

The Energy Security Strategy Model for Industry in Indonesia: An Interpretive Structural Model and AHP Approach

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ABSTRACT

The industrial sector is a major energy consumer and thus requires a robust energy security system to ensure reliable energy availability. This study aims to develop a strategic model of energy security tailored to Indonesia's industrial sector. A systems-based methodology is employed, consisting of three stages: (1) identifying energy management issues through a desk study of existing energy security literature, (2) determining strategic priority indicators using the Analytical Hierarchy Process (AHP), and (3) constructing a hierarchical model of energy security strategy using Interpretive Structural Modeling (ISM). The primary goal is to optimize fossil energy availability, with the main strategic focus on ensuring a stable energy supply. The highest priority of the strategic program is the diversification of energy sources (importance weight: 0.88), which aims to ensure energy supply through the adoption of renewable energy. The second priority is reducing the mismatch between energy source locations and industrial areas (importance weight: 0.86), which is expected to improve energy accessibility and equity through targeted energy policy. The third is the development of emission-reducing technologies (importance weight: 0.84) implemented via energy conservation initiatives. This study highlights the need for multi-stakeholder collaboration: the government functions as a regulator and coordinator, while industrial entrepreneurs take the lead in implementing renewable energy initiatives supported by energy research institutions, energy providers, the public, and industry associations. To ensure the model's effectiveness, energy security performance should be evaluated using indicators such as overall energy balance, socio-economic dimensions, domestic energy resources, international energy supply and demand, and energy diversification.



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1. Introduction

In Southeast Asia, Indonesia accounts for the highest energy demand, contributing approximately 44% of the total regional consumption, followed by Thailand and Vietnam.



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Data from the ASEAN Center for Energy also indicate that fossil fuels are projected to remain dominant in the regional energy mix, reaching up to 80% by 2030. With this level of demand, Indonesia is classified as the largest energy consumer in Southeast Asia. Driven by rapid economic and population growth, the country faces escalating pressure on its energy supply, culminating in a full-scale energy crisis and scarcity. It is projected that electricity demand will grow by an average of 7% annually over the next 30 years. For instance, household electricity consumption is expected to increase significantly, from 21.52 GWh in 2000 to around 444.53 GWh in 2030. Energy consumption in Indonesia is dominated by four main sectors: household, commercial, industrial, and transportation. Currently, the transportation and industrial sectors are the largest consumers, each accounting for approximately 39% of total energy use. The household sector follows with 13%, while the commercial sector contributes 4%. A key challenge in the industrial sector is the consistent increase in energy demand, which is projected to grow at an average annual rate of 3.9%. The industrial sector is expected to remain the largest contributor to total final energy demand until 2050. Globally, industry consumes nearly half of the world's total energy, making energy efficiency in this sector a critical concern [1]. This is especially true for energy-intensive industries involved in resource processing, such as agro-based industries, including agriculture, plantations, and forestry.

As a critical production factor in modern industry, energy plays a strategic role in enhancing productivity levels. Beyond serving as a source of state revenue, energy functions as a key catalyst for economic growth and a determinant of national resilience. The industrial sector consumes substantial amounts of energy for both core process units—such as processing, manufacturing, and packaging—and supporting utility operations. These processes typically rely on multiple machines and require significant thermal energy input. In general, fossil fuels such as oil, gas, and coal are the primary energy sources used. In 2020, energy consumption in Indonesia's industrial sector—excluding biomass—reached 40.3 million TOE. Coal accounted for the largest share at 39.4%, followed by gas at 33.5% and electricity at 18.8%. Gas is predominantly utilized in industries such as ceramics, petrochemicals, and fertilizers. At the same time, coal is widely used in cement, textile, and paper production, among others. The ongoing global energy crisis and rising energy demands necessitate transformative approaches to energy conservation, particularly in the utilization of fossil fuels. Over the past two decades, energy management has evolved significantly within industrial firms. Previously considered a low-priority issue due to its relatively minor share in total production costs, energy has now become a strategic concern for corporate management [2]. Indonesia possesses vast potential in both fossil and renewable energy resources. However, suboptimal utilization of this potential has undermined efforts to ensure national energy sovereignty and long-term energy security. Since 2004, Indonesia has become a net importer of oil and gas due to uncontrolled domestic consumption and persistent weaknesses in energy governance, particularly in exploration and development activities. Consequently, the country's energy security position has continued to deteriorate in recent years.

Energy policies in Indonesia encompass renewable energy development, alternative energy promotion, and energy conservation initiatives. In addition, the government has prioritized improving energy accessibility, guided by the principles of equity, sustainability, and environmental awareness, to achieve energy independence and strengthen national energy security. Addressing these issues requires the establishment of a comprehensive national energy policy that plays a central role in securing energy sovereignty. This is critical, as threats to energy security extend beyond the energy sector itself, potentially affecting the national economy, social welfare, and both domestic and global socio-political stability. Given Indonesia's limited fossil fuel reserves, the country

has a vested interest in managing and utilizing energy resources as effectively and efficiently as possible [3]. Energy security has become a major policy concern, particularly with the evolution of modern energy systems. Policymakers have implemented strategic measures to protect nations and economies from energy-related vulnerabilities. At the same time, scholars and analysts continue to explore the conceptual and operational frameworks of energy security. In the context of Indonesia, a robust energy security strategy is essential to support industrial development and national economic growth. The key principle is to ensure supply reliability through industrial and technological interventions. The concept of energy security first gained global prominence during the 1973 oil crisis. It was redefined under the Kyoto Protocol in 1997, which emphasized sustainability and global cooperation in energy policy. More recently, the geopolitical impact of the Russia–Ukraine conflict has disrupted global energy markets and underscored the enduring relevance of energy security in international relations. These global events highlight the critical need for rigorous studies and policies to maintain the stability and resilience of energy supply systems.

Despite the increasing volume of research on energy security, comprehensive literature reviews and survey-based studies in this area remain limited. According to [4], energy security has been a significant research focus over the past 28 years and has become an integral part of the energy market discourse. Previous studies have explored various dimensions of energy security, including energy audit practices and program evaluations [5], system and process optimization through statistical modeling [6], the formulation and assessment of end-use industrial energy policies [7], and benchmarking of industrial energy efficiency [8]. Furthermore, [9] introduced a comprehensive approach to energy management by presenting multiple models and developing an innovative software tool for benchmarking energy management systems in industrial settings. Nevertheless, a notable gap remains in the literature. Despite the magnitude and complexity of energy-related challenges in the industrial sector, the topic of energy security has not been explored proportionately. As a concept, energy security has generated considerable debate regarding its definition, scope, and methodological approach [10]. Strategic energy development is typically framed within a top-down, hierarchical governance model, where policy direction is established at the national level and operational implementation is delegated to regional and local authorities [11]. However, existing models often lack clarity in defining strategic priorities for industrial energy management and the roles of relevant stakeholders. It is essential to contextualize energy security within the framework of energy policy-making priorities [12-14].

