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Transitioning to Renewable Energy to Achieve Sustainability in Industrial Products

Sayed Mohamed Salah Mohamed Abdelhamid
Lecturer, Department of Industrial Arts, Faculty of Education, Helwan University, sayedsalahid@yahoo.com

Abstract

Many countries are striving to transition towards a clean and eco-friendly environment to achieve sustainable development. As resource sustainability becomes increasingly important, the role of renewable energy in providing effective solutions for industries, particularly in the manufacturing of metal products, is becoming more significant. The research problem lies in assessing the extent to which the use of renewable energy in metal product factories contributes to environmental preservation and cost reduction. This research focuses on the importance of renewable energy and its benefits in reducing environmental pollution caused by conventional energy sources. The aim of the study is to achieve sustainability and climate preservation through the use of renewable energy in metal product factories and to reduce electricity consumption costs in these factories. The research is based on the hypothesis that the use of renewable energy contributes to environmental preservation and reduces electricity costs in metal product factories. A descriptive methodology and analytical techniques were used to describe and analyze the application of renewable energy in these factories. Costs were calculated under three scenarios: electricity-only, On-Grid, and Off-Grid systems. The results indicated that the On-Grid system is the least expensive, followed by the Off-Grid system, which confirms the validity of the hypothesis and achieves the research objectives. The study recommends raising awareness about the importance and benefits of using renewable energy and aligning with global efforts to combat climate change through renewable energy sources.

Keywords

Sustainable energy, Renewable energy, Industrial Products

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Introduction

Renewable energy sources have rapidly increased worldwide due to their benefits as an environmentally friendly, clean, and abundantly available energy. However, this growth has led to new challenges, such as low efficiency, unstable supply, and the urgent need for accurate forecasting. As a result, energy system operators and researchers are studying these issues and seeking new solutions. (Umit Cetinkaya, et al., 2022). As global energy demand continues to rise, countries are turning to sustainable and renewable energy sources to address climate change and resource scarcity. Waste-to-Energy (WtE) technology is one such renewable source, as it helps convert waste into usable energy. This technology has the potential to solve many of the economic, technical, and managerial challenges faced by emerging economies, such as waste management, energy security, reducing dependence on fossil fuels, and achieving sustainable development goals. (Md. Ruhul Ferdoush, et al., 2024) Sustainable energy sources are more cost-effective in the long run, paying off both financially and environmentally. This results in lower electricity costs for consumers. Solar energy is captured from the sun's rays using silicon solar panels through the "photovoltaic effect," which converts sunlight into electricity. (Mohamed, Shaimaa Mostafa, 2025)

The integration of renewable energy sources (RES) into power systems has significantly increased in recent years due to growing concerns about the environment, economy, and energy security, posing new challenges to power system stability. This paper first presents a modified classification of stability categories for power systems with high RES penetration. (Jana Sheikh Ali, et al., 2025)

Research Problem:

The research problem arises through the following questions:

- To what extent does the use of renewable energy in metal product factories contribute to environmental preservation?
- To what extent does the use of renewable energy help reduce costs in metal product factories?

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Research Significance:

- Highlighting the advantages and benefits of renewable energy.
- Reducing environmental pollution caused by traditional energy sources.

Research Objectives:

- Achieving sustainability and preserving the climate through the use of renewable energy in metal product factories.
- Reducing electricity consumption costs in metal product factories.

Research Hypotheses:

- The use of renewable energy helps preserve the environment and reduces electricity costs in metal product factories.

Research Methodology:

- The research adopted a descriptive approach, utilizing the analytical method to describe and analyze the electrical capacity of the factory under study. It focused on analyzing energy costs in three scenarios: the traditional method and two methods of using solar energy (On Grid, Off Grid).

Research Delimitation:

- The scope of the research was limited to the use of solar energy within a metal products factory.

PREVIOUS STUDIES:

Study (Mohamed, Shaimaa Mostafa, 2025), Titled " The Role of Renewable Energy in Confronting Climate Change and Reducing the Environmental Impact of the Apparel Industry"

The aim of this research is to assess the impact of renewable energy use in Apparel factories on environmental preservation and cost reduction. With the world striving for sustainable development amidst climate change, the study focuses on the benefits of renewable energy and its potential to reduce environmental pollution from conventional sources. The research examines three energy scenarios—electricity-only, On-Grid, and Off-Grid—finding the On-Grid system to be the most cost-effective. The results confirm that renewable energy preserves the environment and reduces electricity costs, with recommendations for raising awareness and supporting global efforts to mitigate climate change.

