فصلنامه نوآوری در مهندسی و تکنولوژی شماره 1- دوره 2- صفحات199-213
*Journal of Innovation in Engineering and Technology*
*ISSN 3060-6098*

# A Green Procurement and Distributed Renewable Generation Framework for Industrial Supply Chain Resilience under Energy Crisis Conditions

Alireza Nazeri Gahkani[1], *, Erfan Ghane Sheykh Abadi[2],
1 M.Sc. in Electrical Engineering, Hormozgan Regional Electric Company, Iran
2 Ph.D. Student in Physics, General Directorate of Industry, Mining, and Trade of Hormozgan Province, Iran.

## Abstract

Iran's electricity crisis, rooted in decades of inefficient policymaking and underinvestment in power generation infrastructure, has turned into a devastating shock for the industrial sector following the recent war. Hormozgan Province, as the country's industrial hub and host to strategic industries such as steel, aluminum, refineries, and petrochemicals, lies at the epicenter of this crisis due to its high concentration of electricity consumption and the vulnerability of the transmission network. Under these conditions, the traditional strategy of rebuilding centralized infrastructure is neither feasible nor desirable; a transition toward distributed renewable generation systems and supply chain reconfiguration has thus become a strategic necessity. This study aims to design an integrated conceptual model to enhance the resilience of the industrial supply chain in Hormozgan Province by combining green procurement strategies and distributed renewable generation in the context of the post-war electricity crisis. Adopting a qualitative, concept-driven approach, the study develops a four-layer model consisting of Resilient Energy Supply, Green Procurement and Supply Diversification, Smart Digital Management, and Governance and Institution Building. The first layer reduces dependence on the national grid by deploying solar-battery microgrids with islanding capability. The second layer manages the risk of disruption in raw material flows through supplier base diversification, strategic reserves, and closed-loop supply reinforcement. The third layer enables real-time monitoring and proactive response using the Internet of Things and artificial intelligence. The fourth layer provides the institutional and financial foundation for implementation through the design of a steering council, a joint investment fund, and a guaranteed purchase framework. Model validation is conducted through scenario analysis of four grid disruption scenarios and a comparative study of successful global experiences (Puerto Rico, Ukraine, and India). The results indicate that implementing the proposed model improves the province's supply chain resilience by 55 to 65 percent, depending on the scenario. The greatest improvement is observed in the system robustness component, such that even in the scenario of a complete national grid blackout, it becomes possible to maintain minimal production in critical industries and prevent irreparable damage. Furthermore, supplier diversification and reduced dependence on high-risk logistics pathways significantly accelerate post-disruption recovery speed. The findings offer clear policy implications for Hormozgan Province and the country as a whole: a paradigm shift from rationing to empowering industries for energy self-supply, establishing a single window to facilitate investment, prioritizing resource allocation to critical industries based on a criticality-vulnerability analysis, and investing in digital infrastructure for smart energy management. This model can also serve as a blueprint for resilient industrial reconstruction in other provinces and conflict-affected countries.

**Keywords:** Resistance Economy, Supply Chain Resilience, Distributed Renewable Generation, Post-War Reconstruction, Hormozgan Province, Electricity Crisis, Solar Energy, Smart Energy Management.

## The Energy Crisis in Iran: From Chronic Imbalance to War-Induced Shock

The energy crisis in Iran is not a nascent phenomenon; rather, it is rooted in decades of inefficient policymaking, subsidized pricing, and underinvestment in power generation infrastructure. Prior to the recent war, the imbalance between electricity production and consumption had reached alarming levels. The Chairman of the Board of the Iranian Power Plant Industry Syndicate had projected that the electricity deficit in the final year of the Seventh Five-Year Development Plan would be so massive as to equal the combined generation capacity of several major power plants. This chronic shortage had rendered the country's industries highly fragile. Official reports indicate that, in the last season of the year preceding the onset of war, Iranian industrial plants were operating, on average, at less than half of their nominal capacity, primarily due to severe shortages of electricity and natural gas. In the year before the war, Iran's semi-finished steel exports experienced a sharp and statistically significant decline compared to the previous year, illustrating the profound impact of the energy crisis on foreign trade. With the outbreak of a forty-day war in early 1404 (2025), this chronic crisis escalated into an acute shock. Direct attacks on the nation's critical infrastructure inflicted massive and extensive damage on the power industry damage that experts estimated to be equivalent to several years of the country's development budget. Energy facilities, including power plants, transmission substations, and distribution lines, were subjected to systematic targeting. For instance, the Persian Gulf Fajr Energy facilities, which serve as the primary supplier of electricity and steam to the Pars Special Economic Energy Zone, sustained severe damage; the failure of its turbines led to a complete blackout and a total halt of production across all dependent industrial units. This pattern of destruction, beyond the physical damage to equipment, revealed a strategic principle of modern warfare: targeting energy supply infrastructure and mother industries results in the cascading paralysis of all downstream industries. The consequences of this war for the manufacturing sector were catastrophic. The Secretary-General of the Iranian Cement Industry Association announced that electricity quotas for cement plants had been reduced to such an extent that their production fell to less than one-tenth of their nominal capacity, signifying an almost complete shutdown of production lines. Virtually all of the country's steel production units ground to a halt due to the acute power shortage. Estimates suggest that industries lost between one-third and over one-half of their production capacity solely as a result of electricity shortages. Overall, several state-owned industrial estates and one private industrial zone sustained damage during the war, with a significant number of manufacturing units suffering damage to between half and more than half of their total equipment. The cost of reconstructing the nation's energy infrastructure, under the worst-case scenario, has been estimated at an astronomical figure far exceeding the country's ordinary financial capacity. Exacerbating the situation are the intensifying international sanctions, which have severely constrained Iran's access to the advanced technologies and equipment required for reconstruction. Under such circumstances, the traditional strategy of rebuilding exactly as before is neither feasible nor desirable. What is imperative is a transformative approach grounded in the principle of "building back better," one that simultaneously pursues multiple objectives: sustainable energy supply, resilience against future shocks, environmental sustainability, and industrial competitiveness. Global experience demonstrates that post-war countries possess a unique window of opportunity for technological leapfrogging and redefining development paradigms. Ukraine, as a contemporary case, has designed its energy system reconstruction plan based on a full transition to a renewable and electrified system; a study demonstrates that the country could meet its future energy demand through an entirely renewable system at costs competitive with fossil fuels and nuclear power. In a similar vein, the Ukrainian steel industry is moving toward green steel, with an emphasis on carbon-free energy supply chains, the establishment of new steelmaking sites adjacent to renewable sources, and the formation of regional coalitions for a green iron and steel market. Iran, endowed with one of the highest solar irradiation levels in the world and a unique geostrategic position, similarly possesses a historic opportunity to redefine its energy and industrial model.

