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The role of artificial intelligence methods in enhancing the work of Energy infrastructure networks in industrial cities - A case study – the industrial city in Hasiya

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Abstract:

The global economy is witnessing a radical shift from the existing development model towards the sustainable development model, in order to remedy the dangerous effects that resulted from traditional development models. In this field, artificial intelligence applications are one of the approaches that have a role in promoting sustainable development. The research highlights the operation of energy infrastructure networks and facilities in industrial cities and their importance in governing the work of the network and enhancing its sustainability, as smart energy management systems based on artificial intelligence can help industrial cities in raising the efficiency of energy demand, reducing costs, and reducing artificial environmental impact, and thus integrating intelligence The energy infrastructure networks in industrial cities holds great potential to enhance operational efficiency, sustainability and resilience.

The research aims to develop a special methodology to enhance the work of the energy network in the industrial city of Hassia by evaluating the indicators of the work of this network. To achieve this, a questionnaire was designed directed to a sample of experts in the industrial city, and the results of the research were concluded with an analysis of the work of this methodology before and after its application. And special recommendations to serve decision-makers and those responsible for the planning process.

Keywords: Artificial Intelligence, Industrial cities, Smart infrastructure.

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دور منهجيات الذكاء الاصطناعي في تعزيز عمل شبكات البنى التحتية للطاقة في المدن الصناعية – الحالة الدراسية المدينة الصناعية في حسياء

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الملخص:

يشهد الاقتصاد العالمي تحولاً جذرياً من نموذج التنمية القائم نحو نموذج التنمية المستدامة، وذلك لاستدراك الآثار الخطيرة التي نتجت عن نماذج التنمية التقليدية، وفي هذا المجال تعد تطبيقات الذكاء الاصطناعي إحدى المناهج التي لها دور في تعزيز التنمية المستدامة، يبرز البحث أهمية تطبيقات الذكاء الاصطناعي في تعزيز عمل شبكات ومرافق البنى التحتية للطاقة في المدن الصناعية وأهميتها في حوكمة عمل الشبكة وتعزيز استدامتها، حيث يمكن لأنظمة إدارة الطاقة الذكية المعتمدة على الذكاء الاصطناعي أن تساعد المدن الصناعية في رفع كفاءة الطلب على الطاقة، وخفض التكاليف، وتقليل التأثير البيئي، وبالتالي ان دمج الذكاء الاصطناعي في شبكات البنية التحتية للطاقة في المدن الصناعية يحمل إمكانات كبيرة لتعزيز الكفاءة التشغيلية والاستدامة والمرونة.

يهدف البحث إلى تطوير منهجية خاصة لتعزيز عمل شبكة الطاقة في المدينة الصناعية في حسياء وذلك من خلال تقييم مؤشرات عمل هذه الشبكة، ولتحقيق ذلك تم تصميم استبانة موجهة إلى عينة من الخبراء في المدينة الصناعية، وخلصت نتائج البحث إلى تحليل عمل هذه المنهجية قبل وبعد تطبيقها، وتوصيات خاصة بما يخدم صناع القرار والجهات المسؤولة عن عملية التخطيط.

الكلمات المفتاحية: الذكاء الاصطناعي، المدن الصناعية، البنى التحتية الذكية.

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Introduction

In shadow evolution, technological accelerators and increasing environmental challenges make it essential to strengthen the effectiveness of infrastructure networks for energy in industrial cities, to ensure sustainability and meet the needs of industrial growth. These networks face great pressure as a result of industrial expansion and economic development, which calls for improving their efficiency and sustainability using modern techniques. Artificial intelligence is considered one of the main tools that can significantly contribute to improving the performance of these networks, thanks to its ability to process and analyze huge quantities of data and provide innovative solutions.

Industrial cities, being complex environments, require integrated and advanced management for a wide range of operations to ensure the efficient provision of energy, improve transmission systems, reduce carbon emissions, and face multiple challenges, including energy shortages and the need to provide clean and sustainable resources. Here, the role of artificial intelligence emerges, offering smart solutions that contribute to improving these aspects.

Notable improvements in the efficiency of these networks can be achieved through the development of smart control systems, better demand management, and fault prediction before their occurrence. This technology then opens broader ways to control energy production and distribution more effectively.

The research paper seeks to clarify the role of artificial intelligence in strengthening the infrastructure networks for energy in industrial cities, through a review of the methods and technologies used in data analysis and energy management, as well as an evaluation of network performance indicators, and how artificial intelligence techniques can strengthen these networks and make them more sustainable in the long term.

Research Problem

Energy infrastructure networks in industrial cities face major challenges, requiring effective management of an integrated set of operations to ensure their efficiency and continuity. However, traditional practices and solutions have led to decreased energy efficiency and a marked inability to meet demand. Hence, the need has emerged to strengthen the performance of these networks using artificial intelligence.