Study (Alexandra Catalina Lazar, et al., 2023), Titled " Analysis of the Operation of a University Campus using Renewable Energy Sources, Hydrogen Generator and Fuel Cells"

The aim of this study is to analyze a small system installed on a university campus that consists of renewable energy sources (solar panels on rooftops and a wind turbine within the campus), a hydrogen generator, fuel cells, and a methanizer, with the goal of achieving a circular economy. The hydrogen generator produces hydrogen, which can be stored in tanks and used by the fuel cells to meet demand. The methanizer uses hydrogen produced by the generator and carbon dioxide from the exhaust of a diesel engine to produce methane. The study also analyzes the expansion of the existing system. This research supports the growing trend of installing new renewable energy sources (RES) and achieving climate neutrality, in line with the European Green Deal.

Study (Y.A. Medvedkina and A.V. Khodochenko, 2020), Titled " Renewable Energy and Their Impact on Environmental Pollution in the Context of Globalization "

The aim of this study is to assess the environmental impacts of energy production from renewable sources. Advances in renewable energy technology promote sustainability by improving energy conservation and reducing carbon emissions through the replacement of fossil fuels. Several researchers have examined the environmental effects of renewable energy, finding that emissions and environmental impacts can occur, for example, during renewable energy production compared to fossil fuel-based electricity generation. This research presents a model integrating energy and the environment. Its results can aid in planning energy systems and policies to ensure a fair and green energy transition at global, regional, and national levels.

Theoretical Framework:

The increased use of renewable energy sources (RES) in the electrical grid has a positive environmental impact, but it causes significant challenges for grid stability, such as fluctuating production and unpredictability. Renewable energy sources are also influenced by location and available resources, and they have low inherent inertia compared to traditional synchronous generators, weakening their ability to mitigate frequency deviations. The challenges vary by geographic regions, where geopolitical and economic barriers can affect the expansion of solar and wind energy. Additionally, outdated infrastructure and a lack of investment hinder the integration of renewable energy sources, especially in developing regions. (Jana Sheikh Ali, et al., 2025)

Although renewable energy sources are abundant, their variability necessitates compensation methods for stability, often relying on fossil fuel plants as

backups. Currently, renewables account for 23% of global electricity, but by mid-century, this share could rise to 50% or more, potentially meeting 80-90% of electricity needs and fulfilling most heating and transportation demands in many countries.

(David Elliott, 2016)

There is significant importance in clean and renewable energy sources for addressing energy shortages. Renewable energy sources such as solar, wind, hydropower, and biomass can be integrated with a larger share of fossil fuel-based energy to help meet growing demand and the increasing global focus on climate change. Renewable energy also supports manufacturing and creates green jobs for national development. Despite their availability, renewable energy sources are still not fully utilized.

(Sunday Aigbiniode Lawani, et al., 2023)

Renewable energy is a rapidly growing field, widely welcomed by many as part of the solution to climate change and energy security issues. (David Elliott, 2020)

Sustainable Product Design and Development

Sustainable product design and development are vital for promoting a more eco-friendly and sustainable industrial products sector. Reducing the environmental impact of industrial products can be achieved by closing the manufacturing loop, applying eco-design principles, conducting life cycle assessments, and implementing product certification and labeling. (Roy, R., Chavan, et al., 2024)

Renewable energy

Renewable energy refers to energy sourced from natural resources that are continuously replenished or cannot be depleted, renewing at a rate faster than their consumption. It is known for its rapid regeneration and constant availability. Its sources are diverse and include solar, wind, hydropower, biomass, geothermal energy, and more.

Sustainable energy = renewable energy + energy efficiency.