## Hormozgan Province: The Beating Heart of Iran's Industry Besieged by Crisis.

Owing to its strategic location along the Persian Gulf and the Strait of Hormuz, Hormozgan Province plays an irreplaceable role in Iran's economy and industry. The province hosts some of the country's largest and most strategic industries, including steel (Hormozgan Steel Company), aluminum (Al-Mahdi Aluminum Company), refineries (Bandar Abbas Oil Refinery), petrochemicals, cement, and shipbuilding. This high concentration of energy-intensive industries has turned Hormozgan into one of the highest electricity-consuming provinces in the country; according to statistics, industries in Hormozgan require over 2,000 megawatts of electricity daily. Yet, this very province, which plays a vital role in the nation's GDP and non-oil exports, itself faces numerous challenges in securing a stable electricity supply. Energy shortages in Hormozgan, particularly during the hot seasons, have persistently been one of the province's fundamental problems. Reports indicate that in the summer of 2025, despite the province's significant role in national power generation, it experienced widespread blackouts. The Bandar Abbas Power Plant, one of the province's main electricity sources, suffered a significant decline in output during the winter of 2024–2025 due to a deficit in fuel supply. This situation has dramatically worsened in the post-war period, as, on the one hand, transmission and distribution infrastructure has been damaged, and on the other, the prioritization of electricity supply for household and public sector consumption has drastically reduced the quota allocated to industries. Large-scale industries in Hormozgan have been particularly hard hit by this crisis. Hormozgan Steel Company, whose CEO stated that it would break production records whenever sufficient electricity was available, now faces severe power supply constraints. The aluminum plant is similarly grappling with electricity shortages, and even before the war, shutdowns of some of its units due to a lack of power had been reported. This situation has exposed the supply chains of downstream industries dependent on steel, aluminum, and cement products from Hormozgan to systemic disruption. The closure of the Strait of Hormuz has compounded these problems, increasing shipping and cargo insurance costs and reducing the speed of export deliveries. Thus, Hormozgan Province, as the beating heart of Iran's industrial economy, finds itself at the center of a multifaceted energy, logistics, and production crisis.

## The Imperative of Transitioning to Renewable Energy in Post-War Reconstruction

Under such critical conditions, the question of how to secure a stable supply of electricity for industries while simultaneously guaranteeing the resilience of the energy system and supply chains against future shocks all within the shortest possible timeframe inexorably drives a transition from the traditional model of centralized power generation toward decentralized, renewable-based systems. First, from a systemic resilience perspective, the centralized nature of Iran's energy infrastructure has rendered it acutely vulnerable to attacks. A distributed generation system comprising thousands of small-scale renewable units is far more difficult to target and disable than a small number of large thermal power plants. Francesco La Camera, Director-General of the International Renewable Energy Agency (IRENA), emphasized in the aftermath of the Iran war that “a decentralized energy system with a growing share of renewables and more market players is structurally more resilient.” Second, from the standpoint of reconstruction speed, the construction of a large thermal power plant typically takes between three and five years, whereas an industrial solar power plant can become operational within a matter of months. In March 2026, the Minister of Energy announced that more than one thousand sites across the country are currently witnessing the construction of distributed and solar power plants. In a single week, 250 megawatts of new solar capacity were brought online, and executive operations for an additional 780 megawatts of new capacity commenced. The weekly installation of 100 megawatts of new solar capacity demonstrates that the deployment speed of this technology is vastly superior to that of thermal power plants. Third, regarding the indigenous potential of Hormozgan Province, it ranks among the regions with the highest solar irradiation in Iran. Numerous studies have demonstrated that the areas surrounding Bandar Abbas possess exceptionally high potential for the construction of solar power plants. Technical assessments indicate that in selected locations within the province, suitable solar energy is available for more than eight months of the year, averaging over ten hours per day. The abundance of flat, non-arable land in the province further substantially increases the feasibility of installing solar power plants and associated arrays. Fourth, from the perspective of national policy, the Iranian government has set ambitious targets for the development of renewable energies. The goal of increasing renewable capacity to 30 gigawatts by 2028, along with the installation of 7 gigawatts of new solar capacity, signals serious resolve in this domain. The Iranian Mines and Mining Industries Development and Renovation Organization (IMIDRO) has also initiated negotiations to conclude long-term renewable power purchase agreements to shield the mining and metals sector from electricity outages. Nonetheless, the deployment of renewable energies alone is insufficient. The central issue lies in the systematic integration of these resources with the industrial supply chain structure—such that green energy provision is not merely an "add-on" to the existing system, but becomes an inseparable component of the supply chain resilience architecture.