Ahmed and his colleagues (Ahmad et al., 2022) indicate that artificial intelligence methodologies may play a pivotal role in automating operations such as energy demand management, distribution control, and reducing the environmental impacts resulting from industrial activities. Since supplying industrial cities with energy requires specific standards, it is necessary to develop an approach that aligns with the tools and methodologies of artificial intelligence, while also harmonizing with the spatial characteristics and specific operational conditions of the industrial city.

This leads to the emergence of the main research problem, which can be formulated in the following question:

To what extent can artificial intelligence methodologies contribute to strengthening the performance of energy infrastructure networks in industrial cities?

Objectives

The importance of this research lies in addressing a vital service-oriented sector that has a significant impact on sustainable development. The study aims to clarify the role of artificial intelligence methodologies in strengthening the effectiveness of energy infrastructure networks and facilities in industrial cities. To achieve this, the research will focus on two main strategies:

- Establishing performance indicators for energy infrastructure networks in industrial cities:
- Analyzing basic indicators that reflect the efficiency and sustainability of energy network performance.
- Evaluating the current performance of energy infrastructure networks using these indicators.
- Developing a methodology based on artificial intelligence techniques to enhance the performance of energy infrastructure networks in industrial cities:
- Designing a framework that employs artificial intelligence techniques to improve the efficiency of energy networks and demonstrate the differences in network performance evaluation.
- Applying machine learning and big data analysis to develop smart control systems that support management and improve energy network performance.

Methodology

This research relies on a descriptive-analytical approach, which combines the description of the studied phenomenon with its analysis in order to reach a deeper understanding of its dimensions and mechanisms. This includes identifying energy infrastructure network indicators, evaluating their current performance, and clarifying the extent to which artificial intelligence methodologies can improve them. The research will proceed according to the following sequence:

First: Data Collection

Data were collected from various sources, including:

Governmental data

Benefiting from reports and statistics issued by governmental bodies concerned with energy and industry in Syria.

Review of Previous Research and Studies

A review of the scientific literature and previous studies addressing the role of artificial intelligence in energy networks will be conducted, in order to extract key lessons and apply them to the Syrian context.

Interviews and Questionnaires

Questionnaires will be designed and directed to workers in the energy and industrial sectors in the Industrial City of Hassia. In addition, interviews will be conducted with experts and specialists to collect their insights and experiences.

Secondly: Data Analysis

Statistical analysis tools will be used to analyze complex data and identify patterns and trends. This includes:

Analysis of basic indicators:

Identifying indicators that reflect the efficiency and sustainability of energy network performance, such as electrical capacity, energy conversion efficiency, stability, and governmental support.

Comprehensive evaluation:

Assessing the current performance of energy infrastructure networks using these indicators.

Thirdly: Development of the Network Strengthening Matrix

Based on the analysis results, a practical framework will be designed relying on artificial intelligence techniques to enhance energy network efficiency. This will include:

Applications of machine learning:

Developing models that analyze big data derived from energy networks, enabling demand and consumption forecasting as well as fault detection.

Smart control systems:

Proposing smart control systems that use the results of machine learning models to improve demand-side management and energy distribution more effectively.

Model testing:

Testing and evaluating the developed models and systems within energy infrastructure networks.

Fourth: Case Study Evaluation

A survey will be designed to evaluate the academic case study across several axes, including:

Effectiveness of AI applications:

Assessing the success of artificial intelligence applications in improving network efficiency and harmony.

Environmental alignment:

Evaluating the extent to which energy production and distribution activities comply with environmental standards and protection laws.

Control and distribution:

Assessing the ability of control and distribution systems to allow for decentralized and integrated management of energy production and distribution.

Literature Review

The integration and development of energy systems with artificial intelligence not only improve efficiency and safety but also provide a better experience for investors.

Zhao and colleagues (2023) studied the role of artificial intelligence applications in enhancing the energy system of the industrial city of Shenzhen, China, through an evaluation of network performance indicators. Their research methodology relied on methods such as predicting energy loads, energy management, fault diagnosis, and monitoring of the overall network structure. The results showed that one of the main challenges facing the energy network in the industrial city was the large volume of data related to energy

flows to and from substations, along with the ability to process this data. This required high processing capacity and effective algorithms to manage the data.
Liang and his colleagues (2018), in a study of a sample of European factories, developed a smart system model to enhance facility management by using big data analytics. Their methodology was based on analyzing the current situation and redesigning operations, including scheduling, monitoring, adaptive learning, and system preparation throughout the factory's lifecycle. This process was enabled by intelligent learning algorithms that took into consideration dynamic conditions and virtual aging. An effective evolutionary algorithm was applied to create an adaptive energy scheduling table and to improve temporal scheduling under variable operating conditions. The study's results showed about a 40% energy savings and a 30% improvement in yield within the studied sample during the research period.
Another study by Zhao (2023) highlighted that improving the efficiency of energy management in industrial facilities requires applying artificial intelligence methodologies to analyze consumption patterns. The results of his study showed that smart energy management systems have positive effects and can mitigate environmental impacts. His methodology was based on design capacities, working hours, and functional descriptions of energy-efficient industrial facilities. The study concluded with the development of a pulse prediction model that provides improved control strategies for managing internal mechanical and electrical equipment in an integrated manner, which ultimately reduces energy consumption.
Bevilacqua and his colleagues, through a pilot study conducted in an Italian industrial complex, demonstrated that developing a methodology for integrating IoT-based energy management with the existing energy system in any industrial city requires a multi-layered model, consisting of three layers...