Implementing an effective energy security system requires a strategic model that supports resilient energy management and ensures the continuous availability of energy at affordable costs. Energy audits play a pivotal role in assessing energy security by evaluating energy efficiency and identifying potential savings in consumption and operational costs. These audits involve a structured set of procedures for planning and measuring energy performance. When organizations understand and apply these procedures systematically, they can enhance their energy management practices, identify efficiency improvement opportunities, and achieve long-term sustainability. Integrating energy planning with performance measurement creates a robust framework that enables organizations to more accurately evaluate energy use, manage associated risks, and maintain energy security while pursuing strategic goals. One promising opportunity in developing an energy security strategy model lies in adopting a holistic approach to identifying and analyzing key determinants of energy security. As demonstrated in the case of Lithuania, a diverse portfolio of energy sources—both in terms of supply and production—can significantly enhance system resilience against supply and demand shocks [15]. In the context of Indonesia's industrial sector, which encompasses a wide

range of industry types and scales, a successful model must begin with identifying specific objectives and relevant indicators of energy security. This includes determining strategic priorities by mapping relevant issues, formulating targeted strategies, and constructing a hierarchical model that reflects the interrelations among components and assigns importance weights to each element. Given the diversity in industrial processes, energy efficiency is highly contingent upon the types of equipment and technologies employed in production. This study aims to develop a strategic model of energy security tailored for the Indonesian industrial sector, with objectives to enhance energy efficiency, reduce dependence on fossil fuels, and anticipate risks related to energy supply. The main contribution of this research lies in its proposal of an adaptive, multi-layered energy strategy model, along with the refinement of decision-making frameworks in energy policy. This study is expected to enrich the academic literature through the application of Interpretive Structural Modeling (ISM) and the Analytical Hierarchy Process (AHP) while also offering practical insights to support sustainable industrial development in Indonesia.

2. Methods

This study focuses on the processing industry in Indonesia, particularly sectors with high energy intensity, such as the palm oil processing industry (including cooking oil and oleochemicals), the pulp and paper industry, the food and beverage industry (e.g., refined sugar, cocoa, instant noodles, and light beverages), animal feed manufacturing, and meat and poultry processing. The primary non-renewable energy sources examined in this study include oil, gas, and coal. Primary data were collected through expert surveys using focus group discussions (FGDs) and in-depth interviews. The FGDs were conducted to identify key issues and constraints within the energy security system in the industrial sector. Participants included representatives from the Ministry of Industry, the Ministry of Energy and Mineral Resources, energy research institutions, academic experts, industrial entrepreneurs, energy providers, and professional associations. In-depth interviews were carried out to complete the paired comparison matrix, which served to rank the constraints, indicators, strategic focus areas, program priorities, and stakeholder roles within the industrial energy security framework. A total of five experts representing energy research institutions, academia, industry practitioners, energy companies, and associations participated in the interviews.

The formulation of issues and constraints within the industrial energy security system is guided by the legal principles and objectives outlined in Law No. 30 of 2007. The structure of the energy security model used in this study adopts the framework developed by the Agency for the Assessment and Application of Technology of the Republic of Indonesia, which includes four key elements: availability, affordability (ability to utilize), assessability (ability to provide), and acceptability (community acceptance). The identification process was conducted by defining the main objectives (elements) and their corresponding indicators (sub-elements) within the energy security system. This was achieved through a desk study that reviewed key national policy documents related to energy security, including the National Energy Management Blueprint (Presidential Regulation No. 5 of 2006), the National Energy General Plan (Presidential Regulation No. 22 of 2017), and the Indonesia Energy Outlook 2020 published by the Agency for the Assessment and Application of Technology. Secondary data were also utilized to support the development of the model. These data include documented energy security issues, structural elements, and sub-elements that have been previously established and agreed upon by various national energy institutions. The secondary sources comprised both qualitative and quantitative literature relevant to the field of energy security and policy in Indonesia.

The research methodology adopts a systems approach comprising three main stages. The first stage involves identifying energy management problems in the industrial sector. The second stage focuses on determining the priority of indicators within the strategic model by formulating and mapping strategies related to energy security issues using the Analytical Hierarchy Process (AHP). The third stage entails constructing a hierarchical model of the energy security strategy through the application of Interpretive Structural Modeling (ISM). The prioritization of energy security indicators is performed using AHP, a structured method designed to determine the relative importance of objectives (elements) and indicators (sub-elements) within the energy security system. This method facilitates the decomposition of a complex, unstructured, and strategic decision-making problem into a hierarchical framework. According to [16], AHP is a reliable, rigorous, and robust tool for capturing and quantifying subjective expert judgments within multi-criteria decision-making (MCDM) contexts. The AHP methodology enables decision-makers to compare elements pairwise, synthesize the results, and rank the priorities, thereby supporting transparent and systematic policy formulation under conditions of uncertainty.

According to [16], the Analytical Hierarchy Process (AHP) algorithm comprises several systematic stages. (1) The first step involves constructing a hierarchical structure by breaking down the decision problem into multiple levels, beginning with the overall goal, followed by criteria, sub-criteria, and finally, alternatives. (2) The second step is the development of pairwise comparison matrices, where elements at each hierarchical level are compared two using a scale of relative importance ranging from 1 to 9. Inconsistencies in judgment may occur if the transitivity rule is violated, i.e., when the product of two comparisons does not equal the third. The degree of inconsistency is quantified through the calculation of the maximum eigenvalue λ_{max} , followed by the Consistency Index (CI), computed as $CI = (\lambda_{max} - n)/(n - 1)$, and the Consistency Ratio (CR), which is the ratio between CI and the Random Index (RI). A CR value less than or equal to 0.1 indicates that the consistency of the judgments is acceptable. (3) The third step involves calculating the inconsistency rate in detail, which includes deriving the weighted sum vector, computing the consistency vector by dividing each element of the weighted sum vector by the corresponding local priority, and obtaining λ_{max} as the average of the consistency vector. The inconsistency index (II) is then calculated as $II = (\lambda_{max} - m)/(m - 1)$, and the inconsistency ratio (IR) is defined as $IR = II/IRI$, where IRI is derived from simulation-based tables. (4) The fourth step is to calculate local priorities, which represent the relative weights of each criterion and alternative, using various methods such as the eigenvector approach, arithmetic or geometric mean, and least squares techniques. (5) The fifth step entails computing the overall priority of each alternative by aggregating its local priorities across all criteria using a weighted sum. (6) Finally, alternatives are ranked based on their overall priority values, with the highest-ranking alternative being the most preferred.

The development of a hierarchical model for energy security strategies in this study utilizes the Interpretive Structural Modeling (ISM) approach. ISM is a strategic policy formulation tool that facilitates a structured group learning process to address complex systems by producing graphical and narrative-based structural models. It provides a conceptual roadmap for understanding multifaceted problems. It supports decision-making by clarifying relationships among variables and identifying appropriate courses of action. The ISM method, which incorporates the nine-element framework proposed by Saxena, is implemented in two main phases: sub-element classification and hierarchical compilation. The construction process fosters transparency and shared understanding among participants, with substantial analysis and communication typically occurring during ISM sessions. According to [17], the ISM technique involves several key steps. (1) Identifying elements relevant to the problem, often through expert surveys; (2)

establishing contextual relationships between these elements through pairwise comparisons; (3) developing a Structural Self-Interaction Matrix (SSIM) to capture these relationships; (4) transforming the SSIM into a reachability matrix while verifying transitivity—based on the assumption that if element A influences B, and B influences C, then A also influences C; (5) partitioning the reachability matrix into different hierarchical levels; (6) constructing a directed graph (digraph) to visualize the relationships and removing transitive links; (7) converting the digraph into a finalized ISM-based model by assigning statements to each node, and (8) reviewing the model to ensure conceptual consistency and making necessary refinements.

The interpretation of ISM results includes classifying elements into four categories: (S1) autonomous (weak driver–weak dependent), (S2) dependent (weak driver–strong dependent), (S3) linkage (strong driver–strong dependent), and (S4) independent (strong driver–weak dependent). In constructing the SSIM, four symbols are used to define the direction of relationships between elements i and j : V (i influences j), A (j influences i), X (mutual influence), and O (no influence). These symbols are then converted into binary values to form the initial reachability matrix, where $e_{ij} = 1$ indicates the presence of a contextual relationship and $e_{ij} = 0$ indicates its absence. As emphasized by [18], the frequent occurrence of industrial energy security issues underscores the need for an integrated and systematic approach to strategy development. In this study, AHP is employed to assign weights to strategic program factors and to evaluate their relative importance. At the same time, ISM is used to map and explain the interrelationships among these factors intuitively. Despite being developed over three decades ago, both AHP and ISM remain highly relevant due to their robustness and adaptability in complex decision-making environments. The hierarchical model developed in this study comprises five levels—goals, strategic focus, key factors, stakeholders, and programs—and illustrates the interconnections and relative importance among elements to determine strategic priorities effectively.