## The Industrial Supply Chain in the Era of Energy Crisis: From Disruption Management to Green Procurement

In post-war Iran, the industrial supply chain confronts an unprecedented confluence of simultaneous disruptions: severe and prolonged electricity fluctuations, escalating logistics costs, disruptions in maritime transportation routes, shortages of raw materials, and crippling sanctions. Under such conditions, the concept of supply chain resilience has transformed from a purely academic notion into a strategic imperative for industrial survival. Power shortages resulting from extreme events have, in recent years, emerged as one of the most serious threats to supply chains on a global scale. Recent research demonstrates that enhancing supply chain resilience necessitates the combination of novel recovery strategies including alternative energy sources and alternative transportation vehicles—with traditional strategies. This research underscores that integrating renewable energies into supply chain operations is not a luxury choice but an operational imperative for business continuity. At the international level, the concept of green supply chain resilience, as an emerging research domain, has attracted increasing attention. Numerous conceptual frameworks have been developed to identify the dimensions, components, and applications of the resilient green supply chain, emphasizing aspects such as sustainability, flexibility, risk management, and technological integration. Studies indicate that the nexus between green production, supply chain vigilance, and supply chain preparedness exerts a significant impact on manufacturing performance and sustainability in developing economies. In the specific context of green procurement, multiple studies have been conducted. Research in Iran's construction industry has shown that green procurement is an essential component of the supply chain, exerting a considerable influence on all its segments, and that its adoption is essential for achieving the dimensions of economic, environmental, and social sustainability.

### Distributed Renewable Generation: The Backbone of Industrial Energy Resilience

Distributed generation refers to the production of electricity near the point of consumption, as opposed to the traditional model of centralized generation in large power plants with transmission via high-voltage networks. This approach offers multiple advantages, particularly for energy-intensive industries: reduced transmission and distribution losses, enhanced reliability of power supply, and relative immunity to disruptions in the national grid. Moreover, the inherent passive defense attributes of distributed generation systems, stemming from their decentralized nature, substantially increase the security of electricity supply. The nominal capacity of distributed and self-supply generation plants in Iran has exceeded 2,500 megawatts; however, given the country's potential and the accelerating pace of development, this figure is rapidly increasing. Global experience corroborates this trend. Recent research on enhancing industrial load hosting capacity in rural areas of developing countries through the integration of distributed energy resources has presented a comprehensive methodology for assessing grid capacity for industrial loads and defining a sustainable solution based on the integration of distributed renewable energy resources. Within the context of Hormozgan Province, the concept of distributed renewable generation assumes specific operational dimensions. More importantly, combining distributed generation with the notion of industrial energy self-supply can elevate industries from the status of passive consumers to active prosumers. This transition not only guarantees the security of electricity supply for industries but also contributes to the overall stability of the provincial and national energy system by alleviating demand pressure on the national grid.

### Designing an Integrated Conceptual Model of Industrial Supply Chain Resilience Based on Green Procurement and Distributed Renewable Generation

The present study adopts a qualitative, concept-driven approach to designing an integrated model aimed at enhancing the resilience of the industrial supply chain in Hormozgan Province under post-war electricity crisis conditions. Given the multi-layered and interdisciplinary nature of the problem which simultaneously encompasses technical, economic, institutional, and strategic dimensions the use of research methodologies grounded in conceptual modeling and systemic analysis is essential. Accordingly, the methodological framework of this study is organized into five interconnected steps: structural analysis of the problem, conceptualization of the four-layer resilience model, definition of evaluation indicators, scenario analysis and validation, and, finally, the formulation of an indigenous implementation roadmap for Hormozgan Province. Across all steps, emphasis is placed on designing a model that is practically implementable under the specific conditions of this province, one that does not necessitate extensive field data collection through questionnaires or interviews, but is instead built upon document analysis, global experiences, and logical reasoning.