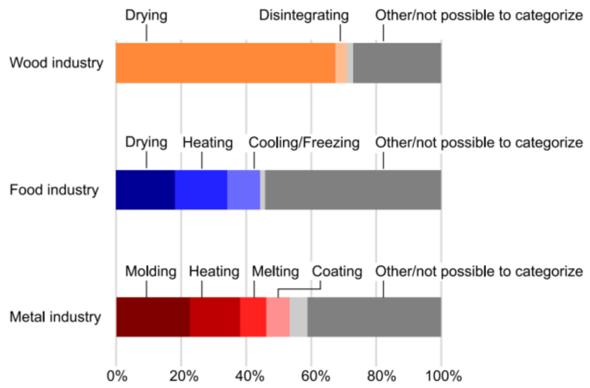
1. Data collection layer.
2. Data analysis layer.
3. Data management layer.

In order to test the proposed methodology in his case study and evaluate its impact on improving energy efficiency, a set of smart meters was installed at the level of devices and machines with the aim of collecting real-time energy consumption data. This data was analyzed and integrated into production management methods. The results of the study concluded with the presentation of a data analysis model based on artificial intelligence tools aimed at enhancing decision-making related to energy management and improving resource efficiency and productivity in manufacturing. (Bevilacqua, 2017)
When comparing these studies, we note that studying consumption patterns constitutes a major common factor in understanding the relationship between energy supply and demand. The first study focused on load prediction methods to study patterns, the second study on smart learning algorithms in creating a system for adapting to loads and providing smart energy, the third study on design and critical capacities, and the fourth study focused on using Internet of Things applications in studying actual demand. Based on the above, a set of criteria will be extracted and employed in developing a special methodology that is consistent with the specificity of the case study.

Theoretical background

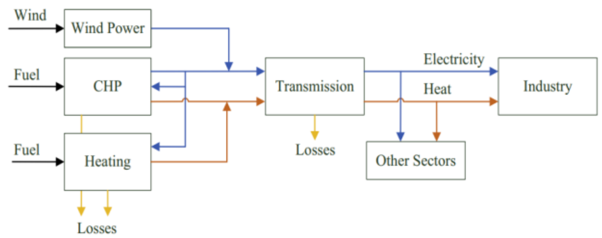
Assessing the industrial sector's energy needs:

Recent studies indicate that industrial energy consumption represents about 40% of total global energy use. A study by Johnson and Smith (2017) confirms the importance of evaluating patterns of electrical energy consumption in the industrial sector, with the aim of identifying potential areas for improving energy efficiency. On the other hand, assessing energy demand is a general issue, and there is no quantitative measure for it. It must be estimated through two main indicators: first, thermodynamic indicators, and second, thermoeconomic indicators (Johnson et al., 2017).
Energy consumption density varies from one industrial sector to another, depending on the production operations in each sector. Figure 1 shows the final division of energy consumption in various industries. In Denmark, for example, the pulp and paper, and mineral industries are considered to have the highest energy demand. The mineral industry requires significant energy input during the molding phase, while the paper industry's highest energy consumption occurs during the drying phase. In comparison, the food industry consumes less energy in these phases (Andersson, 2020).



Figure(1): shows the final division of energy consumption in transformation-intensive industries in Denmark (Andersson, 2020).

Energy management in the industrial sector includes various strategies and practices. Figure 2 shows a model for supplying the industrial sector with energy in Denmark. This model is one of the common methods for Energy Management Systems (ENMS). It provides a framework to determine energy goals, create energy performance indicators, and implement energy efficiency measures. This system enables industrial facilities to monitor energy consumption, identify areas for improvement, and implement measures to optimize energy supply (UNIDO, 2018).



Figure(2): shows a model mechanism for supplying energy to the Danish industrial sector (Bühler et al., 2016)

Indicators for Evaluating the Operation of the Power Grid in the Industrial City:

In light of increasing environmental and economic challenges, improving the efficiency and sustainability of energy networks in industrial cities has become vital to achieving sustainable development. The effectiveness of energy networks depends on a set of indicators that measure their performance, determine their ability to meet demand, ensure environmental security, and guarantee continuity of supply. A set of indicators was selected and extracted from a report by the International Energy Agency (IEA, 2022) on the efficiency of the energy network in cities and industrial areas. Table 1 shows the aspects of these indicators, ranging from energy output capacity to environmental impacts.

Table (1) shows the most important indicators for evaluating the energy network in industrial cities.