3. Results and Discussion

According to [18], in the current context of rapid industrial development, the situation is further intensified by the ongoing energy crisis. To ensure the continuity of industrial operations, several critical infrastructures must be available, particularly access to electricity, natural gas, and fuel. These energy provisions are essential to support uninterrupted industrial activities. Based on the consensus among various national energy security institutions—reflected in multiple policy documents as previously described—three primary issues have been identified as key challenges to industrial energy security in Indonesia. These include (1) the unavailability or limited supply of fossil energy, (2) the inefficient utilization of fossil energy, and (3) the suboptimal development of alternative energy programs. These three issues are closely interconnected and constitute a fundamental component of industrial energy management. Each issue is further elaborated into a series of specific constraints, totaling 14 sub-elements (E1–E14), which represent detailed barriers that hinder the achievement of energy security in the industrial sector. A comprehensive summary of these issues and their corresponding constraints is presented in Table 1.

Recent studies have expanded the concept of the energy efficiency gap by highlighting that incorporating energy management practices can further enhance energy performance. This includes not only technical improvements but also non-technical aspects such as enhanced operational practices [5, 18]. Previous research has also emphasized that the limited implementation or delayed adoption of available energy-efficient technologies is often due to various structural and behavioral barriers [19].

Table 1. The Issues and The Constrains of Energy Security Systems in The Industrial Sector

No	Elements (Issues)	No	Sub Elements (Constraints)
1.	Unavailability of fossil energy (E1)	1.	Nonoptimality of coordination among agencies related to the energy supply (KS-E1)
		2.	Nonoptimality of Energy conservation programs and energy resources (KE-E2)
		3.	Nonoptimality Diversification of energy sources programs(DDE-E3)
		4.	The recurrence of a discrepancy between the energy source and the location of industry (PPL-E4)
2.	Inefficiency of Utilization of fossil energy (E2)	5.	Nonoptimality Development of technology that is capable of reducing emissions (PTE-E5)
		6.	Constraints in terms of the application of energy-efficient process technology (PTH-E6)
		7.	Application of the Energy Management System(ISO 50001:2011) to regulate and supervise the amount of energy consumed in industrial uneven (PMS-E7)
		8.	Nonoptimality restructuring machining in order to use energy more efficiently (RPI-E8)
		9.	Construction of a waste management industry that is integrated with a variety of industries in which voracious energy is not realized evenly (IPL-E(9))
3.	Nonoptimality of development of alternative energy (E3)	10.	The provision of infrastructure that supports the provision of alternative energy isn't yet fully available (PIE-E10)
		11.	Nonoptimality program of technology transfer to industry in production process technology of alternative Energy (TTI-E11)
		12.	Investment assistance program in the provision of alternative energy in the industry (IEA-E12)
		13.	Constraints in terms of reward or easiness given to industries that use alternative energy were not realized evenly (REA-E13)
		14.	Weak subsidy policies that support the development of alternative Energy (SEA-E14)

Furthermore, the inherent characteristics of many energy-efficient technologies—such as high upfront investment, integration complexity, or operational uncertainty—pose additional challenges to implementation [3]. From a technical standpoint, the development of efficient technologies with minimal emissions is essential. This aligns with the findings of [20], which suggest that emission reduction goals can be synergized with other energy-related objectives, such as promoting indigenous renewable resources and minimizing local environmental pollution. Policymakers are, therefore, encouraged to design interventions that maximize these synergies while avoiding unintended disincentives, such as excessive cost-cutting measures. In this study, the three main issues of industrial energy security were further broken down into 14 specific constraints (E1–E14) that represent actionable sub-elements of the system. The analysis of contextual relationships among these elements, as illustrated by the reachability matrix, reveals that Element 2 (inefficiency in the utilization of fossil energy) and Element 3 (non-optimal development of alternative energy) exhibit the highest driver power values. This indicates that these two elements exert a strong influence over the system and must be prioritized

in strategy formulation. In contrast, Element 1 (unavailability of fossil energy) has the lowest driver power, suggesting that while it remains a critical issue, it functions more as a consequence than as a primary driver of industrial energy insecurity. As such, it should be addressed through the resolution of the more fundamental issues identified in Elements 2 and 3 (see Figure 1).

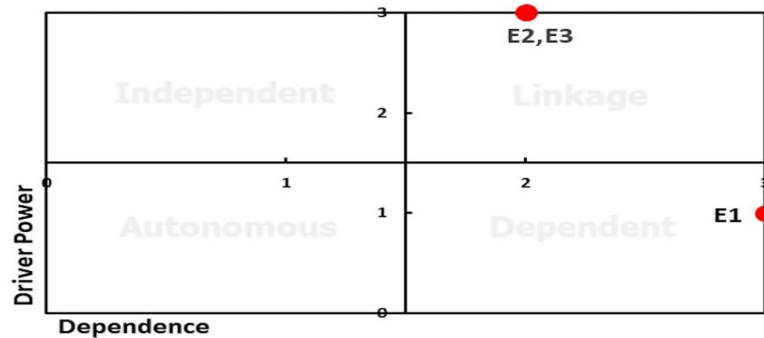


Figure 1. Reachability Matrix of The Issues of Energy Security System in

Table 2. Average Values of Pairwise Comparison Matrix For Sub Elements (Constraints) of Energy Security System in The Industrial Sector

	KS	KE	DDE	PPL	PTE	PTH	PSM	RPI	IPL	IPT	TTI	IEA	REA	SEA
KS	1	0.25	0.25	0.25	4	0.25	0.333	4	4	4	5	0.25	0.25	0.25
KE	4	1	0.25	0.25	4	0.25	0.333	4	4	0.25	4	0.25	0.25	0.25
DDE	4	4	1	0.333	0.25	0.25	0.25	4	4	4	4	0.25	0.25	0.25
PPL	0.25	0.25	0.25	1	0.25	0.25	0.25	0.333	4	4	4	0.25	0.25	0.25
PTE	0.25	0.25	4	4	1	4	4	0.25	5	5	5	4	4	4
PTH	4	4	4	4	0.25	1	4	4	5	4	4	4	4	4
PSM	0.25	0.25	0.333	0.25	0.25	0.25	1	0.25	4	4	0.333	0.333	0.333	0.333
RPI	0.25	0.25	0.25	0.333	0.333	0.32	0.25	1	0.25	0.25	0.25	0.25	0.25	0.25
IPL	0.25	0.25	0.2	4	4	0.25	4	4	1	0.25	0.25	4	4	4
IPT	0.25	0.25	0.333	4	4	0.333	4	4	4	1	0.25	4	4	4
TTI	0.2	4	0.2	4	4	0.25	3	4	4	4	1	0.25	4	5
IEA	4	4	4	4	0.333	4	4	4	4	4	4	1	0.25	0.2
REA	4	4	4	4	0.25	4	4	4	4	4	4	4	1	5
SEA	4	4	0.25	4	4	0.25	3	4	5	5	5	5	0.2	1

The inefficient utilization of fossil energy directly affects its availability, making the supply increasingly uncertain and unreliable. To properly assess the availability of fossil energy, it is essential to evaluate the severity of vulnerabilities—referred to as "valleys"—within the context of security and energy supply in a regional integrated energy system. This assessment should identify specific weak points or shortfalls that require improvement [21]. Another significant issue is the suboptimal development of alternative energy sources. The lack of progress in this area remains a pressing concern. To enhance the effectiveness of alternative energy development, it is crucial to strengthen coordination and evaluation mechanisms. These efforts should ensure that renewable energy is effectively integrated into the national power system and consumed efficiently

[22, 23]. Within the broader framework of industrial energy security, a total of 14 sub-elements (constraints) have been identified, each contributing to the complexity of the system. The relative importance of these constraints was evaluated using pairwise comparisons, with the average values summarized in Table 2.