### Step One: Structural Analysis and Qualitative Prioritization of Critical Industries

The first step in designing the model is to identify and prioritize those industries whose disruption in electricity supply would have the greatest impact on the stability of the province's entire supply chain. Rather than employing quantitative techniques such as the Fuzzy Analytic Hierarchy Process, which require the collection of judgmental data, this study utilizes the Importance–Vulnerability Analysis (IVA) framework. This framework evaluates each industrial unit along two key dimensions: strategic importance within the supply chain and the degree of vulnerability to power outages. The strategic importance dimension consists of three sub-criteria. First, economic value-added, which reflects the industry's contribution to the province's GDP and export revenues. Second, the intensity of forward and backward linkages, which captures the number of upstream industries supplying raw materials and downstream industries consuming the products, serving as a measure of the cascading effects of disruption. Third, direct and indirect employment generation, which addresses the social dimension of resilience. The vulnerability dimension is assessed through two sub-criteria: specific electricity consumption per unit of output, indicating the degree of dependency of the production process on a continuous flow of electricity, and critical downtime, which specifies the maximum tolerable duration of a power outage before irreparable damage to equipment occurs or in-process batches are completely lost. Using data from official reports of the provincial Industry, Mine, and Trade Organization, corporate financial statements, employment statistics, and technical reports from the Hormozgan Electricity Distribution Company, each of the province's major industries is qualitatively ranked on these five criteria at three levels: "High," "Medium," and "Low." Industries that score "High" on both the importance and vulnerability dimensions are identified as critical and are prioritized for resource allocation within the model. A preliminary analysis reveals that the steel (Hormozgan Steel Company) and aluminum (Al-Mahdi Aluminum Company) industries are among the most critical in the province. This is due to their extremely high electricity consumption, continuous electrolysis and smelting processes that cannot tolerate even short-term interruptions, and their pivotal position in the supply chains of downstream industries (construction, automotive, packaging). The petrochemical, refinery, and cement industries rank next in order of criticality.

### Step Two: A Four-Layer Conceptual Model of Industrial Supply Chain Resilience

The core of this research is the design of a four-layer conceptual model, in which each layer addresses one of the fundamental dimensions of resilience while maintaining an organic interconnection with the other layers. The model has been developed by drawing upon the concept of systems-of-systems: the resilience of the whole is not the mere sum of the resilience of its parts, but rather the product of the synergy among the different layers. The four layers of this model are: the Resilient Energy Supply Layer, the Green Procurement Layer, the Digital and Smart Management Layer, and the Governance and Institution Building Layer. Each layer is elaborated upon in detail below.

### Layer One: Resilient Energy Supply through Hybrid Industrial Microgrids

The first layer of the model is dedicated to the reconfiguration of the industrial electricity supply infrastructure and is founded on a fundamental principle: the transition from a passive consumer to an active prosumer. In this layer, rather than sole reliance on the national grid—which has become severely vulnerable in the post-war period—a hybrid microgrid is designed for each of the province's major industrial hubs, fed by three primary sources. The first source is on-site photovoltaic solar power plants. Hormozgan Province, with an average annual solar irradiation exceeding 2,000 kWh per square meter and more than 300 sunny days, ranks among the richest regions in the world for solar energy deployment. The proposed model targets the installation of solar panels on the rooftops of industrial sheds and on unused barren lands adjacent to industrial estates. The nominal capacity of these plants is set such that, during peak irradiation hours, they can supply at least a significant portion of the host industry's electricity demand. For industries operating 24-hour processes (such as electric arc furnaces in steelmaking), this share can be increased with the addition of storage systems. Preliminary estimates indicate that by utilizing merely 20 percent of the industrial rooftop area and the unallocated barren lands surrounding the industrial hubs west and east of Bandar Abbas, a capacity exceeding 100 megawatts can be achieved. The second source is battery energy storage systems (BESS). The variable nature of solar generation necessitates a storage buffer. In the proposed model, for each megawatt of installed solar capacity, a storage capacity equivalent to several hours of electricity supply for critical processes is considered. These storage systems serve two primary functions: first, smoothing short-term generation fluctuations (such as passing clouds), and second, supplying power during the early nighttime hours when industrial consumption remains high but solar irradiation has ceased. The storage capacity is designed based on the concept of critical coverage, meaning it must be capable of supplying the electricity required by those processes whose sudden shutdown would result in severe damage, for a sufficient duration. The third source is the intelligent bidirectional connection to the national grid. The industrial microgrid remains connected to the national grid, but this connection is bidirectional and intelligent. Under normal conditions, the industry can inject its surplus solar generation into the grid and benefit from the associated revenue. In the event of a disruption, an advanced protective relay automatically disconnects the microgrid from the national grid and transfers it to islanded mode. In this state, the industry continues to operate in a fully self-reliant manner, independent of the damaged grid. This islanding capability, which is also a requirement of passive defense, constitutes the backbone of energy resilience in the proposed model. For Hormozgan Province, the model designs three main industrial microgrids: the West Bandar Abbas Microgrid (encompassing Hormozgan Steel, Al-Mahdi Aluminum, and associated industries), the East Bandar Abbas Microgrid (covering cement industries, petrochemicals, and industrial estates), and the Qeshm Island Microgrid (a hybrid of solar and wind, given the region's wind potential).

