studies on SCM in power generation and highlights the need for an integrated bibliometric and case-based perspective.

Table 1

Synthesis of Selected Prior Studies on SCM in Power Generation

Author(s)	Context	Method	Key finding / gap
Satapathy (2020)	Indian thermal power plants	Survey / SSCM	Identifies sustainability challenges and highlights the need for emissions reduction.
Soda and Aggarwal (2022)	Indian power industry	Empirical / GSCM	Shows that green supply chain management improves economic and environmental performance.
Kar et al. (2020)	Thermal power plants	Conceptual	Indicates that coal quality and transportation issues contribute to erosion and emissions.
Mishra and Mishra (2022)	Indian coal plants	Optimization	Highlights that multi-supplier and lead-time uncertainty may increase the risk of shortages.
Jauhari et al. (2021)	Hybrid power generation	Inventory model	Shows that sustainable energy supply chain management can reduce cost and emissions.
He et al. (2020)	Coal supply chain	Network model	Suggests that blockchain-based supply chain finance can improve coordination and trust.
Liu et al. (2023)	Virtual power plants	CVaR optimization	Shows that risk-optimized dispatch can reduce exposure to extreme-event risks.

Table 1 shows that limited research has examined SCM in power generation systems, with most prior studies focusing on Indian power generation contexts. In terms of methodology, many studies have used mathematical modelling, optimization, or survey methods. However, limited research has connected bibliometric structures with the operational practices of a single imported-coal power plant under CPEC.

RESEARCH METHODOLOGY

Research Design

This study adopted a two-stage research design that combines bibliometric analysis with a document-based case study. The bibliometric analysis was used to examine the development of supply chain management (SCM) research in the power generation sector by identifying publication trends, major journals, keyword clusters, and author collaboration patterns. This approach provides a macro-level understanding of how SCM research in power generation has evolved over time.

The second stage involved a document-based case study of the Sahiwal Coal-Fired Power Plant. This stage was used to examine how the main themes identified from the bibliometric analysis are reflected in the supply chain practices of an actual imported-coal power generation project under CPEC. The case study focused on procurement, inventory management, transportation logistics, supplier relationships, performance measurement, risk management, and sustainability practices. By combining both approaches, the study connects broader research trends with plant-level operational practices.

Data Sources and Database Coverage

The bibliometric data were collected from four major academic databases: IEEE Xplore, ScienceDirect, Wiley, and Emerald. These databases were selected because they provide broad coverage of peer-reviewed publications in engineering, energy, technology management, logistics, and supply chain management.

The use of multiple databases enabled the study to capture a wider range of relevant literature on SCM in the power generation sector.

For the case study component, data were obtained from publicly available secondary sources, including official CPEC project information, government and project-related documents, industry reports, and publicly accessible information on the Sahiwal Coal-Fired Power Plant. These documents were used to describe and analyse the plant's supply chain structure, operational processes, stakeholders, logistics arrangements, performance monitoring practices, challenges, and improvement opportunities.

Search Strategy

The bibliometric search was conducted using combinations of supply chain and power generation terms. The core search string used was:
("supply chain" OR "supply chain management" OR "SCM" OR "logistics" OR "procurement" OR "inventory") AND ("power generation" OR "power plant" OR "coal-fired" OR "thermal power" OR "energy supply" OR "electricity")

The search was applied to publication titles, abstracts, and keywords where supported by the database. The search syntax was adjusted according to the requirements of each database. When the search produced overly broad results, the records were refined by limiting them to relevant subject areas such as energy, engineering, management, logistics, and supply chain management.

Inclusion and Exclusion Criteria

The study applied specific inclusion and exclusion criteria to ensure the relevance and quality of the bibliometric dataset. Publications were included if they met the following criteria:

1. The publication was a peer-reviewed journal article or conference paper.
2. The publication was written in English.
3. The publication was published between January 2014 and April 2024.
4. The publication focused on supply chain management, logistics, procurement, inventory, risk management, sustainability, or technology adoption in the power generation or energy supply context.

Publications were excluded if they were editorials, abstracts without full text, duplicate records, non-English publications, or studies in which power generation or supply chain management was only mentioned briefly and was not central to the article. The 2014 to 2024 period was selected because it corresponds with the development of CPEC and the operational period of the Sahiwal Coal-Fired Power Plant, making it relevant to the case context.

Screening Process and Final Sample

The initial search produced approximately 760 records across the selected databases. After duplicate records were removed, approximately 690 records remained for screening. The remaining records were reviewed based on titles and abstracts to exclude publications that were not directly related to SCM in the power generation or energy supply context. The shortlisted publications were then assessed further based on their relevance to the study objectives.

The final bibliometric corpus consisted of publications that met the inclusion criteria and were suitable for mapping the development of SCM research in the power generation sector. The final records were exported in plain-text and RIS formats and imported into VOSviewer for bibliometric analysis. Table 2 summarises the article screening process.

Table 2
Summary of the Article Screening Process

Screening stage	Number of records	Description
Initial records identified	760	Records retrieved from IEEE Xplore, ScienceDirect, Wiley, and Emerald
Records after duplicate removal	690	Duplicate records removed
Records screened by title and abstract	690	Records assessed for relevance to SCM and power generation
Records excluded	128	Records excluded because they did not meet the inclusion criteria
Final records included in bibliometric analysis	562	Records included for VOSviewer analysis

Bibliometric Analysis Procedure

The bibliometric analysis was conducted using VOSviewer. VOSviewer was selected because it enables the visualisation of bibliometric networks, including keyword co-occurrence and author collaboration patterns. In VOSviewer, each item is represented by a label and a circle. The size of the circle indicates the weight or frequency of the item, the distance between items represents their relatedness, and the lines indicate links between items. Colours represent different clusters within the network.