Indicator	Aspects	Measurement method
electrical power	The total amount of electrical energy that the grid can generate and distribute to consumers.	Use of energy meters in power plants and main distribution points to determine the energy produced and consumed.
Stability and quality	The network's ability to provide stable, high-quality electrical power without fluctuations or interruptions.	Electrical quality control devices are used to measure voltage, frequency, and power stability.
Efficiency and effectiveness	Efficiency is the ratio of energy actually used to total energy produced, while effectiveness refers to the extent to which the network achieves its goals with the least cost and effort .	Use key performance indicators (KPIs) such as energy loss and energy conversion efficiency, and analyze operating and maintenance costs .
Distribution and feeding	How to distribute electrical energy from generation stations to final consumption points.	Power flow maps and network management systems are used to monitor network performance and distribute loads in a balanced and efficient manner.
Safety and Maintenance	Security is the ability of a network to operate without major disruptions, while maintenance relates to the processes involved in keeping the network up and running.	Analyzing fault records and routine maintenance, using indicators such as the mean time to failure (MTTF) and the mean time to repair (MTTR) .
Environmental impact	Environmental impacts from energy production and distribution, such as carbon emissions and pollution .	Use of emission measuring devices and analysis of environmental quality data to monitor pollution levels and emissions from power plants .
Renewable resources	Use of renewable energy sources such as solar and wind energy within the grid .	The percentage of renewable energy generated from the total energy produced, and the use of performance analysis techniques to evaluate the effectiveness of renewable energy.
Government support	Government policies and incentives to support the development and improvement of energy networks .	Government policies and programs, monitoring funding allocated to energy projects, and evaluating the impact of these policies on improving network performance .

Concept of Smart Infrastructure

Smart infrastructure refers to material systems reinforced with digital technology to improve their performance, efficiency, and sustainability. These systems can be used to monitor and manage various urban services, such as transportation, energy, water, and waste management. They help cities improve the quality of life for their citizens, minimize environmental impact, and increase resilience against challenges and pressures (Berglund et al., 2020).

Smart Infrastructure Tools

Smart infrastructure tools are considered decisive for strengthening the efficiency and sustainability of energy networks in industrial cities. These tools include distributed control systems, advanced sensing devices, big data analysis techniques, and artificial intelligence applications that support effective resource management, improve performance, and reduce energy loss. They contribute to creating sustainable and flexible industrial environments. Table 2 highlights the five main tools and their uses.

Table(2): shows the most important smart infrastructure tools and their uses.

Tools	Usage
sensors	Used to collect data from the surrounding environment, these devices can measure a variety of parameters such as temperature, humidity, traffic flow, and water usage. This data enables analysis of patterns, identification of environmental changes, and aids in data-driven decision making (Smith، 2020).
Data Warehousing and Analytics Tools	used to store and analyze quantities Huge from Data that It is done Collect it by Devices Sensing, maybe for this Tools to set Patterns and trends in Data, Which Allows by Prediction By behavior The future and improve efficiency Operations. (Johnson M. T., 2019)
Visualization tools	It is used to convert a data complex that It was completed Collect it And analyze it to photo and fees Graphic Easy understand it, Help This is amazing Tools in Facilitate explanation Data And present it In a way Visual Help in take Decisions Fast And the built on information minute. (Lee K. Y., 2021)
Networking and Communications Tools	Allow By tying Devices Sensing, and tools Storage and analysis, and tools perception Some of them Some, Which Allows exchange Data between Systems different, this Linking Enhances from efficiency Use Data And contributes in Integration Systems Multiple. (Williams R. &., 2018)
Security tools	It is considered necessary to protect Data that Gather it Systems structure Infrastructure smart from attacks Electronic. Includes This is amazing Tools Techniques Encryption Data, Authentication Users, and monitoring Activities Suspicious To ensure safety Data And preservation on Its privacy. (Chang H. &., 2020)

Artificial Intelligence Methodologies in Energy Networks in Industrial Cities

Industrial cities face significant challenges in meeting energy demand for their industrial operations. This creates a crucial role for artificial intelligence (AI) in strengthening these networks through smart monitoring and facilitating adaptive decision-making. AI works with algorithms, particularly automated learning, to enhance smart monitoring systems by collecting and analyzing data independently. This allows AI technologies to plan automation, evaluate risks, and assess infrastructure vitality, helping identify potential weaknesses. Additionally, deep learning algorithms can enhance energy infrastructure networks through prediction, adaptation, and independent real-time decision-making (Danie et al., 2020).