**Layer Two: Green Procurement and Supply Chain Diversification**

The second layer of the model addresses the question of how procurement and raw material sourcing processes can be redesigned to simultaneously strengthen supply chain resilience and environmental sustainability. In this layer, the traditional strategy of minimizing procurement costs which typically results in the selection of one or two large suppliers offering the lowest prices is replaced by a multi-objective optimization strategy of combined value. This new strategy simultaneously pursues three objectives: reducing disruption risk through diversification, improving environmental performance by selecting green suppliers, and maintaining economic competitiveness. Supplier base diversification constitutes the first component of this layer. Instead of solely relying on a single foreign or domestic supplier, the proposed model recommends creating a supply portfolio comprising a mix of local intra-provincial, national, and international suppliers. The weight of local suppliers within this portfolio is purposefully increased to reduce supply chain vulnerability to international logistics disruptions such as the closure of the Strait of Hormuz, maritime shipping sanctions, or exchange rate fluctuations. The supplier selection criterion shifts from the lowest price to the best combined value, which, in addition to price, incorporates criteria such as the reliability of on-time delivery history, geographical distance (to reduce logistics risk), and a sustainability score based on the use of renewable energy in the production process, waste management, and recyclable packaging. The second component is the establishment of strategic reserves of raw materials. Inspired by the concept of "safety stock" in supply chain management, the proposed model mandates the creation of provincial strategic reserves for critical raw materials. These reserves are defined in both physical and virtual forms. Physical reserves consist of strategically located warehouses that hold inventories of key raw materials (such as iron ore, alumina, copper cathode, and specific chemicals) sufficient to cover several weeks of consumption. Virtual reserves include pre-purchase agreements and call option contracts with alternative suppliers, which remain inactive under normal conditions but can be activated immediately upon the declaration of a crisis. This dual mechanism reduces inventory holding costs under normal conditions while preserving access assurance in crisis situations. The third component is the reinforcement of closed-loop supply chains and the circular economy. The proposed model steers the province's industries toward cross-sector synergies. For instance, the slag from Hormozgan's steel furnaces, which is disposed of as waste in the linear model, can be utilized as a valuable raw material for the province's cement industry. The waste heat from the Bandar Abbas refinery can be employed in the preheating processes of adjacent industries. Such synergies not only enhance resilience by reducing dependence on external suppliers but also simultaneously lower logistics costs and carbon emissions. To operationalize this component, the model proposes the creation of a shared industrial procurement platform, where industries can post their supply requirements and become aware of synergy opportunities such as joint purchasing, combined transportation, and the exchange of by-products.

## Layer Three: Digital and Smart Management of Energy and the Supply Chain

The third layer of the model encompasses the digital infrastructure and intelligent systems that, functioning as a nervous system, enable the real-time monitoring, prediction, and dynamic control of the two preceding layers. Without this layer, the model would resemble a body devoid of senses and a brain, incapable of reacting swiftly to sudden shocks. This layer consists of three primary systems. The first system is the Smart Energy Management System (EMS). By installing smart meters and Internet of Things (IoT) sensors at key points of electricity consumption each production line, each furnace, each large pump this system enables real-time monitoring of energy usage. The artificial intelligence algorithms embedded within this system continuously analyze data on consumption, solar generation, battery state-of-charge, grid tariffs, and weather forecasts, and automatically make optimal decisions. For instance, the system can shift high-consumption yet flexible processes such as charging preheating furnaces or water pumping to peak solar irradiation hours, or, if a decline in solar output is predicted due to cloud cover, automatically curtail non-essential loads. The second system is the Early Warning and Disruption Prediction System. By integrating meteorological data (for solar irradiance and wind forecasts), grid stability data (voltage, frequency, rate of change), market data (real-time electricity and energy carrier prices), and security data (passive defense alerts), this system predicts the likelihood of a disruption within a 24- to 48-hour horizon. The output of this system is communicated to industry managers and the provincial Industry, Mine, and Trade Organization in the form of color-coded alerts: yellow, orange, and red. This predictive capability shifts the crisis management paradigm from post-event reaction to pre-event preparedness, providing a golden window of time for preventive actions such as fully charging batteries, reducing work-in-progress production, or activating backup suppliers. The third system is the Integrated Supply Chain Resilience Dashboard. This managerial dashboard, housed in the joint control room of the provincial Industry, Mine, and Trade Organization and the regional Electricity Distribution Company, displays the resilience status of the province’s entire industrial supply chain in real time, using key performance indicators (KPIs) that will be detailed in the third step. These indicators are visualized as a traffic-light system green for normal status, yellow for warning, and red for crisis enabling senior provincial managers to have, at any moment, a clear picture of the system’s resilience level and to initiate corrective actions before minor disruptions escalate into major crises.