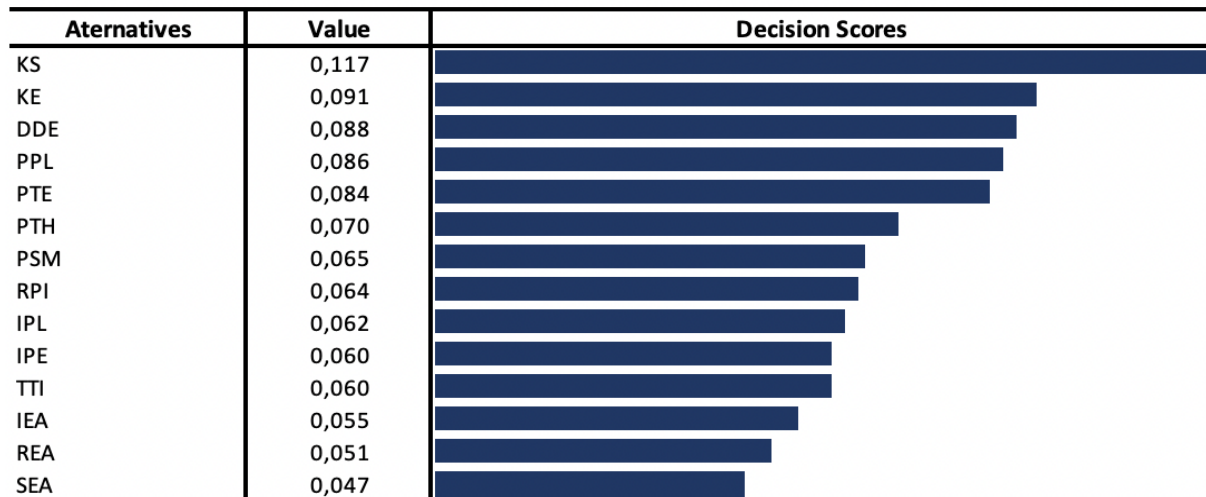


Figure 2. Ranking of The Constraints of Energy Security Systems in The Industrial Sector

Based on the average values derived from the pairwise comparison of weighted importance between sub-element constraints, and with a Consistency Ratio (CR) of 0.02—indicating high reliability of the expert judgments—the ranking of energy security sub-elements was obtained and is presented in Figure 2. The sub-element with the highest priority is Sub-element 1, which reflects the non-optimal coordination among institutions involved in energy supply. This suggests that institutional misalignment remains a critical bottleneck in achieving energy security. Conversely, the sub-element with the lowest priority is related to weak subsidy policies supporting alternative energy development, indicating that this issue, while relevant, exerts minimal influence as a driver within the system. This prioritization implies that sub-elements categorized within the dependent sector have limited systemic influence and rely heavily on changes initiated by elements in the independent sector. Consequently, their role in the energy security strategy of the industrial sector is reactive and positioned to follow strategic shifts driven by more influential factors (see Figure 3). The mapping of sub-elements, as illustrated in Figure 4, confirms that the highest driver power is associated with Sub-element 1—indicating the need to enhance inter-ministerial coordination regarding energy supply—and Sub-element 2, which highlights the urgent need to implement comprehensive energy conservation programs. These findings are consistent with [16], which emphasizes that the successful deployment and scaling-up of renewable energy technologies require the presence of well-defined policies, institutional clarity, and measurable targets. Similarly, the results support [17], which identifies energy conservation as a strategic priority in achieving substantial improvements in national energy efficiency plans.

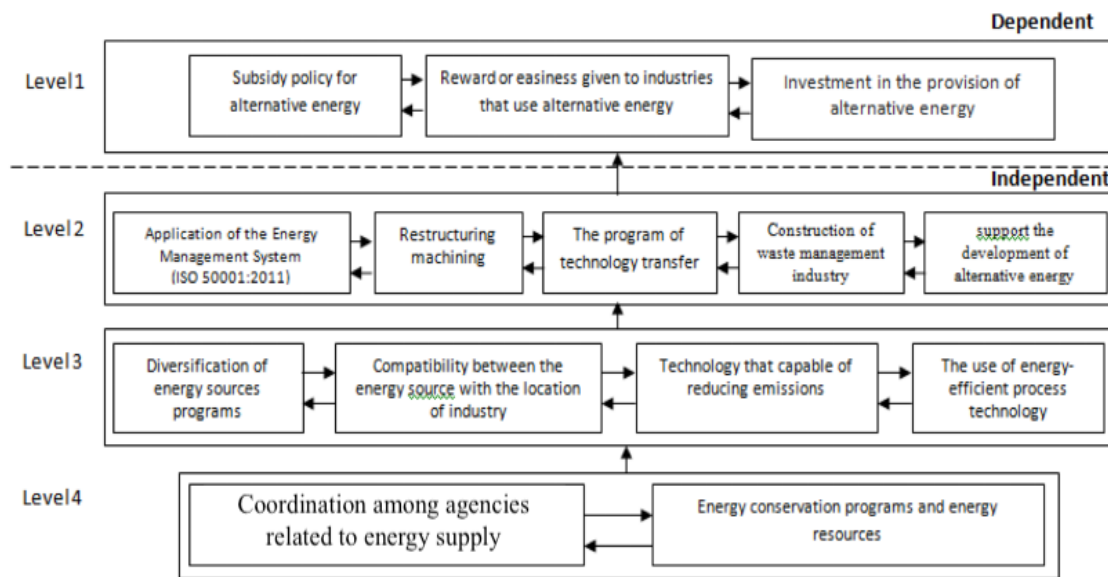


Figure 3. Hierarchy Structure of The Issues and Constraints of Energy Security Systems in The Industrial Sector

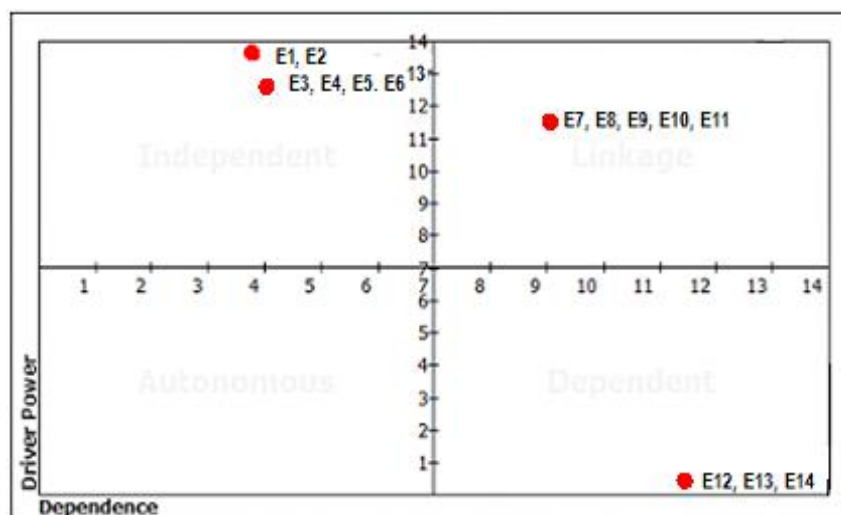


Figure 4. Reachability Matrix of The Constraints of Energy Security Systems in The Industrial Sector

The analysis reveals that the lowest driver power values are associated with Sub-element 12 (the need for investment assistance in alternative energy development), Sub-element 13 (the need for incentives or rewards for industries utilizing alternative energy), and Sub-element 14 (inadequate subsidy policies to support alternative energy initiatives). Although these constraints have limited influence in driving systemic change, they still represent critical issues that must be addressed to resolve broader energy security challenges. These findings highlight the need for aligning strategic goals with these constraints to ensure more effective policy intervention and implementation.