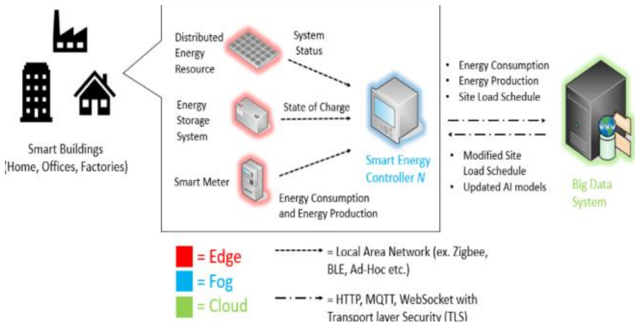
AI applications can be used for load forecasting, demand prediction, request management, energy storage process optimization, leak detection, predictive maintenance, energy pricing, and forecasting energy-related environmental conditions (Li et al., 2023). Therefore, artificial intelligence can enhance energy networks in the industrial sector through various applications, including:

Demand forecasting

AI algorithms analyze historical energy consumption data along with external factors such as weather patterns and industrial activity levels to accurately predict future energy demand. Zohra and colleagues developed a demand forecasting tool, Comb-TSB, a hybrid method of intermittent and cumulative demand patterns. It automatically selects the best model from a range of methods, enabling energy providers to anticipate peak demand periods and adjust energy production accordingly, improving grid stability and efficiency (Zohra et al., 2021).

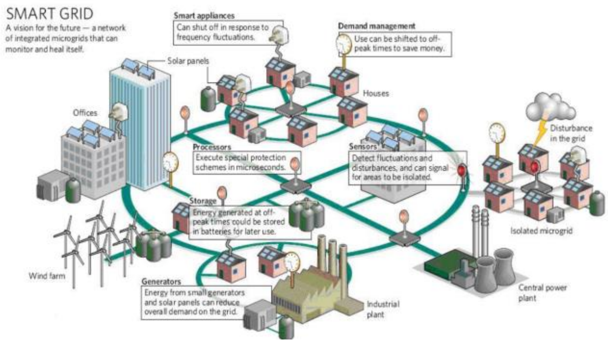
Energy management systems

AI-operated energy management systems monitor energy consumption and control the operation of industrial facilities in real time. Figure 3 shows a model of energy management in smart grids. These systems provide advanced analytics to identify energy-saving opportunities, operate equipment optimally, and detect anomalies indicating energy waste or inefficiency (Pawar et al., 2020).



Figure(3): shows the energy management model in the smart grid (Li et al., 2023).

AI-based automation technologies improve smart grid functionality by enabling autonomous control of components such as smart meters, switches, and sensors. Figure 4 shows a smart power grid automation model developed by researchers in the Netherlands, allowing real-time monitoring and adaptive response to energy demand and supply changes, improving grid flexibility and reliability (Wolsink, 2013).



Figure(4): shows the smart power grid automation model (Wolsink, 2013).

Predictive Maintenance

AI enables predictive maintenance of energy infrastructure by analyzing sensor data from equipment such as transformers, generators, and transmission lines. Çınar’s study indicates that detecting patterns signaling potential failures allows AI algorithms to proactively schedule maintenance, reducing downtime and lowering operating costs.

Grid Optimization

AI enables predictive maintenance of energy infrastructure by analyzing sensor data from equipment such as transformers, generators, and transmission lines. Çınar’s study indicates that detecting patterns signaling potential failures allows AI algorithms to proactively schedule maintenance, reducing downtime and lowering operating costs.

Table (3): shows the results of using artificial intelligence applications in the industrial energy network across several countries.

The state	Smart applications used	Results
US	Artificial intelligence systems for demand analysis	Improve energy efficiency by 20% and reduce carbon emissions by 15 % (Smith et al, 2020)
Germany	Smart Grids and Distributed Control	Increase network efficiency by 25% and reduce operating costs by 10 %(Johnson, 2019)
China	Machine learning techniques to improve energy transfer	Improve transportation efficiency by 30% and reduce energy loss by 20 % (Lee, 2019)
Denmark	Artificial intelligence to monitor and analyze network performance	Increase reliance on renewable energy by 35%, and improve energy efficiency by 15 % (Williams, 2018)
Japan	Intelligent control systems and deep learning	Improve network stability by 40%, reduce power outages by 25 % (Chang, 2022)

Based on the above, some of these methodologies will be employed, and a specific practical framework will be developed that is compatible with the spatial characteristics of the case study.

1- Conclusion of the research criteria that will be Use it

The Delphi method was adopted to engage with a specific segment of experts in energy planning for industrial cities and academic researchers. The Delphi method is a fundamental research technique in the investigation process, and its purpose is to:

Assess the energy infrastructure in the industrial city and evaluate its potential for enhancement through artificial intelligence applications.

Identify the factors of importance for enhancing the operation of the energy infrastructure network.

Based on the pursuit of achieving the goals of sustainable development and relying on literature and previous studies, the criteria specific to the case study and methods for enhancing it were combined into a matrix. This matrix integrates specific development axes with criteria for evaluating the efficiency of energy networks. The matrix was discussed with experts in a manner consistent with the Delphi technique to achieve the second strategy of the research objectives. Figure 5 illustrates this matrix.