### Layer Four: Governance and Institution Building

The fourth and final layer of the model addresses the design of institutional and governance mechanisms that ensure the success and sustainability of the three preceding layers. Global experience demonstrates that many technically excellent solutions fail at the implementation stage due to the absence of an appropriate institutional platform. Accordingly, the proposed model designs three institutional mechanisms. The first mechanism is the formation of the Hormozgan Province Energy and Industrial Resilience Steering Council. This council, composed of senior managers from the Electricity Distribution Company, the Industry, Mine, and Trade Organization, the Governor's Office, the Crisis Management Organization, the Chamber of Commerce, and the

CEOs of the province's five largest industries, will serve as the highest decision-making body in the realm of industrial energy resilience. The council's responsibilities include approving annual plans for distributed generation development, coordinating among various executive bodies that currently operate in silos, monitoring project progress, and periodically reviewing objectives and strategies based on operational feedback. The second mechanism is the creation of a Joint Industrial Energy Reconstruction Investment Fund. One of the principal barriers to the deployment of distributed generation is the lack of financial resources and the difficulty individual industries face in obtaining bank loans, particularly in the post-war economic environment. The proposed model recommends the establishment of a joint investment fund capitalized by the province's major industries as shareholders, provincial operating banks, and government resources—including credits under Article 16 of the Knowledge-Based Production Leap Law and crisis management funds. This fund pools financial resources and, by leveraging economies of scale in equipment procurement and reducing risk through portfolio diversification, significantly lowers the financing costs of solar and storage projects. The third mechanism is the design of a contractual framework for the guaranteed purchase of industrial renewable electricity. This framework, developed in coordination with Tavanir (the national power generation and transmission company) and the Hormozgan Regional Electricity Company, enables industries that generate renewable electricity in excess of their own needs to sell the surplus to the grid at incentive tariffs. This mechanism not only creates a powerful economic incentive for investment beyond the minimum requirement but also contributes to the overall stability of the province's electricity grid.

### Step Three: Supply Chain Resilience Assessment Framework

To measure the success of the model and to enable progress tracking over time, an assessment framework based on five core resilience components has been developed. Rather than relying on complex mathematical formulas, this framework is grounded in the definition of qualitative and semi-quantitative indicators that are easily comprehensible and observable by managers and policymakers. Component One: Robustness. This component refers to the system's ability to maintain the flow of goods and energy during a disruption. It is assessed qualitatively by the proportion of critical industries' electricity demand that continues to be met under various disruption scenarios, ranging from seasonal restrictions to a complete grid blackout. The higher this proportion, the more robust the system. In the current state, the near-total dependence on the national grid results in a low level of robustness. Component Two: Redundancy. Redundancy denotes the existence of surplus capacity and alternative pathways within the system. In the proposed model, redundancy is created through battery storage capacity, which serves as a backup for solar generation, and through the number of alternative suppliers for each raw material. The level of redundancy is evaluated by comparing the nominal storage capacity and supplier diversity against the maximum coincident demand. Component Three: Recovery Speed. This component measures the time required to return to an acceptable level of operational capacity after a major disruption has been resolved. In a system based on distributed generation, recovery speed is inherently higher due to the decentralized nature of the resources and the elimination of dependence on extensive transmission network repairs. This component is assessed through the analysis of various disruption scenarios and an estimation of the time needed for a full restart. Component Four: Visibility. Visibility refers to the level of transparency and the capacity for real-time tracking of energy and material flows throughout the supply chain. It is gauged by examining the percentage of industries equipped with smart energy management systems and cargo tracking systems. In the current state, visibility across the province's supply chain is very low, and decisions are frequently made based on data that is several days old. Component Five: Flexibility. Flexibility refers to the system's ability to rapidly adapt to changing conditions, including switching suppliers, altering the energy mix, or modifying production schedules. This component is evaluated through criteria such as the number of available alternative suppliers, the diversity of deployed renewable technologies (solar, wind, and, prospectively, biomass), and the capacity for rapid reconfiguration of production lines. The combination of these five components yields a comprehensive picture of the resilience level of the province's industrial supply chain. By comparing the pre-implementation baseline with the target state after the model's implementation, the degree of resilience improvement can be determined qualitatively. Based on conservative estimates and drawing on comparable global experiences, the full implementation of the four-layer model is expected to enhance resilience by more than 50 percent relative to the current state.

**Step Four: Scenario Analysis and Validation**

To ensure the model's effectiveness under varying conditions and to validate it without the need for extensive field data, two methods are employed: scenario analysis and comparative benchmarking against global experiences. These methods are particularly well-suited to research concerned with designing complex systems under conditions of high uncertainty. In the scenario analysis, four distinct states are defined for the province's electricity grid: Scenario One represents normal conditions with mild seasonal restrictions; Scenario Two involves a 50 percent curtailment of industrial electricity, similar to the conditions experienced in the summers preceding the war but with damaged infrastructure; Scenario Three entails a 75 percent curtailment of industrial electricity, resembling the initial months following the war; and Scenario Four constitutes a complete blackout of the national grid resulting from a military attack or total system collapse. For each scenario, the performance of the four-layer model is analyzed through reasoned argumentation: which layers are activated, what proportion of the demand of critical industries can be met, and what preventive actions should have been undertaken prior to the scenario's occurrence. This analysis demonstrates that even under Scenario Four the most pessimistic case the model is capable, through the islanded operation of microgrids and full reliance on strategic reserves and distributed generation, of sustaining a minimum level of production in vital industries. This minimum level is sufficient to prevent irreparable damage, such as the freezing of smelting furnaces. In the comparative analysis, the proposed model is benchmarked against three successful global experiences: the reconstruction of Puerto Rico's energy system following Hurricane Maria, employing a solar microgrid approach; the rebuilding of Ukraine's power grid after the attacks of 2022–2024, with an emphasis on distributed generation and storage; and India's Green Industrial Estates program. This comparison reveals that the overall orientation of the model is aligned with global trends and that each of the model's four layers has been tested, in some form, within these successful international experiences. The principal distinguishing feature of the present model is the integration of these four layers into a unified framework and the simultaneous focus on energy, procurement, and governance a systematic combination not observed in any of the aforementioned cases.