This study conducted three main bibliometric analyses. First, publication trend analysis was used to examine the distribution of publications by year. Second, source analysis was used to identify the journals and publication outlets that contributed most frequently to the research field. Third, keyword co-occurrence analysis was used to identify dominant themes and research clusters in SCM and power generation. In addition, author co-authorship analysis was conducted to examine collaboration patterns among researchers in the field.

Case Study Analysis Procedure

The case study analysis focused on the Sahiwal Coal-Fired Power Plant as an imported-coal power generation project under CPEC. The plant was selected because it is one of the major early-harvest CPEC energy projects and depends heavily on imported coal, making supply chain management central to its operational reliability.

The case analysis was conducted by reviewing publicly available documents related to the project. Relevant information was extracted and organised according to major SCM dimensions: procurement, inventory management, transportation logistics, supplier relationships, performance measurement, risk management, and sustainability. These dimensions were then compared with the themes identified from the bibliometric analysis. This allowed the study to examine how broader SCM research themes, such as optimization, reliability monitoring, decarbonisation, coal-fired technology, and smart grid development, are reflected in the operational practices of the Sahiwal plant.

Methodological Integration

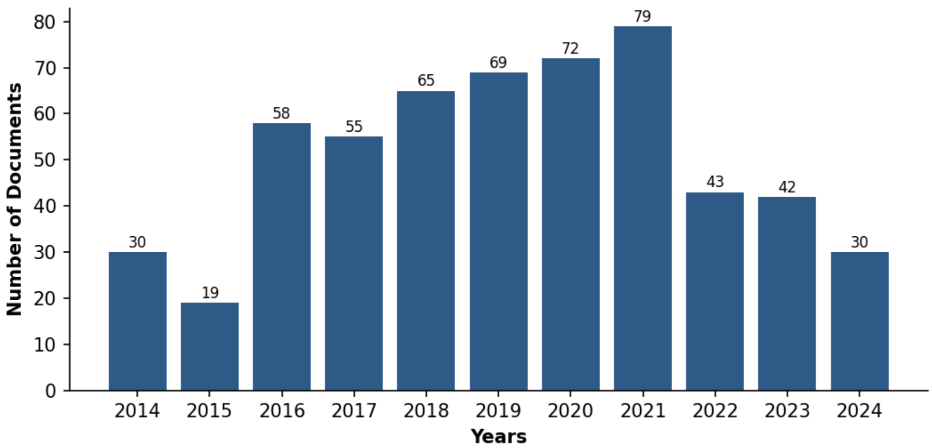
The integration of bibliometric analysis and case study analysis was conducted at the interpretation stage. The bibliometric analysis provided a macro-level map of the SCM research landscape in the power generation sector, while the case study provided a micro-level view of SCM practices in a specific CPEC coal-fired power project. This integrated approach enables the study to link academic research trends with practical operational issues, thereby addressing the gap between publication-based knowledge and real-world supply chain practices in the power generation industry.

ANALYSIS AND RESULTS

Distribution of Articles per Year

The articles included in the bibliometric corpus were published between January 2014 and April 2024. As shown in Figure 1, publication output began with 30 articles in 2014, decreased to 19 articles in 2015, and then increased sharply to 58 articles in 2016. The number of publications then remained relatively consistent, with annual output generally ranging between 40 and 80 articles. The highest publication activity was recorded in 2021, followed by a decline in 2022 and 2023. The lower number recorded in 2024 should be interpreted with caution because the data only covered publications from January to April 2024.

The publication trend suggests that supply chain management in the power generation sector has become an increasingly active research area since 2014. This pattern is consistent with the growing importance of energy security, sustainability, digital technologies, and supply chain resilience in the power sector. The sustained research output also indicates that the field has moved beyond early conceptual discussion and is developing into a more mature research stream. This justifies the use of bibliometric analysis to map the development of the literature and identify the major themes shaping the field.



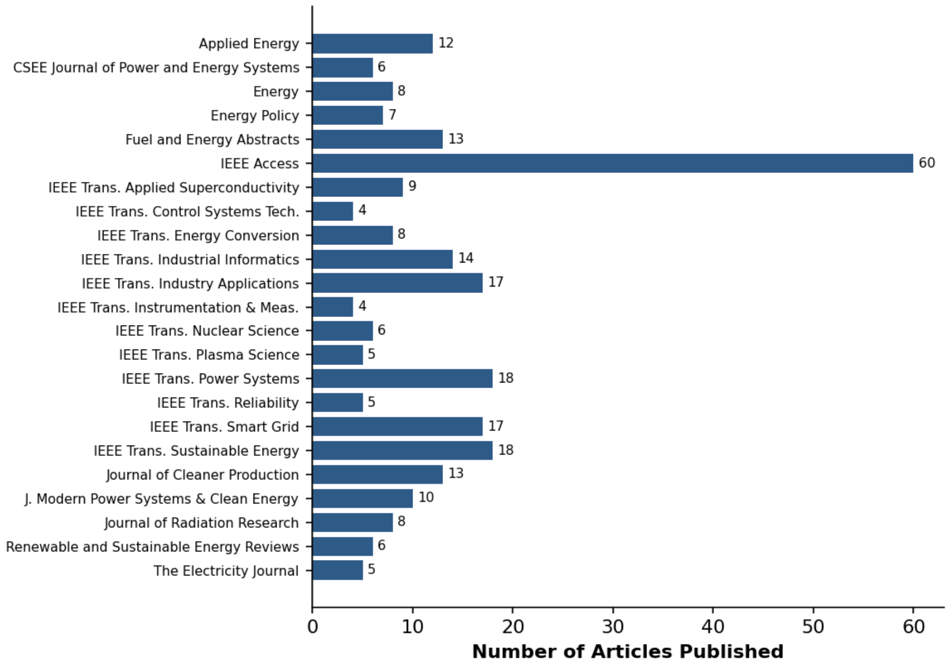
Source. Authors' bibliometric corpus (IEEE, ScienceDirect, Wiley, Emerald), 2014–2024.