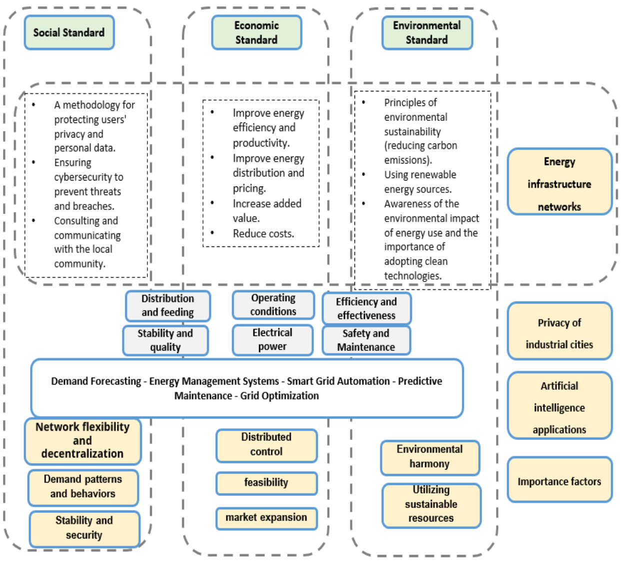


Figure (5): shows the matrix of the concluded research criteria, prepared by the researcher.

Due to the specificity and scope of the research, Table 4 presents the aspects and methods for measuring one indicator for each of the identified factors.

Table (4): shows the aspects and methods of measuring the indicators of important factors.

Indicator	Aspects	Measurement
Environmental harmony	The extent to which energy production and distribution activities comply with environmental standards and environmental protection laws.	CO_2 Emissions Environmental Audit
Utilizing renewable resources	The extent of use of renewable energy sources such as solar energy, wind energy, and geothermal energy.	Renewable energy contribution renewable energy capacity
Distributed control	Distributing grid control systems to allow for decentralized and integrated control of energy production and distribution	Distributed controllers System efficiency
feasibility	Evaluating the economic benefits provided by power grids versus their operating and maintenance costs	Operating and maintenance costs Return on Investment (ROI)
market expansion	The network's ability to meet growing market needs and accommodate new users	Energy demand growth Number of new users
Network flexibility and decentralization	The network's ability to adapt to changes in demand and supply without major disruptions	Response time Number of decentralized energy units
Demand patterns and behaviors	Analyze how consumers use energy and peak energy consumption times.	Consumption data analysis Artificial intelligence applications
Stability and security	The network's ability to provide continuous and safe power without interruptions.	Outage rate Security and protection systems

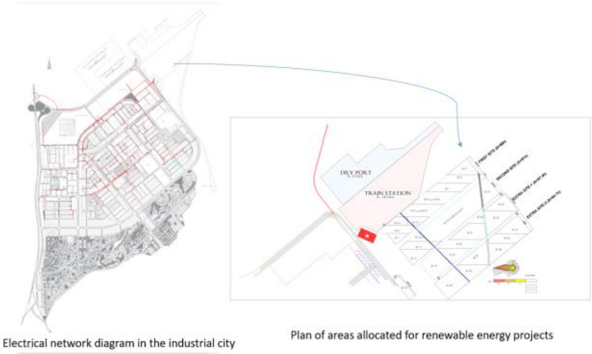
Evaluation of the Performance Indicators of the Energy Infrastructure Network in the Industrial City

The Syrian government seeks, through its current policies, to encourage the implementation of renewable energy projects, particularly in energy-intensive industries. Investors can benefit from the provisions of Law No. 32 of 2021, which allows them to buy and sell energy generated from renewable sources at competitive prices.

In addition, field visits to the industrial city have indicated that industrialists are required to establish power stations within designated areas, ensuring that 30% of their total energy consumption comes from renewable sources.

The industrial city primarily relies on energy generated by the Jandar power station and a 230 kV network to meet its electricity demand. The city’s total electricity requirement is approximately 255 megawatts, with consumption distributed among four main industries: Textile, Engineering, Food, and Chemical.

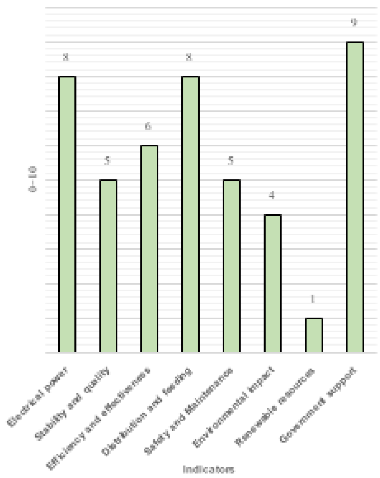
Energy generated from solar power stations contributes 5% of the total supply, equivalent to 15 megawatts. Figure 6 illustrates the organizational chart of the industrial city, highlighting the electrical network and the areas designated for the establishment of renewable energy stations.



Figure(6): shows the electrical network diagram and the area allocated for renewable energy projects in the Industrial City Directorate.

The figure demonstrates the sufficiency of allocated spaces, confirming the interest of decision-makers and policy-makers in promoting renewable energy projects.

Based on Table 1, which lists indicators for evaluating the operation of the power grid, a field visit was conducted to the industrial city. Personal interviews were recorded with a sample of experts from the Electricity Directorate in the city. The evaluation results are summarized in Figure 7.