To follow up on the highest-ranked constraint—the non-optimal development of alternative energy—three overarching goals were formulated. These goals are further elaborated into 10 sub-element indicators (E1–E10) that form the foundation of the industrial energy security model, as outlined in Table 3. Subsequent analysis of driver

power values indicates that the highest systemic influence is held by Element 2 (efficiency of fossil energy utilization) and Element 3 (enhancement of alternative energy development). Meanwhile, Element 1 (optimization of fossil energy availability) demonstrates the lowest driver power, making it a priority area that must be supported through interventions targeting the more influential goals (see Figure 5).

The ten sub-element indicators associated with these goals were evaluated using pairwise comparison methods, and the results—along with their consistency—are presented in Table 4. With a Consistency Ratio (CR) of 0.02, the expert judgments used in the weighting process are considered highly reliable. Based on the average values of the weighted importance scores, the ranking of energy security indicators was established and is illustrated in Figure 6.

Table 3. The Goals and The Indicators of Energy Security System in The Industrial Sector

No	Elements (Goals)	No	Sub-Elements (Indicators)
1	Optimization of fossil energy availability (E1)	1	Increased cooperation among the agencies related to energy supply (PKS-E1)
		2	Fossil energy conversion into renewable Energy (PKE-E2)
		3	Diversification of energy sources programs (PDE-E3)
		4	Mapping correspondence between the energy source to the location of industry (PKL-E4)
2	Efficiency of fossil energy (E2)	5	Technology development and technology transfer efficiently and minimal emissions (PTE-E5)
		6	Application of energy management system programs (ISO 50001:2011) to regulate and supervise the amount of energy consumed in industry (PME-E6)
		7	Restructuring machining which accompanied with some incentives so that use energy more efficiently (PRM-E7)
		8	Waste industry management development program that is integrated with variety industry which voracious energy (PIL-E8)
3	Enhancement of alternative energy development (E3)	9	Budgeting funds for the construction of infrastructure to support the provision of alternative energy in priority area (PPI-E9)
		10	Plan subsidy program of alternative energy development (PSE-E10)

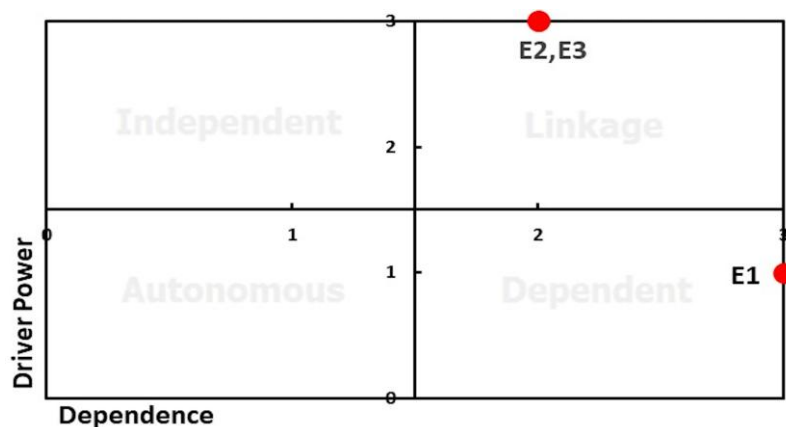


Figure 5. Reachability Matrix of the Goals of Energy Security System in The Industrial Sector

Table 4. Average Values of Pairwise Comparison Matrix For Sub Elements (Indicators) of Energy Security System in The Industrial Sector

	PKS	PKE	PDE	PKL	PTE	PME	PRM	PIL	PPI	PSE
PKS	1	0.25	0.25	4	0.25	4	4	4	4	4
PKE	4	1	0.25	4	0.25	0.333	4	4	0.25	0.25
PDE	4	4	1	0.333	0.25	3	3	3	0.25	0.25
PKL	0.25	0.25	3	1	0.25	4	0.333	4	0.25	0.25
PTE	4	4	4	4	1	4	5	4	3	4
PME	0.25	3	0.333	4	0.25	1	4	4	4	0.333
PRM	0.25	0.25	0.333	3	0.2	0.25	1	0.25	0.25	0.25
PIL	0.25	0.25	0.25	0.25	0.25	0.25	4	1	0.25	0.2
PPI	0.25	4	0.333	4	3	4	4	4	1	0.2
PSE	0.25	0.25	0.25	4	0.25	0.25	4	5	5	1

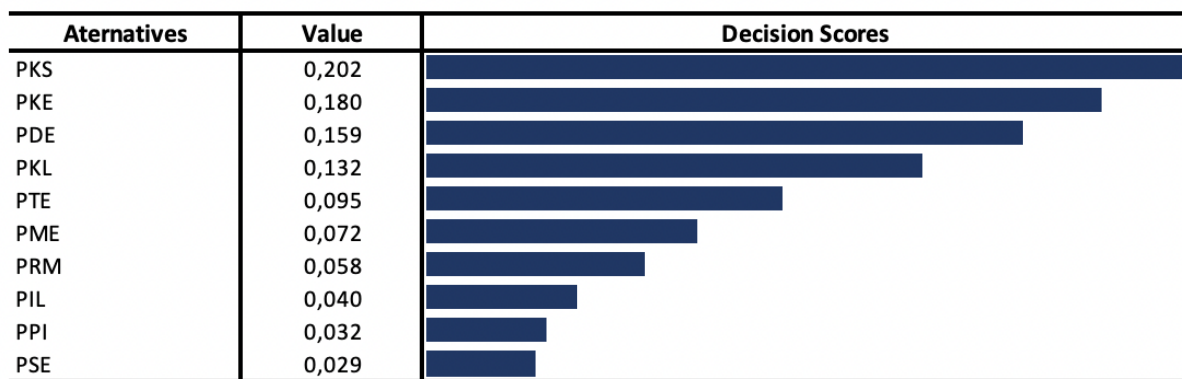


Figure 6. Ranking of The Indicators of Energy Security System in The Industrial Sector

Figure 6 illustrates that the optimization of fossil energy availability (E1) holds the highest driver power value among the energy security goals. Within this element, the most influential sub-element is PKS/E1—enhancing cooperation among directorates involved in energy supply. As executive bodies of the government, these directorates play a pivotal role in ensuring effective inter-agency coordination, which is essential for the successful implementation of national energy strategies. This finding aligns with the results of [24], which emphasize that the absence of strong institutional coordination, dedicated government bodies, financing mechanisms, research institutions, and microfinance channels—along with the lack of clear policy targets—constitute major barriers to the advancement of renewable energy development.

The hierarchical structure of industrial energy security indicators is further detailed in Figure 7, which shows that fossil energy utilization efficiency and the development of alternative energy function as linkage elements. These elements serve as both drivers and dependents within the system, highlighting their dual influence. Improvements in these areas are expected to have a significant impact on the overall system, particularly in supporting the optimization of fossil energy availability, which remains a key strategic objective within Indonesia's industrial energy security framework.