Figure 1
Distribution of Articles Per Year

Most Popular Journals with Publications in the Power Generation Industry

Figure 2 presents the distribution of articles by publication outlet. The results show that IEEE Access contributed the highest number of articles in the corpus, followed by several IEEE Transactions and energy-related journals. Other relevant outlets include Renewable and Sustainable Energy Reviews, Journal of Cleaner Production, Applied Energy, Energy, and Energy Policy.

This pattern indicates that research on supply chain management in power generation is interdisciplinary. The strong presence of IEEE outlets suggests that the field is closely connected to engineering, smart grid systems, energy technologies, reliability, and digital infrastructure. At the same time, the presence of sustainability and energy policy journals indicates that environmental performance, renewable energy integration, decarbonisation, and policy-related issues are also central to the literature. Therefore, the publication outlet distribution shows that SCM research in power generation is shaped by both technical-operational concerns and sustainability-oriented concerns.



Source. Authors' bibliometric corpus (IEEE, ScienceDirect, Wiley, Emerald), 2014–2024.

Figure 2
Distribution of Articles by Publishing Journals

Most Frequent Keywords

A keyword co-occurrence analysis was conducted using VOSviewer to identify the dominant research themes in the literature. The analysis used publication keywords as the unit of analysis, with the minimum occurrence threshold set at four. As shown in Figure 3, the keyword network produced seven major clusters. These clusters represent the main thematic areas in supply chain management research related to power generation.

Cluster 1 focuses on reliability, monitoring, safety, maintenance, and power system performance. This cluster indicates that operational reliability remains a central concern in power generation supply chains.

Cluster 2 is associated with carbon emissions, climate change, renewable energy, life cycle assessment, and energy policy. This shows that sustainability and decarbonisation have become important themes in power sector supply chains. Cluster 3 focuses on optimization, uncertainty, energy storage, distributed power generation, and stochastic programming, suggesting that researchers are increasingly interested in decision-making under uncertainty and the optimization of complex power supply systems.

Cluster 4 relates mainly to wind power generation, power system stability, voltage control, and turbine-related issues. Cluster 5 focuses on demand response, electricity markets, resource management, and load management, reflecting the growing importance of market-based and demand-side approaches in energy supply chains. Cluster 6 is associated with coal-fired power plants, boilers, thermal power plants, predictive models, and reinforcement learning. This cluster is particularly relevant to the Sahiwal Coal-Fired Power Plant because it captures the coal-fired technology and operational monitoring dimension of the literature. Finally, Cluster 7 relates to smart grids, power grids, frequency control, regulation, renewable energy sources, and virtual power plants, indicating the increasing importance of digital and distributed energy systems.

Overall, the keyword analysis shows that the literature is not limited to traditional logistics or procurement issues. Instead, SCM research in power generation has expanded to include reliability monitoring, sustainability, optimization, smart grids, demand response, and digital technologies. These themes provide a useful analytical lens for examining the Sahiwal case, especially in relation to imported coal logistics, inventory planning, supplier reliability, environmental management, and technology-enabled supply chain monitoring.

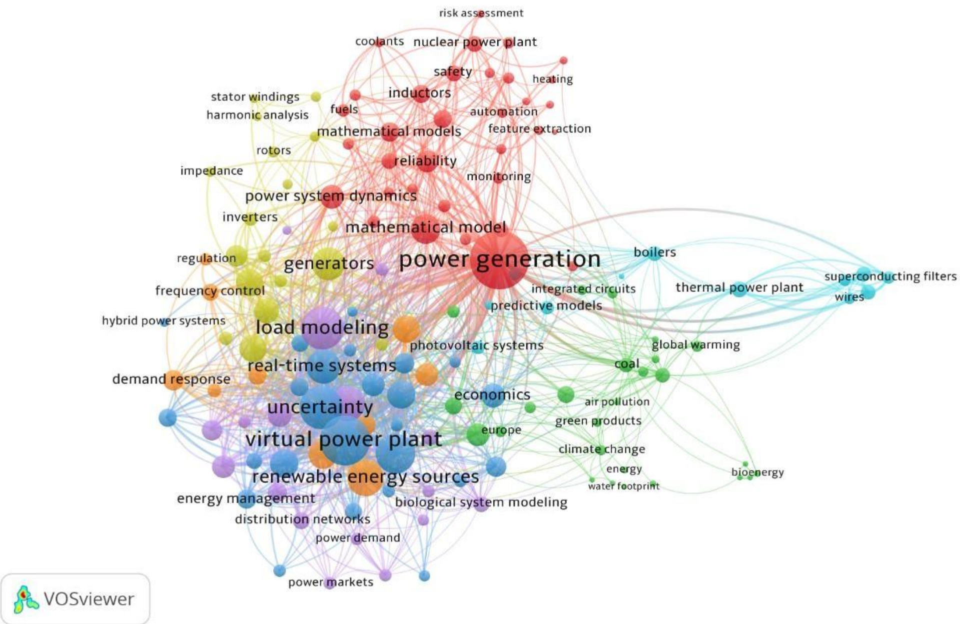


Figure 3
Most Frequent Keywords (Network Visualization)