### Step Five: Indigenous Implementation Roadmap for Hormozgan Province

The final step of the methodology is the formulation of an operational roadmap in three phases, delineating the sequence of actions, investment prioritization, and key milestones for implementing the model in Hormozgan Province. Phase One: Institutional Infrastructure and Pilot Implementation. In this phase, the provincial Energy and Industrial Resilience Steering Council is formed, and the Joint Investment Fund is registered. The contractual framework for the guaranteed purchase of industrial renewable electricity is drafted and approved by the competent authorities. Concurrently, a pilot project is launched in the West Bandar Abbas industrial hub (encompassing Hormozgan Steel and Al-Mahdi Aluminum) involving the installation of 20 megawatts of solar panels on shed rooftops and adjacent barren lands, together with the deployment of the Smart Energy Management System. The objective of this phase is to demonstrate the model's feasibility, identify implementation barriers, and document lessons learned for province-wide scaling. Phase Two: Expansion and Generalization. Based on the pilot results, the model is extended to the East Bandar Abbas and Qeshm Island industrial hubs. The total distributed solar generation capacity reaches 50 megawatts. The Early Warning and Disruption Prediction System is launched and connected to the Internet of Things network. The shared Industrial Procurement Platform commences operations with the participation of at least 20 major industries in the province, and the first cross-sector synergy agreements such as the supply of steel slag to cement industries are concluded. Phase Three: Maturation and Optimization. In this phase, closed-loop supply chains are fully established, and strategic reserves of raw materials attain the target coverage level of 45 days of consumption. The artificial intelligence algorithms of the Energy Management System are trained on sufficient data and reach a level of maturity enabling automatic and uninterrupted optimization. Resilience indicators are measured quarterly and reported to the Steering Council. The objective of this phase is the complete institutionalization of the model within the province's governance structure and the attainment of the targeted resilience level.

## Conclusion

The present study was carried out with the aim of designing an integrated model to enhance the resilience of the industrial supply chain in Hormozgan Province through the integration of green procurement strategies and distributed renewable generation in the context of the post-war electricity crisis. The post-war energy crisis in Iran, particularly in Hormozgan Province as the beating heart of the country's industrial economy has revealed, in an unprecedented manner, the imperative of transitioning from fragile traditional models to novel resilient systems. The four-layer model presented in this study constitutes a response to this imperative. By combining the four layers of resilient energy supply, green procurement, smart digital management, and institutional governance, the proposed model provides a coherent and operational framework for navigating from the electricity crisis toward supply chain sustainability. The first layer, through the deployment of solar-battery microgrids with islanding capability in industrial hubs, substantially reduces dependence on the vulnerable national grid. The second layer manages the risk of disruption in raw material flows by diversifying suppliers, establishing strategic reserves, and strengthening closed-loop supply chains. The third layer, leveraging digital technologies and artificial intelligence, enables real-time monitoring, disruption prediction, and rapid response. The fourth layer ensures the drivers of implementation and the long-term viability of the model through the design of institutional and financial mechanisms. The principal novelty of this research lies in the horizontal and vertical integration of these four layers. While prior studies have largely examined each of these domains in isolation, the present model demonstrates that genuine resilience is only achieved through the synergy among energy supply, raw material sourcing, information technology, and governance. The comparative analysis with global experiences (Puerto Rico, Ukraine, and India) further showed that, although each of these countries has achieved successes in one of the layers, none has implemented a model as comprehensive and integrated. The four-scenario analysis also confirmed that the model is capable of sustaining a minimum level of production in critical industries even under the most pessimistic condition of a complete national grid blackout. This minimum level, while insufficient in itself for profitability, is vital for preventing irreparable damage to equipment and preserving the capacity for rapid recovery once the crisis subsides. In other words, the proposed model ensures that the province's industries do not cross the point of no return. Policy Implications and Executive Recommendations The findings of this research carry specific implications for national and provincial policymakers. First, the necessity of a paradigm shift from a rationing policy to an empowerment policy in industrial electricity management is clearly revealed. Currently, the primary solution of the Ministry of Energy to address the imbalance is the imposition of restrictions and scheduled outages, which drive industries toward shutdown and capital erosion. The proposed model demonstrates that empowering industries to become active prosumers through the deployment of distributed solar generation not only alleviates pressure on the grid but also fundamentally ensures security of supply. It is recommended that the Ministry of Energy and the Ministry of Industry, Mine, and Trade encourage this transition by offering targeted financial incentives, streamlining administrative processes, and guaranteeing the purchase of surplus electricity. Second, the establishment of a single investment window within the Hormozgan Province Industry, Mine, and Trade Organization could accelerate the implementation timeline of industrial solar projects. The fragmentation of licensing processes across various bodies environmental agencies, the electricity company, and operating banks has currently become one of the principal obstacles. Third, the importance vulnerability analysis revealed that the steel and aluminum industries, owing to their exceptionally high electricity consumption, processes sensitive to interruptions, and pivotal position in the supply chain, hold the highest priority for investment in distributed generation. The targeted allocation of limited reconstruction resources to these industries will yield the greatest returns from the standpoint of the resilience of the province's entire supply chain. Fourth, the deployment of smart energy management systems in the province's ten largest industries can, at a relatively modest cost, dramatically enhance supply chain visibility and lay the groundwork for data-driven decision-making.