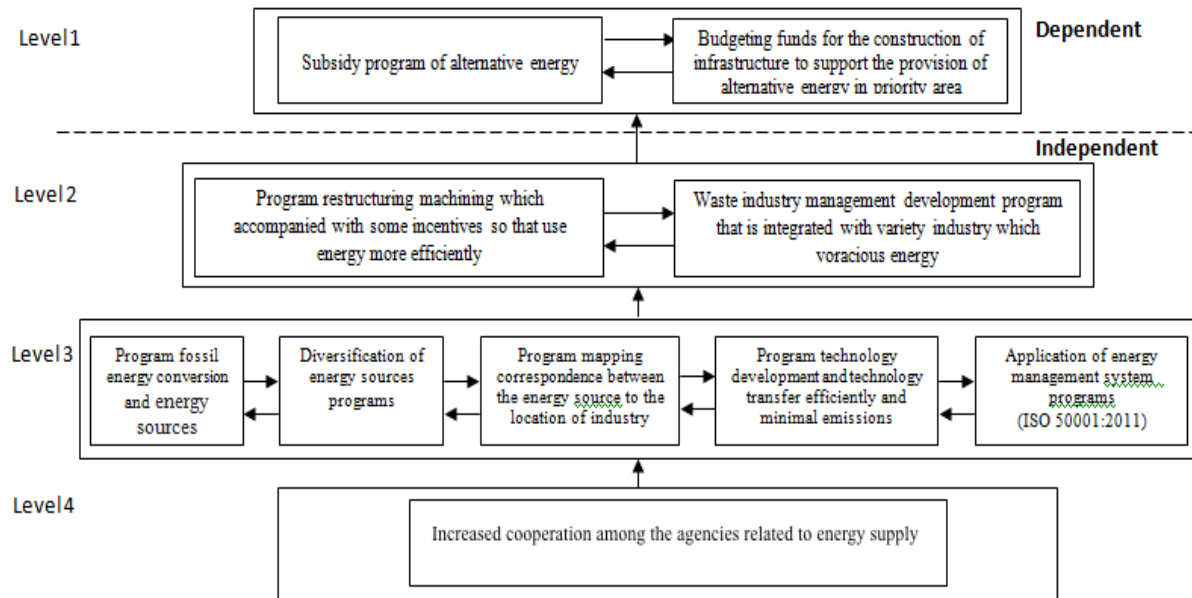


Figure 7. Hierarchical structure of The Goals and The Indicators of Energy Security System in The Industrial Sector

The results presented in Figure 8 show that the indicator with the highest driver power is PKS-E1—enhancing cooperation among agencies related to energy supply. This indicator plays a central role in driving the overall energy security strategy, particularly in relation to improving fossil energy availability. In contrast, the indicators with the lowest driver power values are PPI-E9—budgeting funds for the construction of infrastructure to support the provision of alternative energy in priority areas, and PSE-E10—planning subsidy programs for alternative energy development. Despite their lower systemic influence, these indicators remain essential follow-up items as they support foundational elements of long-term energy sustainability. Based on the reachability matrix analysis of the energy security indicators illustrated in Figure 8, a strategic formulation process was undertaken to realize the overarching goal of the industrial energy security system. This goal centers on the optimization of fossil energy availability (E1), with PKS/E1 identified as the key sub-element for implementation. These findings underscore the importance of strengthening institutional coordination as a strategic lever, which not only drives system-wide improvements but also facilitates the achievement of broader energy security objectives in Indonesia's industrial sector.

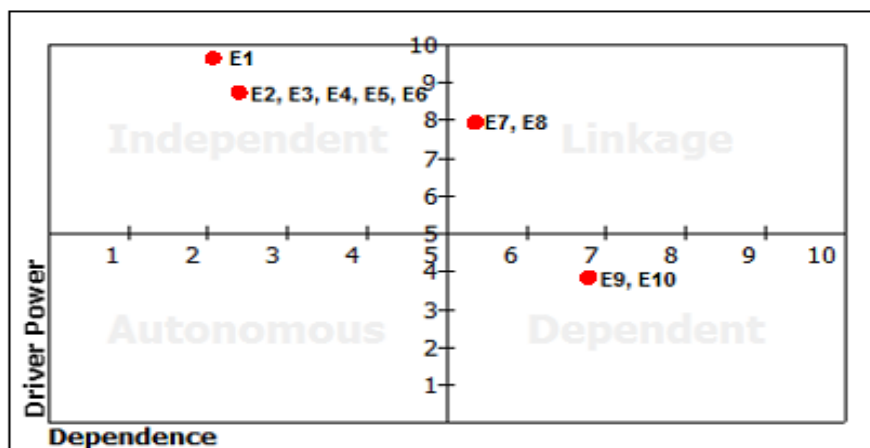


Figure 8. Reachability Matrix of The Indicators of Energy Security System in The Industrial Sector

An expert-based approach was employed through in-depth interviews to identify the dominant components of energy security in the agro-industry sector. The experts involved in this process represented a broad range of key stakeholders, including officials from the Ministry of Industry, the Ministry of Energy and Mineral Resources, the Agency for the Assessment and Application of Technology (BPPT), as well as academic scholars, agro-industrial entrepreneurs, and representatives from community-based agro-industry associations. The study identifies four strategic focus areas for industrial energy security: (1) guaranteed energy supply (JPS), (2) investment and independent energy management (IKPE), (3) availability of renewable Energy (RE), and (4) a competitive renewable energy pricing system (SHK). Among these, the analysis reveals that the highest strategic priority lies in ensuring a guaranteed energy supply (JPS), as illustrated in Figure 9. This finding underscores the necessity of strengthening inter-ministerial coordination and institutional collaboration to secure continuous and reliable energy access for the agro-industrial sector. To support this primary strategic focus, four energy security programs have been formulated: (1) energy policy (KE), (2) development of potential energy resources (PSDE), (3) subsidy mechanisms (S), and (4) enhancement of energy generation capacity (KP). Among these programs, the highest-ranked strategy is the establishment and implementation of robust energy policies. At the same time, subsidy mechanisms are ranked as the lowest priority, as shown in Figure 10. These findings suggest that policy coherence and regulatory frameworks play a more pivotal role than financial incentives alone in strengthening industrial energy security within the agro-industry.





Alternatives	Value	Decision Scores
JPS	0,333	
RE	0,309	
IKPE	0,111	
SHK	0,086	

Figure 9. The Priorities of Focus Strategies of Energy Security Systems for the Industrial Sector in Indonesia





Aternatives	Value	Decision Scores
KE	0,500	
PSDE	0,143	
KP	0,089	
S	0,070	

Figure 10. The Priorities of Strategic Programs of Energy Security Systems in the Industrial Sector in Indonesia

The successful implementation of strategic programs in the energy security system is highly dependent on the involvement and commitment of key stakeholders. In the context of the industrial sector, stakeholders identified as having significant influence include industrial entrepreneurs (IA), energy research institutions (ILP), energy supply industries (IP), and the public, including relevant professional associations (M). The analysis of stakeholder functions and roles, as depicted in Figure 11, reveals that industrial entrepreneurs (IA) hold the highest level of influence, indicating their central role in the execution of energy security initiatives. Conversely, the public and associations (M) are ranked lowest in terms of direct influence. However, their support remains essential in promoting awareness and acceptance. As illustrated in Figure 11, while industrial entrepreneurs are the main drivers of implementation, the success of energy security programs depends on collaborative efforts involving all stakeholders. Energy research institutions (ILP) contribute through technological innovation and knowledge transfer, energy supply industries (IP) ensure the reliability and distribution of resources, and public organizations and associations (M) play a supporting role in promoting engagement, transparency, and policy advocacy.