Table 3
Clusters and Keywords

Cluster	Keywords
Cluster 1 (34 items)	adaptation models, analytical models, automation, computational modeling, coolants, data models, fault diagnosis, feature extraction, fuels, heating, inductors, inspection, maintenance engineering, mathematical model(s), monitoring, nuclear power plant (npp), power generation, power measurement, power system dynamics, power system reliability, predictive control, radiation effects, reliability, risk assessment, safety, sensitivity analysis, sensors, standards, task analysis, temperature measurement, turbines, wireless communication
Cluster 2 (26 items)	air pollution, beccs, bioenergy, carbon capture, carbon dioxide, carbon emissions, carbon tax, china, climate change, coal, energy, energy policy, europe, global warming, green products, integrated circuits, investment, life cycle assessment, microgrids, natural gas, optimal scheduling, power plant, renewable energy, supply chains, water footprint, wind energy
Cluster 3 (25 items)	aggregation, batteries, cogeneration, contracts, dispatching, distributed power generation, economics, energy management, energy storage (system), hybrid power systems, informatics, linear programming, optimization, planning, power systems, production, programming, real-time systems, robust optimization, robustness, stochastic processes, stochastic programming, uncertainty, virtual power plant
Cluster 4 (18 items)	circuit faults, generators, harmonic analysis, impedance, inverters, nuclear power generation, power system stability, reactive power, rotors, stability analysis, stator windings, voltage control, wind forecasting, wind power (generation/plant), wind speed, wind turbines
Cluster 5 (17 items)	bidding strategy, biological system modeling, buildings, demand response (dr), distributed energy resources, distribution networks, electricity market, electricity supply industry, heating systems, indexes, load management, load modeling, power demand, power markets, resource management, schedules, virtual power plant (vpp)
Cluster 6 (12 items)	boilers, coal-fired power plant, magnetic separation, photovoltaic systems, prediction algorithms, predictive models, reinforcement learning, saturation magnetization, superconducting filters, superconducting magnets, thermal power plant, wires
Cluster 7 (10 items)	costs, demand response, distributed energy resource, frequency control, power grids, regulation, renewable energy sources, smart grid(s), virtual power plants

Authors Co-Working in the Power Generation Industry

An author co-authorship analysis was conducted using VOSviewer to examine collaboration patterns among researchers in the field. The analysis used authors and co-authors as the unit of analysis, with a minimum threshold of two publications per author. Figure 4 presents the density visualisation of author collaboration in power generation supply chain research.

The density map shows several active author groups, including clusters around authors such as Y. Wang, Y. Zhang, and Y. Xu. However, the collaboration network appears fragmented, with multiple small author clusters rather than one highly integrated research community. This suggests that research on SCM in power generation is still dispersed across different technical, sustainability, and operational domains. The lack of a single dominant collaboration network may reflect the interdisciplinary nature of the field, where engineering, energy policy, logistics, sustainability, and operations management researchers contribute from different disciplinary perspectives.

This finding has important implications for future research. Greater collaboration between operations management scholars, power systems engineers, sustainability researchers, and policymakers may strengthen the development of more integrated SCM frameworks for the power generation sector. In particular, imported-coal power projects such as the Sahiwal plant require expertise that cuts across logistics, procurement, risk management, environmental sustainability, and energy system reliability.

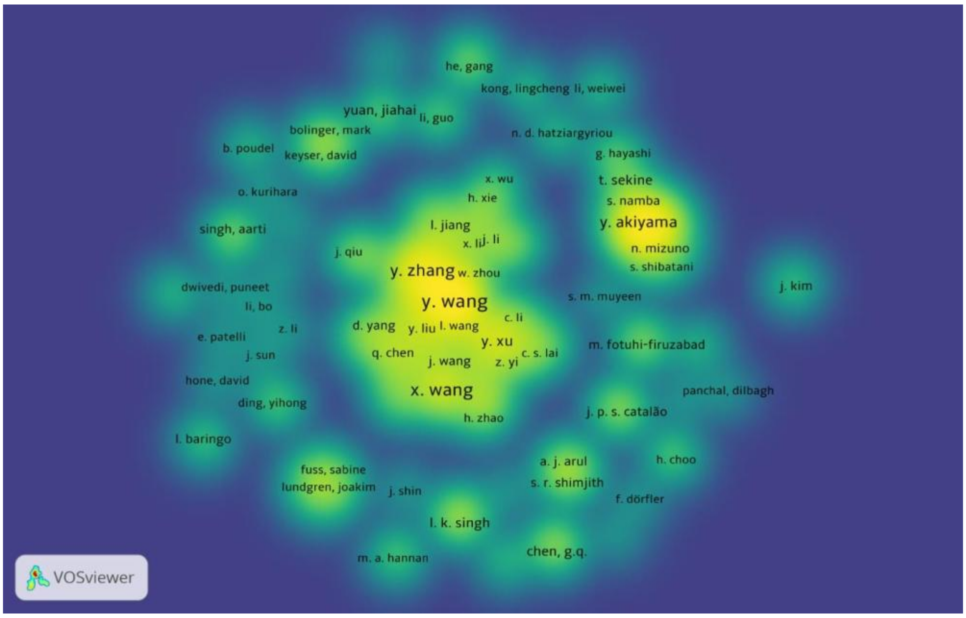


Figure 4
Authors Co-Working in Research on the Power Generation Industry (Density Visualization)

Linking the Bibliometric Themes to the Sahiwal Case

The bibliometric findings provide a useful foundation for interpreting the Sahiwal Coal-Fired Power Plant case. The seven keyword clusters show that SCM research in power generation is shaped by four broad themes that are directly relevant to the plant: reliability monitoring, sustainability and decarbonisation, optimization under uncertainty, and coal-fired power technology.

First, the reliability and monitoring theme is relevant because the Sahiwal plant depends on continuous coal supply, equipment reliability, supplier performance, and logistics coordination to maintain uninterrupted electricity generation. Second, the sustainability and decarbonisation theme is relevant because coal-fired plants face increasing environmental pressure, particularly in relation to emissions, coal ash management, and cleaner operational practices. Third, the optimization and uncertainty theme is directly connected to procurement, inventory planning, supplier lead times, transportation scheduling, and contingency planning. Fourth, the coal-fired technology theme reflects the specific operational context of Sahiwal as an imported-coal power plant.

Therefore, the bibliometric analysis does not function merely as background information. It provides the thematic structure used to interpret the case study. The following sections examine how these themes are reflected in the Sahiwal plant's supply chain design, procurement process, inventory management, transportation logistics, performance measurement, risk management, and improvement practices.