Figure(7): shows the indicators of the operation of the power grid in the industrial city – prepared by the researcher.

Indicator analysis:

The evaluation results reveal several challenges affecting the efficiency of the industrial city's power grid:

High energy demand from energy-intensive industries such as smelting and rolling mills has led to increased production costs, especially amid rising energy prices, negatively impacting competitiveness.

Price fluctuations and restrictions on factory selling prices have reduced the profitability of pharmaceutical factories.

Increased carbon emissions from the chemical industry and limited reliance on renewable energy in less energy-intensive industries, such as engineering and electrical sectors.

Low efficiency in energy conversion and transmission operations, due to weak transmission and distribution infrastructure, reduced maintenance schedules, and limited repair procedures when faults occur.

Outdated equipment and traditional technologies, frequently breaking down, particularly in the food industry.

Insufficient training programs to prepare personnel capable of handling network challenges.

Application of the mathematical matrix of importance factors:

The matrix axes are summarized in three criteria, from which eight common factors are graded based on the variables and the industries studied. A special questionnaire was developed to measure these factors using a five-point Likert scale, as shown in Table 5.

Table (5): presents the questionnaire model for measuring importance factors – prepared by the researcher.

Classification	Importance Factor	Question
Environmental standard	Environmental Harmony	Emissions from industrial facilities can be mitigated through a smart energy grid.
	Utilizing Sustainable Resources	A smart grid can integrate renewable energy sources with the existing energy system, contributing to achieving sustainable development goals.
Economic standard	Distributed Control	Adjust energy distribution mechanisms by providing an automated system supported by artificial intelligence applications.
	Economic Viability	A pricing system based on artificial intelligence applications can help regulate consumption.
	Market Expansion	Raising awareness about the importance of artificial intelligence applications and increasing renewable energy suppliers in the city.
Social standard	Network Resilience and Decentralization	A smart energy grid helps achieve self-sufficiency and mitigate decentralized supply.
	Demand Patterns and Behaviors	Consumption patterns can be predicted based on the size of the facility and its operating hours.
	Stability and Security	Sensors and smart meters can detect leaks and threats and determine maintenance times.

Analysis of survey results:

The survey data were entered into the JASP statistical analysis program to determine the degree of importance of the criteria and their weighting according to expert opinions.

1. Kaiser-Meyer-Olkin (KMO) Test:

The KMO test confirmed the adequacy of the sample:

Overall MSA: 0.77

This indicates that the sample size is sufficient both at the scale level and for each item in the questionnaire.

2. Bartlett's Test of Sphericity:

This test determines whether the correlation matrix is spherical. The results were:

Chi-square value: 31.562

Degrees of freedom: 20

Probability (p-value): 0.048 (<0.05)

Since the p-value is less than 0.05, the null hypothesis is rejected, indicating that the proposed factor model is appropriate. The data are sufficiently correlated, and the correlation matrix is suitable for factor analysis.

3. Linear Regression Analysis:

Regression analysis was conducted to demonstrate the importance of the criteria. The regression equation is:

Y=0.314X+2.07Y=0.314X+2.07

A statistically significant relationship was found between the importance factors and their respective criteria. The results indicate that for every one-unit increase in the accessibility of machine learning and augmented intelligence applications in energy infrastructure management, the network performance is enhanced by 0.314 units.

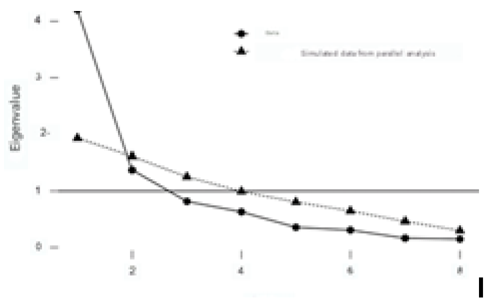


Figure (8): shows the latent root results chart for the factors used.

Based on these results, the identified factors will be adopted in designing a framework that leverages artificial intelligence (AI) applications to enhance the efficiency of the power grid, in line with the research objectives.

Methodology for Enhancing the Energy Grid in Hasiya Industrial City through AI Applications

The methodology aims to gradually increase renewable energy projects over time, as the total allocated area is sufficient to cover the city's energy needs. Given the variable nature of renewable energy due to weather conditions, the city will rely on a hybrid energy system integrating both traditional and renewable sources.