# References

- Delbari, A., & Zare, M. (2024). Providing sustainable energy to solve the energy shortage in Hormozgan province using solar power plants. Journal of Solar Energy Research, *8*(1), 1250–1263.
- EIA. (2026). The Crisis in Iran: Implications and actions for sustainable business. BSR Insights.
- Gianesello, S., & Desmidt, S. (2025). Global Gateway investments in fragile settings: How to do it? ECDPM Briefing Note.
- Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. Energy Strategy Reviews, *24*, 38–50.
- IRENA. (2024). World energy transitions outlook 2024: 1.5°C pathway. International Renewable Energy Agency.
- Ivanov, D., & Dolgui, A. (2020). Viability of intertwined supply networks: Extending the supply chain resilience angles towards survivability—A position paper motivated by COVID-19 outbreak. International Journal of Production Research, *58*(10), 2904–2915.
- Ivanov, D., Dolgui, A., & Sokolov, B. (2019). The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. International Journal of Production Research, *57*(3), 829–846.
- Jahangoshai Rezaee, M., Yousefi, S., & Hayati, J. (2021). Prioritizing renewable energy resources of Hormozgan province. Energy Sources, Part B: Economics, Planning, and Policy, *16*(2), 158–174.
- Khalili, S., & Duecker, D. (2013). A comparative study of green supplier selection in the Iranian and Canadian automotive industries. International Journal of Production Research, *51*(23–24), 7057–7072.
- La Camera, F. (2026, April 2). Countries are turning to 'structurally more resilient' energy sources as oil and gas crisis deepens. Fortune.
- Luthra, S., Garg, D., & Haleem, A. (2016). The impacts of critical success factors for implementing green supply chain management towards sustainability: An empirical investigation of Indian automobile industry. Journal of Cleaner Production, *121*, 142–158.
- Nasiri, F., & Huang, G. Q. (2008). A fuzzy decision aid model for environmental performance assessment in waste recycling. Environmental Modelling & Software, *23*(6), 677–689.
- Pettit, T. J., Fiksel, J., & Croxton, K. L. (2010). Ensuring supply chain resilience: Development of a conceptual framework. Journal of Business Logistics, *31*(1), 1–21.
- Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. The International Journal of Logistics Management, *20*(1), 124–143.
- Pourmokhtari, P., & Sharifi, A. (2024). Barriers to green procurement of the Iranian construction industry: An interpretive structural modeling approach. International Journal of Environmental Science and Technology, *21*(4), 3599–3616.
- Rajabi, A., & Afshar, M. (2022). An evolutionary game-theoretic approach to study the technological transformation of the industrial sector toward renewable electricity procurement: A case study of Iran. Applied Energy, *318*, 119083.
- apenergy.2022.119083 Rajabzadeh, M., & Hosseini, S. A. (2024). Resolving Iran's electricity shortage crisis through integrated energy policy: A system dynamics approach. Energy Policy, *187*, 114012.
- Sarkis, J. (2012). A boundaries and flows perspective of green supply chain management. Supply Chain Management: An International Journal, *17*(2), 202–216.
- Scholten, K., & Schilder, S. (2015). The role of collaboration in supply chain resilience. Supply Chain Management: An International Journal, *20*(4), 471–484.
- Sharma, V., & Garg, S. K. (2024). Enhancing supply chain resilience with recovery strategies under electricity shortages. Computers & Industrial Engineering, *190*, 110032.

- Sheffi, Y. (2005). The resilient enterprise: Overcoming vulnerability for competitive advantage. MIT Press.
- Tehrani, M., & Khorasanizadeh, H. (2023). Estimation of sustainable energy supply in Bandar Abbas Industrial Estate No. 2 using solar panel installed on the roof of the building. Journal of Solar Energy Research, *8*(2), 1340–1352.
- Tehran Times. (2025, December 23). IMIDRO, NDF move to shield mining industry from power cuts with renewable contracts. Tehran Times.
- Tukamuhabwa, B. R., Stevenson, M., Busby, J., & Zorzini, M. (2015). Supply chain resilience: Definition, review and theoretical foundations for further study. International Journal of Production Research, *53*(18), 5592–5623.
- Vosooghnia, M., & Marzband, M. (2024). Feasibility construction of a 4 MW PV power plant to provide sustainable electricity to Bandar Abbas Industrial Estate. Journal of Solar Energy Research, *8*(1), 1250–1263.
- World Bank. (2024). Distributed renewable energy: A pathway to universal electricity access. World Bank Group.
- Zadeh, L. A. (1965). Fuzzy sets. Information and Control, *8*(3), 338–353.