CASE ANALYSIS: SUPPLY CHAIN MANAGEMENT PRACTICES AT THE SAHIWAL POWER PLANT

Supply Chain Design and Coal Logistics

The Sahiwal Coal-Fired Power Plant represents a complex imported-coal power generation supply chain. Its supply chain involves several interconnected activities, including coal sourcing, port handling, inland transportation, warehousing, inventory control, fuel input for electricity generation, power transmission, and coal ash disposal. These activities require coordination among coal suppliers, logistics providers, plant operators, regulators, contractors, and power distributors.

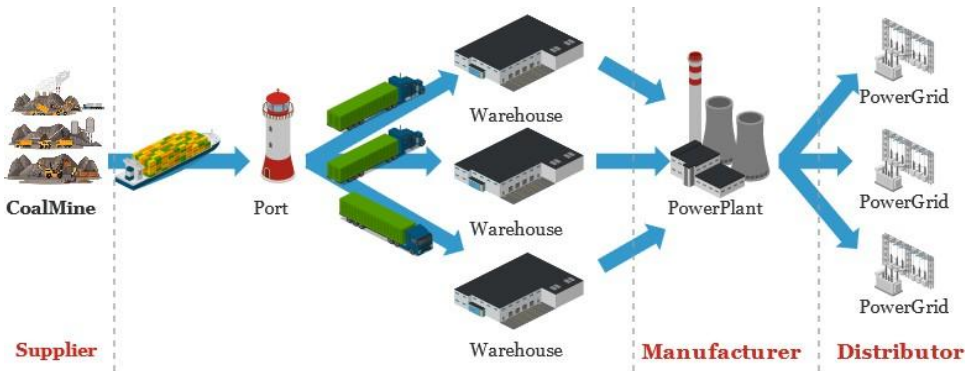


Figure 5
Supply Chain Web

As shown in Figure 5, coal is sourced mainly from overseas suppliers and transported by sea to Pakistani ports before being moved inland to the plant through rail and road networks. The supply chain is designed to ensure continuous coal availability because any interruption in fuel supply may directly affect electricity generation. Therefore, the plant's supply chain strategy focuses on three main priorities: reliable coal supply, cost-efficient logistics, and risk mitigation.

The location of the Sahiwal plant also reflects important supply chain considerations. Sahiwal is located in Punjab, an agricultural and industrially active region with access to labour, supporting infrastructure, water resources, and power distribution networks. From a logistics perspective, the plant location supports inland coal transportation and connection with power distributors. Since the plant depends on imported coal, location and transportation planning are not only technical decisions but also supply chain decisions that affect transportation cost, lead time, delivery reliability, and operational continuity.

Coal sourcing is a central element of the plant's supply chain. Similar to other imported-coal power projects in Pakistan, the plant relies mainly on coal sourced from countries such as Indonesia and South Africa. Imported coal was selected because of quality and reliability considerations, while local coal from the Thar coalfield was considered less suitable due to quality concerns such as higher lime and sulphur content. The coal transportation process involves multimodal logistics, including sea transportation, port handling, rail movement, road transportation, and final delivery to storage facilities at the plant.

The reliance on imported coal demonstrates the relevance of supply chain resilience in power generation. Long-distance coal supply chains are exposed to lead-time variation, port congestion, transportation delays, weather-related disruptions, supplier reliability issues, price volatility, and regulatory changes. These risks make logistics coordination, supplier relationship management, strategic inventory, and contingency planning essential to the plant's operational reliability.

Procurement, Inventory, and Supplier Coordination

Procurement is a critical component of the Sahiwal plant's supply chain because the plant depends on a continuous supply of coal to sustain electricity generation. The procurement process involves identifying reliable coal suppliers, specifying coal quality requirements, issuing tenders, evaluating supplier proposals, negotiating supply terms, and monitoring delivery performance. Coal quality is particularly important because it affects combustion efficiency, plant performance, emissions, and maintenance requirements.

Suppliers are assessed based on criteria such as moisture content, ash content, sulphur content, calorific value, delivery reliability, financial stability, and compliance with sustainability requirements. These criteria are important in an imported-coal supply chain because quality variation, long lead times, and logistics disruption may affect operational continuity. Supplier monitoring is therefore necessary to ensure that coal is delivered according to the required specification, quantity, and timeline.

The Sahiwal project also involved multiple contractors and suppliers across different stages of development and operation. Engineering, procurement, and construction activities involved firms such as Albario Engineering, Habib Rafiq (Pvt.) Ltd., and SEPCOI Electric Power Construction. Shanghai Electric Group supplied major equipment, including steam turbines and generators, while Harbin Boiler supplied steam boilers for the plant units. Huaneng Shandong Ruyi (Pakistan) Energy serves as the operations and maintenance contractor. These stakeholder arrangements show that supplier coordination is not limited to coal procurement but also includes equipment, spare parts, maintenance services, technical support, and operational services.

Inventory management is another important element of the plant's operational reliability. Since coal-fired power generation requires a steady input of fuel, insufficient inventory may disrupt electricity generation, while excessive inventory may increase storage and handling costs. Therefore, inventory planning must balance supply continuity, storage capacity, order lead time, demand stability, safety stock requirements, and transportation reliability.

The plant reportedly uses forecasting and inventory planning based on expected coal consumption and historical data from comparable coal-fired power plants. Safety stock is maintained to reduce the risk of stock-outs caused by delivery delays, port congestion, transportation disruption, or supplier-related problems. The manuscript also indicates that inventory planning approaches such as part-period balancing and economic order quantity are used to support replenishment decisions. However, because this study relies on secondary documentation, these practices should be interpreted as reported operational practices rather than independently verified internal procedures.