Furthermore, as emphasized by [25], energy security is intrinsically linked to institutional dynamics. To avoid inconsistencies and confusion during program implementation, the development and execution of energy security policies must align with the institutional mandates and policy frameworks of relevant national bodies. A coordinated institutional approach ensures that energy security programs are not only technically viable but also administratively and politically sustainable.





Aternatives	Value	Decision Scores
IA	0,278	
ILP	0,278	
IP	0,111	
M	0,063	

Figure 11. The Priorities of The Functions and The Roles of Stakeholders of Energy Security Systems in the Industrial Sector in Indonesia

3.1 Hierarchy Model of Industrial Energy Security Strategy

The hierarchical model of strategic energy security, constructed in five levels, illustrates the structured stages of prioritization and decision-making, as presented in Figure 12. According to the figure, the central focus in optimizing fossil energy availability

lies in ensuring a guaranteed energy supply. This is primarily achieved through the implementation of appropriate energy policies supported by enhanced inter-agency cooperation. The effectiveness of this focus depends on the active engagement of key stakeholders, particularly industrial entrepreneurs, who are expected to play a leading role in facilitating collaboration among agencies responsible for energy supply and in improving the implementation of energy conservation and energy resource development programs [24].

The realization of these strategies requires not only technical and institutional alignment but also strong leadership in energy management. As highlighted by [26], successful energy leadership must balance responsiveness to diverse perspectives with the decisiveness needed to drive change within organizations where hesitation or resistance may exist. Thus, beyond structural and procedural frameworks, the human and organizational dimensions of leadership are essential in ensuring the long-term effectiveness of industrial energy security initiatives.

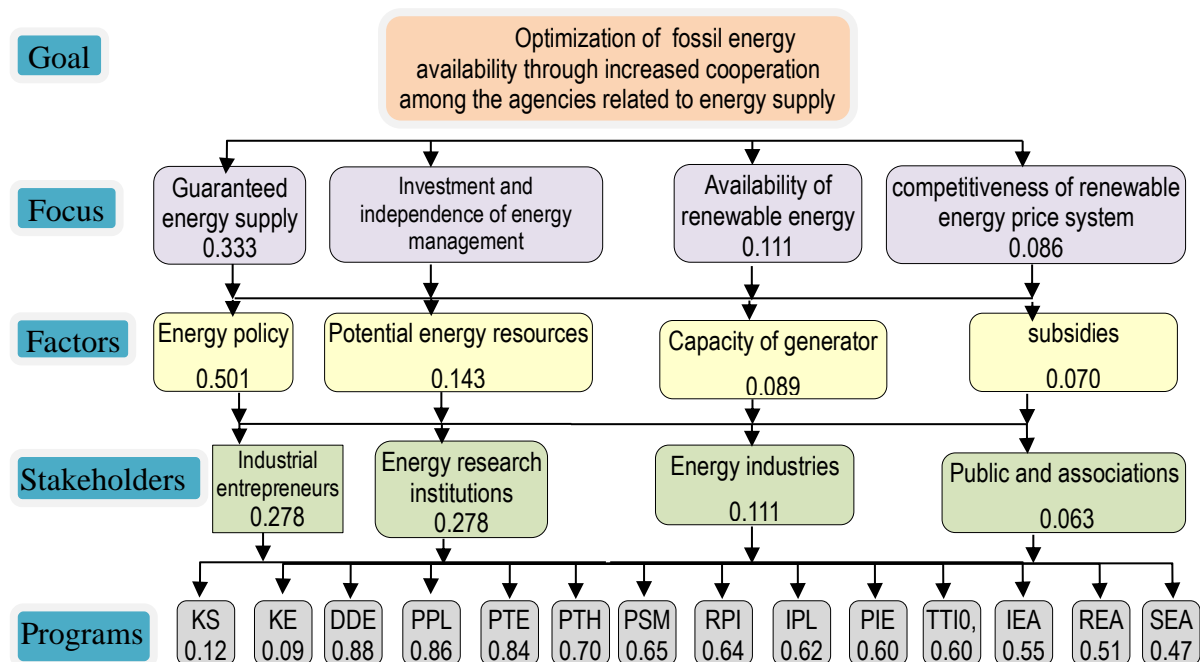


Figure 12. The Hierarchy of Strategic Model of Energy Security System in the Industrial Sector in Indonesia

The analysis of strategic energy security programs highlights three main activities with the highest priority based on their weighted importance values: (1) diversification of energy sources (DDE, 0.88), (2) reduction of the spatial discrepancy between energy sources and industrial locations (0.86), and (3) development of emission-reducing technologies (0.84). The diversification of energy sources program is designed to ensure a reliable energy supply for industrial operations. As noted by [27], diversification serves as an effective strategy to support sustainable development, particularly during energy system transitions. A practical implementation of this program involves replacing fossil fuels with renewable energy sources such as solar, wind, and bioenergy, thereby enhancing energy resilience and reducing dependence on limited resources.

The reduction of discrepancy between energy sources and industrial locations seeks to improve energy efficiency and promote sustainability by minimizing logistical and infrastructural mismatches. To address this issue, the government can stimulate the

development of integrated industrial zones, which are equipped with essential infrastructure such as electricity and gas networks. This strategic infrastructure development facilitates public access to energy and supports equitable energy distribution, especially in emerging industrial areas. The third priority program focuses on emission reduction, targeting the mitigation of greenhouse gas emissions that contribute to environmental degradation. In the electricity sector, emission reduction can be achieved through increased operational efficiency and reduced consumption of energy and materials. Additionally, transitioning to renewable energy sources plays a crucial role in lowering CO₂ emissions. Emission reduction strategies may encompass a range of actions including energy efficiency improvements, renewable energy utilization, and material recycling, all of which contribute to environmental sustainability and industrial compliance with global emission standards.

3.2 Research Implication

The implication of this research highlights the critical need for multi-stakeholder involvement in implementing strategic energy security programs. The government serves as a regulator, responsible for establishing policy frameworks and facilitating comprehensive coordination among relevant institutions. Meanwhile, industrial entrepreneurs assume the primary role of implementers, particularly in the areas of renewable energy adoption, industrial area development, and energy conservation initiatives. Their efforts must be supported by the active participation of energy research institutions, energy supply industries, public stakeholders, and industry associations, especially in terms of providing access to appropriate technologies, facilities, and resource management systems. Effective collaboration among these actors is essential to ensure the sustainability and operational success of energy security strategies within the industrial sector. The role of each stakeholder in the energy security industry can be seen in Figure 13.

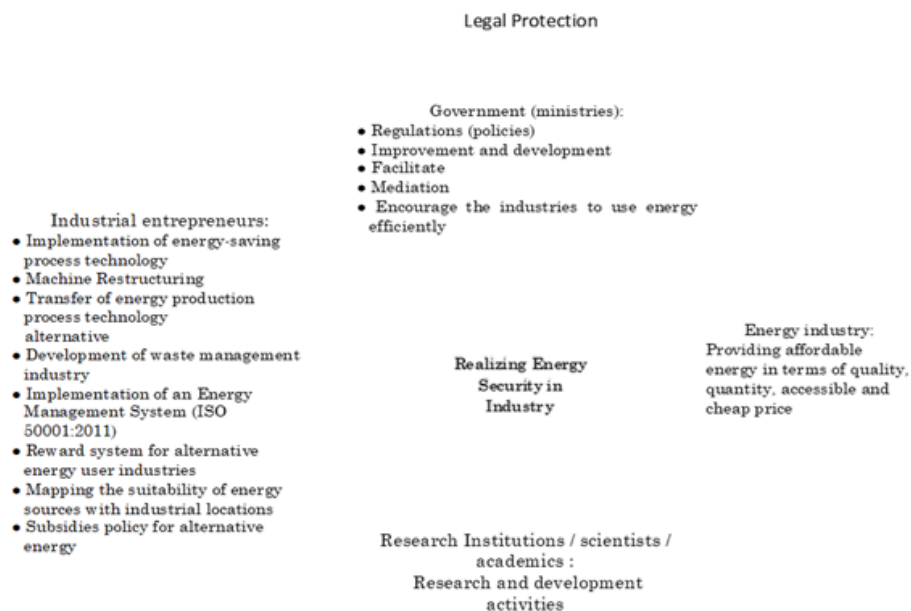


Figure 13. The Role of Each Stakeholder in Energy Security in Industry

The successful implementation of the diversification of energy sources program requires active involvement from key stakeholders, particularly industrial entrepreneurs and energy research institutions, which hold a combined importance weight of 0.278. Industrial entrepreneurs play a pivotal role by adopting renewable energy sources, such