To organize and optimize this system, a smart control and regulation system is required. This system can be enhanced with AI methodologies, including:

- Neural network applications
- Reinforcement learning
- Internet of Things (IoT) integration

Given the special operating conditions of the industrial city, it is necessary to:

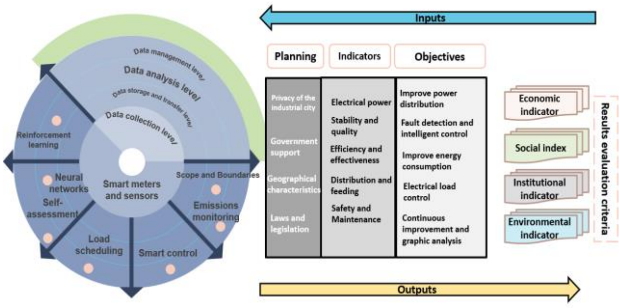
- Analyze hourly consumption data
- Evaluate long-term trends in temperature and solar irradiance
- Process complex, large-scale energy data
- Predict time series and peak load periods

Figure 9 illustrates the proposed methodology, which is hierarchical and integrated across several levels:

1. Data Collection Layer: Smart meters and sensors collect real-time energy consumption data and dynamic professional data.
2. Advanced Data Processing Layer: Machine learning predictions estimate the efficiency and consumption of energy resources from all sources.
3. Data Interpretation and Visualization Layer: Neural networks transfer information to data centers, where machine learning models are presented to users via dynamic charts and tables.

This methodology demonstrates daily advantages, including:

- Improved energy efficiency
- Cost reduction
- Energy savings
- Reduced emissions



Figure(9): shows the proposed methodology for strengthening the energy network in the industrial city – prepared by the researcher.

To evaluate the effectiveness of the methodology, a re-evaluation of energy network operating indicators was conducted. The methodology was presented to experts, and Figure 10 shows a comparison of results before and after implementation.

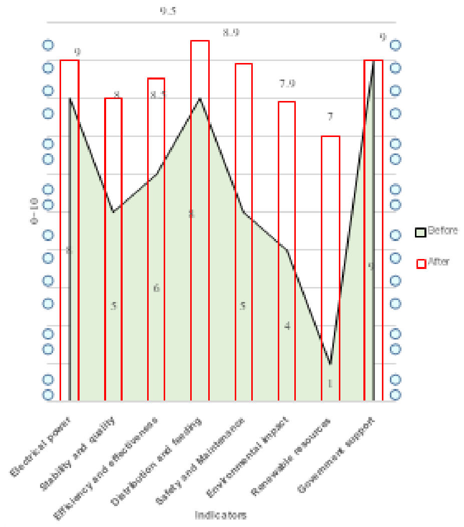


Figure (10): shows the indicators of the operation of the power grid in the industrial city before and after applying the reinforcement methodology – prepared by the researcher.

Results

Currently, AI applications in the industrial sector remain under study, with ongoing debates regarding their readiness for full-scale adoption. AI technologies primarily rely on data collection and analysis, which presents two main challenges:

1. Data-related challenges: Ensuring the validity of collected data and handling complex analyses accurately.
2. Prediction and automation challenges: Assessing the accuracy of AI-driven predictions and using them effectively without human intervention.

A specific methodology was developed to strengthen the industrial city's energy network. It was theoretically tested and presented to experts. By comparing the network's performance before and after the implementation of this methodology, several promising opportunities for network enhancement were identified, particularly with adequate governmental support in concept and execution.

Opportunities for Network Enhancement

The opportunities can be categorized as follows:

1. Technical Aspect:

- Fuzzy logic systems assist in detecting and diagnosing network faults.
- Smart sensors and meters identify leaks, threats, and maintenance requirements.
- Predictive maintenance improves network security and stability.

2. Economic Aspect:

- Big data analytics provides accurate forecasts, enabling greater integration of solar and wind power.
- AI-based software refines wind speed and power data, allowing turbines to operate more efficiently.
- This reduces the cost of energy production and consumption while maximizing renewable energy utilization.

3. Social Aspect:

- Investors and operators are informed of potential network disruptions in real time.
- Encourages demand-side management and energy conservation.
- Promotes a balance between traditional energy sources and renewable, sustainable sources.

4. Environmental Aspect:

- AI analyzes carbon emissions data to assess the environmental impact of facilities.
- Smart technologies and predictive models support solutions to reduce emissions.
- Contributes to achieving environmental standards and sustainability goals.

5. Flexibility and Decentralization:

- AI empowers smart networks to adapt in real time.
- Supports decentralized energy generation and distribution.
- Enhances overall flexibility and resilience of the energy system.

Recommendations

The researcher recommends enhancing the development and implementation of artificial intelligence (AI) in energy networks through the following measures:

1. Enhance R&D Investments
    - Encourage companies and research institutions to invest in the development of AI applications specifically aimed at improving the efficiency of energy networks.
    - Increase government funding for research and development in AI technologies for energy applications.
2. Develop Standards and Performance Indicators
    - Define clear and achievable criteria to evaluate the performance of power networks using AI.
    - Conduct regular case studies to assess the effectiveness of AI applications in improving industrial power grid performance.
3. Strengthen Public-Private Cooperation
    - Promote partnerships between the government and private sector to develop and deploy AI applications in energy grids.
    - Provide shared platforms to facilitate knowledge and expertise exchange between academics and industry professionals.
4. Develop Technology Infrastructure and Training
    - Establish training and educational programs to qualify engineers and technicians in the use of AI technologies for power grids.
    - Organize workshops and courses to enhance the skills of industrial sector workers in big data analysis and AI-based energy management.

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