Coal storage and handling are also important for maintaining fuel quality. Poor storage practices may lead to coal degradation, contamination, moisture absorption, and handling inefficiencies. The plant reportedly uses covered storage facilities and modern handling equipment to protect coal from environmental exposure and physical damage. These practices contribute to supply chain reliability because consistent coal quality supports stable plant performance.

Performance Measurement and Technology Support

Supply chain performance measurement is important for evaluating whether the Sahiwal plant can maintain a reliable, cost-efficient, and responsive coal supply chain. Since the plant operates continuously, any disruption in coal procurement, transportation, inventory availability, or equipment support may affect electricity generation. Performance measurement therefore provides a mechanism for monitoring supply chain efficiency, identifying operational weaknesses, and supporting corrective action.

The performance measurement practices at the Sahiwal plant can be understood through several key performance indicators (KPIs). These include inventory turnover, inventory days of supply, supplier lead time, order-to-delivery cycle time, transportation cost as a percentage of total logistics cost, inventory accuracy, coal quality rating, on-time delivery performance, defect rates, order fulfilment rate, and logistics cost as a percentage of revenue. These indicators allow plant management to assess both the efficiency and effectiveness of the supply chain.

Inventory-related KPIs help determine whether coal stock is being managed efficiently. Low inventory may increase the risk of fuel shortages, while excessive inventory may increase storage and handling costs. Supplier and logistics-related KPIs are also important because supplier lead time, delivery reliability, coal quality, and transportation cost directly influence plant performance. The Sahiwal plant is reported to operate at a gross efficiency of approximately 42.11%. However, this figure should not be interpreted as a complete measure of supply chain performance because supply chain performance also includes reliability, responsiveness, quality, sustainability, risk exposure, and stakeholder coordination.

Technology can further strengthen performance measurement and supply chain coordination. Systems such as Enterprise Resource Planning (ERP), transport management systems, inventory monitoring tools, Internet of Things (IoT) applications, and data analytics can support procurement planning, inventory control, shipment tracking, supplier evaluation, maintenance scheduling, and decision-making. These technology-enabled processes are consistent with the bibliometric themes of digitalisation, optimization, monitoring, and data-driven supply chain management in power generation.

Continuous improvement is also part of supply chain performance management. Regular supplier performance reviews, internal audits, employee training, and process improvement initiatives can help improve inventory accuracy, procurement efficiency, logistics reliability, and operational responsiveness. The introduction of Lean and Six Sigma initiatives may further support waste reduction, defect minimisation, process standardisation, and continuous improvement.

Challenges, Lessons Learned, and Recommendations

The Sahiwal plant faces several supply chain challenges that may affect the reliability, efficiency, and sustainability of its operations. One major challenge is its dependence on imported coal. Imported-coal supply chains are exposed to longer lead times, international price fluctuations, currency risk, port dependency, geopolitical uncertainty, regulatory changes, and transportation disruption. These risks may increase supply chain vulnerability and affect long-term operational stability.

Logistics disruption is another major challenge. Coal must move through a long logistics chain involving sea transportation, port handling, rail movement, road transportation, warehousing, and final delivery to the plant. Disruptions in any part of this chain may delay coal availability and increase operational costs. Weather-related disruptions, infrastructure limitations, traffic congestion, shipment damage, documentation delays, and shipment security risks can further reduce supply chain efficiency.

Environmental sustainability is also an important concern. Coal-fired power plants face increasing pressure to reduce emissions, manage coal ash, ensure responsible waste disposal, and minimise environmental impact. For the Sahiwal plant, environmental management is not only a technical requirement but also a supply chain concern because sourcing, transportation, storage, combustion, and waste disposal all contribute to environmental performance.

Supplier-related risks also require attention. Supplier financial instability, inconsistent coal quality, delivery delays, and failure to meet sustainability requirements may affect plant operations. Since coal quality influences combustion efficiency, emissions, equipment maintenance, and overall plant performance, supplier selection and supplier monitoring must be continuously strengthened. Stakeholder coordination is also important because large-scale power generation projects involve multiple actors, including coal suppliers, logistics providers, contractors, regulators, plant operators, government agencies, and local communities.

Several lessons can be drawn from the Sahiwal case. First, supplier relationship management is essential for imported-coal power generation. A plant that relies on international coal supply requires long-term supplier relationships, supplier performance monitoring, and supplier diversification. Second, supply chain resilience must be built into the system through strategic inventory, alternative logistics routes, risk monitoring, and contingency planning. Third, technology adoption can improve visibility and decision-making across procurement, logistics, inventory, and maintenance activities. Fourth, sustainability should be treated as part of supply chain management rather than as a separate environmental function.

Based on the analysis, several recommendations are proposed. First, the plant should strengthen supplier diversification to reduce dependency on limited coal sources. Second, contingency planning should be improved through alternative routes, backup suppliers, emergency inventory policies, and disruption response procedures. Third, technology-enabled supply chain monitoring should be enhanced through integrated ERP systems, logistics tracking tools, inventory dashboards, and predictive analytics. Fourth, supplier evaluation should be conducted regularly using clear indicators such as delivery reliability, coal quality, cost competitiveness, financial stability, and sustainability compliance. Fifth, sustainability performance should be incorporated into supply chain evaluation, including transport-related emissions, coal ash handling, waste management, and supplier environmental compliance.

Overall, the Sahiwal case shows that effective supply chain management in imported-coal power generation depends on the integration of supplier collaboration, inventory planning, logistics coordination, performance measurement, technology adoption, risk management, and sustainability practices. These findings demonstrate how the operational realities of the plant reflect the broader themes identified in the bibliometric analysis.

DISCUSSION AND IMPLICATIONS

Discussion of Findings

The findings of this study show that supply chain management in power generation is shaped by both research-level developments and plant-level operational realities. The bibliometric analysis indicates that the literature has increasingly focused on reliability monitoring, decarbonisation, optimization under uncertainty, demand response, coal-fired technology, and smart grid systems. These themes suggest that SCM research in power generation has moved beyond traditional procurement and logistics and now includes broader concerns related to resilience, sustainability, digitalisation, and system reliability.