as solar, wind, and bioenergy, which have significant potential to replace environmentally harmful fossil fuels. The utilization of renewable energy in industrial processes not only supports environmental sustainability but also promotes energy efficiency and long-term cost savings. Technologies such as solar panels and wind turbines are increasingly cost-effective, offering competitive alternatives to conventional energy over time. However, a successful energy transition also depends on strong institutional support, particularly from government bodies and research and development institutions. This aligns with Law No. 30 of 2007, Article 29, which mandates that the government and local authorities are responsible for facilitating scientific research and technological innovation to support the provision and development of energy. Technological advancements—such as in wind turbine design, materials, and operational efficiency—are instrumental in driving down costs and enhancing performance [28].

In addition, the implementation of programs to reduce the spatial discrepancy between energy sources and industrial locations necessitates robust and integrated energy policy frameworks. To achieve a sustainable energy system that ensures accessibility and security across sectors, the government must lead with strong policy commitments supported by consistent coordination with relevant stakeholders [29]. In this context, policymakers serve as the backbone of industrial energy strategies. In contrast, industrial entrepreneurs, energy industries, the public, and associations contribute by formulating and executing development strategies for industrial zones situated closer to primary energy sources. This coordinated approach enhances infrastructure efficiency and supports equitable energy distribution.

The development of emission reduction technologies can be operationalized through energy conservation initiatives, which are vital for advancing sustainable energy policies and generating appropriate policy recommendations. Two interrelated challenges must be addressed simultaneously: the growing demand for energy and the need to mitigate environmental impacts. Energy efficiency represents a key solution to this dual challenge, particularly within the manufacturing sector, which significantly contributes to environmental degradation due to its heavy reliance on fossil fuels. One promising alternative is the implementation of sustainable production scheduling, which aims to minimize energy costs while maintaining operational performance [30-32].

From a strategic management perspective, energy conservation serves as a powerful tool for both cost reduction and risk mitigation, especially in the face of volatile energy markets. It enhances industrial energy efficiency and acts as a critical support function. The successful implementation of energy conservation efforts depends on collaboration among multiple stakeholders, including the government, industrial entrepreneurs, energy providers, research institutions, the public, and industry associations. According to Law No. 30 of 2007, Article 25, each of these actors is mandated to contribute to the development of renewable energy and energy conservation programs.

To evaluate the effectiveness of the proposed strategic energy security model, it is essential to conduct energy security performance assessments. As noted by [33, 34], this evaluation can be structured using a set of well-established indicators, which are typically categorized into five dimensions: (1) overall energy balance, (2) socio-economic aspects, (3) domestic energy resources, (4) international energy demand and supply, and (5) diversification of energy sources. These indicators provide a comprehensive framework for assessing the robustness and sustainability of national energy systems.

Furthermore, the implementation of standardized energy management systems, particularly as part of national policy, is crucial in measuring and enhancing industrial energy efficiency [35]. As shown by [36], ISO standards have proven to be effective instruments in overcoming energy efficiency barriers in a cost-efficient manner. Empirical studies indicate that ISO-certified companies exhibit higher implementation rates of

energy-saving measures. This success is largely attributed to the internalization of energy savings identification processes and the establishment of structured decision-making and governance mechanisms, which together contribute to improved performance in energy management.

The diversity of industrial types and the wide geographical dispersion of industrial locations across the Indonesian archipelago pose significant challenges in ensuring a robust and well-targeted energy security system. In response to these challenges, there is a critical need to develop a comprehensive Energy Management Information System (EMIS) that can facilitate the alignment between energy demand and supply, as well as identify opportunities for fossil-to-renewable energy conversion in various regions. Such a system would not only support more accurate and region-specific energy planning but also function as a coordination platform among institutions involved in industrial energy security. Moreover, EMIS can contribute substantially to improving energy efficiency across industrial operations [37]. Energy Management Information Systems (EMIS) represent a broad and rapidly evolving category of software tools designed to monitor, analyze, and optimize energy use and system performance. EMIS deployments generally consist of three core functional elements: capabilities, scope, and technology stack—which together comprise a system of devices, data services, and software applications that aggregate and analyze facility-level data. These systems help optimize energy use at the building, campus, or institutional level. A fourth element, operations, includes the human resources, organizational processes, and actions required to utilize EMIS technologies effectively.

According to [37, 38], energy system security control involves monitoring the compliance of actual performance indicators with planned targets and ensuring continuity in achieving strategic energy goals. Coordinated and proactive actions by responsible authorities are essential to maintain the safety and stability of the energy supply system, particularly under internal and external pressures. These actions contribute not only to operational energy security but also to improving the economic, environmental, and social sustainability of industrial production processes.

4. Conclusion

This study identifies three major issues in the energy security of Indonesia's industrial sector: (1) limited energy availability, (2) inefficient energy utilization, and (3) the underdevelopment of alternative energy programs. Among these, the inefficient utilization of fossil energy emerged as the top priority issue. The key constraints contributing to this problem are the lack of effective coordination among energy-related agencies and the suboptimal implementation of energy conservation and resource development programs.

The proposed energy security model for the industrial sector is structured into three goals, ten indicators, four strategic focuses, four driving factors, four stakeholder categories, and fourteen program components. The primary goal is to enhance energy security through the optimization of fossil energy availability. To achieve this, the strategic focus lies in ensuring a guaranteed energy supply. The highest priority program is energy source diversification (importance weight: 0.88), which is aimed at ensuring energy supply through the adoption of renewable energy. This is followed by programs addressing the spatial mismatch between energy sources and industrial locations (0.86), and the development of emission-reducing technologies (0.84), which can be implemented through energy conservation initiatives.

The successful implementation of these strategies requires active stakeholder involvement. The government serves as a regulator and coordinator. At the same time,

industrial entrepreneurs act as key implementers of renewable energy deployment, industrial area development, and conservation programs. These efforts must be supported by energy research institutions, energy suppliers, the public, and associations through the provision of relevant technologies, infrastructure, and resources. Energy security performance assessments are essential to evaluate the effectiveness of the model. These can be conducted using five indicator components: overall energy balance, socio-economic aspects, domestic energy resources, international energy trade, and energy diversification.

However, this research has certain limitations. Due to the diversity and scale of industrial sectors in Indonesia, the study was limited to energy-intensive, agro-based industries (e.g., agriculture, plantation, forestry). While this sector provides a valid representation of energy needs in the processing industry, it may introduce bias in the weighting of strategic priorities and stakeholder roles. Future studies should involve a broader and more representative sample of industry types. Additionally, to validate and measure the model's effectiveness, empirical testing or simulation-based approaches are recommended. Finally, enhancing industrial energy security will require integrated policies and cross-sector collaboration to ensure coordinated and sustainable implementation.

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