The Sahiwal Coal-Fired Power Plant case reflects several of these themes. As an imported-coal power generation project, the plant depends on international coal sourcing, multimodal transportation, supplier coordination, inventory planning, performance monitoring, and environmental management. These operational features demonstrate that power generation supply chains require continuous coordination across multiple actors and activities. Any disruption in coal sourcing, port handling, inland transportation, inventory availability, or supplier performance may affect electricity generation continuity.

The integration between the bibliometric findings and the case analysis is important because it shows that academic research themes are not isolated from operational practice. For example, the bibliometric theme of optimization under uncertainty is reflected in the plant's need to manage supplier lead time, transportation disruption, inventory buffers, and contingency planning. The theme of reliability monitoring is reflected in the importance of supplier performance, coal quality, delivery reliability, and supply chain KPIs. Similarly, the theme of sustainability and decarbonisation is reflected in the plant's need to manage emissions, coal ash, waste disposal, and responsible sourcing.

Theoretical Implications

This study contributes to the SCM literature by demonstrating how bibliometric analysis and document-based case analysis can be used together to connect macro-level research patterns with micro-level operational practices. Bibliometric analysis provides an overview of how the research field has developed, while case analysis explains how those research themes appear in a specific operational context. This combined approach is useful for fields such as power generation, where research is often fragmented across engineering, energy policy, sustainability, logistics, and operations management.

The study also highlights the importance of viewing power generation supply chains as integrated socio-technical systems. SCM in coal-fired power generation is not limited to fuel procurement or transport arrangements. It also involves technology adoption, risk management, environmental compliance, supplier governance, performance measurement, and stakeholder coordination. Therefore, future SCM frameworks for power generation should integrate operational, technological, environmental, and institutional dimensions.

In addition, the findings suggest that imported-coal power plants require stronger theoretical attention in SCM research. Many existing studies focus on optimization models, green supply chain management, renewable energy, or power system reliability. However, fewer studies examine how these themes interact within a specific imported-coal power plant operating in a developing economy. The Sahiwal case therefore provides a useful context for understanding how global supply risks, infrastructure dependency, and sustainability pressures influence power generation SCM.

Practical Implications

From a practical perspective, the findings indicate that managers of imported-coal power plants should adopt a resilience-oriented supply chain strategy. This means that supply chain decisions should not focus only on cost minimisation. They should also consider supplier reliability, delivery consistency, inventory security, logistics flexibility, environmental compliance, and disruption response capability.

First, plant managers should strengthen supplier diversification and supplier evaluation. Dependence on a limited number of coal suppliers may increase vulnerability to price changes, delivery delays, supplier insolvency, or geopolitical disruption. Supplier evaluation should include not only cost and coal quality, but also financial stability, delivery reliability, sustainability compliance, and ability to respond to disruptions.

Second, inventory management should be treated as a strategic function. Maintaining sufficient coal inventory is necessary to avoid operational interruptions, but excessive inventory may increase storage and handling costs. Therefore, inventory decisions should be supported by forecasting, safety stock planning, demand monitoring, and periodic review of lead-time variability.

Third, logistics coordination should be strengthened through digital monitoring and contingency planning. Imported coal must move through a long chain involving seaports, rail systems, road transportation, warehouses, and plant-level handling facilities. Digital tools such as transport management systems, ERP systems, IoT-based tracking, and data analytics can improve visibility and allow managers to respond more quickly to disruptions.

Fourth, sustainability should be integrated into supply chain decision-making. Coal-fired power plants face growing environmental pressure, especially in relation to emissions, coal ash management, waste disposal, and transport-related environmental impact. Responsible sourcing, cleaner logistics, environmental monitoring, and compliance-based supplier evaluation can help improve the long-term legitimacy of coal-fired power projects.

Policy Implications

The findings also have implications for policymakers and regulators involved in large-scale energy infrastructure projects. Since imported-coal power plants depend on international supply networks and domestic logistics infrastructure, government agencies should support policies that improve port efficiency, rail and road connectivity, customs processes, environmental compliance, and energy supply security.

For CPEC-related energy projects, policy coordination is particularly important because multiple stakeholders are involved, including government agencies, regulators, foreign investors, contractors, logistics providers, and local communities. Clear regulatory procedures, stable import policies, transparent reporting requirements, and environmental monitoring standards can reduce uncertainty and improve supply chain performance.

Furthermore, policymakers should encourage power generation firms to adopt digital supply chain systems and sustainability-oriented reporting. These practices can improve transparency, risk detection, and accountability across the energy supply chain. In the long term, stronger integration between energy policy, logistics planning, environmental regulation, and technology adoption can support more resilient and sustainable power generation infrastructure.

INTEGRATED SUPPLY CHAIN RESILIENCE FRAMEWORK

Based on the bibliometric findings and the Sahiwal case analysis, this study proposes an integrated supply chain resilience framework for imported-coal power generation projects. The framework consists of five interrelated dimensions: supplier resilience, logistics resilience, inventory resilience, technology-enabled monitoring, and sustainability governance (see Figure 6). These dimensions reflect the major themes identified in the bibliometric analysis and the operational requirements observed in the Sahiwal Coal-Fired Power Plant case.

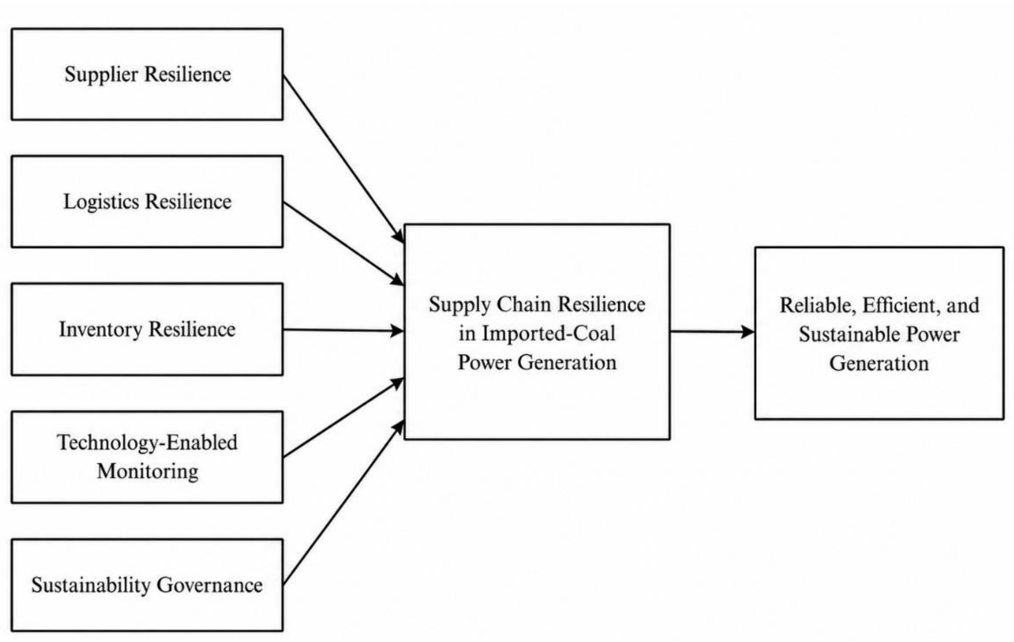


Figure 6
Integrated Supply Chain Resilience Framework for Imported-Coal Power Generation

Supplier resilience refers to the ability of the plant to maintain reliable coal supply through supplier diversification, long-term supplier relationships, supplier performance evaluation, and quality monitoring. This dimension is important because imported-coal power plants are exposed to risks such as supplier insolvency, inconsistent coal quality, delivery delays, and price volatility. Strong supplier governance can reduce supply uncertainty and support more stable power generation.

Logistics resilience refers to the ability of the supply chain to maintain coal movement despite disruptions in shipping, port handling, rail transportation, road delivery, documentation, or weather conditions. Since imported coal must pass through several logistics stages before reaching the plant, disruptions at any point may affect fuel availability. Therefore, alternative transport routes, shipment tracking, route optimization, and contingency planning are essential for maintaining operational continuity.

Inventory resilience refers to the ability of the plant to balance coal availability with inventory cost. Strategic safety stock, demand forecasting, lead-time monitoring, and periodic inventory review can help reduce the risk of stock-outs while avoiding excessive storage and handling costs. This dimension is particularly important for continuously operating power plants because insufficient coal inventory may directly affect electricity generation.

Technology-enabled monitoring refers to the use of digital tools to improve supply chain visibility and decision-making. Enterprise Resource Planning systems, transport management systems, Internet of Things applications, inventory dashboards, and data analytics can support procurement planning, supplier evaluation, shipment monitoring, maintenance scheduling, and disruption response. These tools allow managers to identify potential risks earlier and respond more effectively.

Sustainability governance refers to the integration of environmental and social considerations into supply chain decision-making. For coal-fired power plants, this includes emissions control, coal ash management, responsible sourcing, waste management, supplier compliance, and transport-related environmental impact. This dimension is important because supply chain resilience should not only focus on cost and reliability, but also on environmental responsibility and long-term legitimacy.

Overall, the proposed framework suggests that supply chain resilience in imported-coal power generation depends on the integration of supplier management, logistics coordination, inventory planning, digital monitoring, and sustainability governance. These dimensions provide a practical basis for strengthening SCM practices in the Sahiwal plant and may also guide future studies on power generation supply chains in other developing-economy contexts.

CONCLUSION

This study examined supply chain management (SCM) in the power generation sector by integrating bibliometric analysis with a document-based case study of the Sahiwal Coal-Fired Power Plant. The bibliometric analysis identified seven major research themes: reliability and monitoring, decarbonisation, optimization under uncertainty, electrical-machine dynamics, demand response and electricity markets, coal-fired power technology, and smart grid systems. These themes show that SCM research in power generation has expanded beyond traditional procurement and logistics to include sustainability, digitalisation, risk management, and system reliability.

The case study shows that the Sahiwal plant reflects several of these themes through its dependence on international coal sourcing, multimodal transportation, inventory planning, supplier coordination, performance monitoring, and environmental management. The findings suggest that effective SCM in imported-coal power generation requires reliable supplier relationships, logistics coordination, strategic inventory, technology-supported monitoring, sustainability governance, and contingency planning.

This study contributes by demonstrating how bibliometric analysis and document-based case analysis can complement each other. Bibliometric analysis provides a macro-level understanding of research trends, while case analysis explains how these themes appear in plant-level supply chain practices. This integrated approach helps bridge the gap between publication-based knowledge and operational realities in power generation supply chains.

Several limitations should be acknowledged. The bibliometric analysis was limited to English-language publications indexed in selected databases between 2014 and April 2024. The case study also relied mainly on publicly available secondary documents rather than primary data from interviews, site observation, or internal operational records. Future research may extend this study by using primary data, comparing multiple CPEC and non-CPEC power plants, and examining the role of artificial intelligence, machine learning, blockchain, predictive analytics, and digital supply chain platforms in improving SCM performance.

DECLARATION OF THE USE OF GENERATIVE AI

Authors declare that AI tools such as ChatGPT and Grammarly were used to support language editing, clarity improvement, and manuscript restructuring. These tools were not used to collect data, conduct bibliometric analysis, interpret results, or make scientific decisions. The authors remain fully responsible for the accuracy, integrity, analysis, and conclusions of the manuscript.

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