(Halassa, Hanaa and Trayeche, Moamer, 2024)

The Importance of Renewable Energy

Renewable energy is important as it serves as an alternative to traditional energy sources. It is clean, environmentally friendly, and offers continuous availability and reliability. The following figure (1) demonstrates this. (Mohamed, Shaimaa Mostafa, 2025)

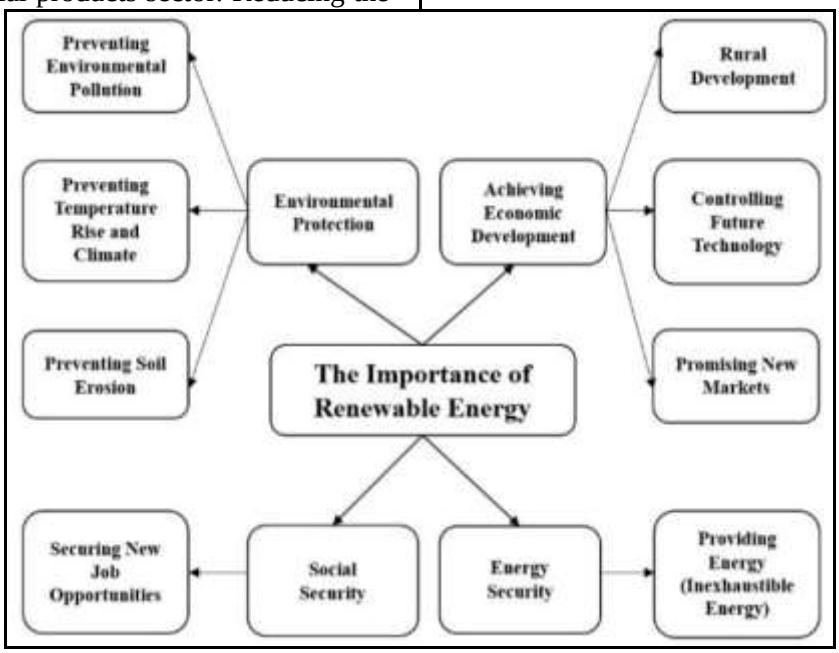

Figure (1) The Importance of Renewable Energy

Future Capacity of Solar Energy

Solar energy offers greater flexibility than wind and hydropower due to its consistent nature and ability to store energy for later use. With advancements in solar technology, including improved DC to AC ratios, solar plants will provide more reliable service. The IEA attributes 60% of renewable energy growth to solar, and Carbon Tracker predicts that by 2040, 72% of global coal power will become unprofitable. (Emily Folkglobal, 2021)

Benefits of Switching to Renewable Energy:

- Cost Efficiency: The cost of renewable energy has significantly decreased, with many options now more affordable than coal, and investments often pay off within five years.
- Environmental Benefits: Shifting away from fossil fuels reduces greenhouse gas emissions and helps combat global warming, offering a sustainable alternative for industries like

textiles.

- Customer Engagement: Consumers are increasingly drawn to brands that prioritize sustainability. Using renewable energy aligns with these values and demonstrates a commitment to environmental responsibility.
- Competitive Advantage: Reliable renewable energy sources can prevent production delays and reduce costs, giving companies a competitive edge.
- Energy Efficiency Tracking: Adopting renewable energy improves energy usage monitoring, allowing companies to optimize operations and replace outdated machinery. (Scarlett Buckley, 2022)

Solar energy is crucial because it generates power without harming the planet. As long as the sun shines, solar energy will not be depleted. Although initial costs may be high, solar panels provide significant benefits. They can be installed on almost any sun-facing surface, making them ideal for powering homes, commercial buildings, or contributing directly to the power grid. (Mohamed, Shaimaa Mostafa, 2025)

Renewable Energy and Digitalization

The integration of renewable energy systems with artificial intelligence (AI) has gained increasing attention in the past two decades, as industries seek to meet growing energy demands while ensuring environmental sustainability. Renewable sources like solar, wind, and hydropower have become vital in addressing climate change and reducing fossil fuel dependence. However, their intermittency and natural variability pose significant challenges to widespread adoption. AI technologies, particularly machine learning and deep learning, are being used to optimize energy systems, improve predictive maintenance, enhance forecasting accuracy, and manage grids more efficiently.

(Yanti Mustapha, et al., 2024)

Energy systems are rapidly evolving with the effective integration and use of emerging digital technologies, including, but not limited to, artificial intelligence, blockchain/Distributed Ledger Technology (B/DLT), and other information and communication technologies. Along with the effective integration of digital technologies into modern energy systems, decarbonization efforts also represent an energy transition that becomes more apparent under the framework of the Green Digital Transformation Agreement. Blockchain/Distributed Ledger Technology (B/DLT) appears to be one of the most promising enabling technologies for achieving a full energy transition toward next-generation energy markets and systems. (Umit Cali, et al., 2024)

Overall, the integration of model-based, optimization-based, and AI-based approaches provides a comprehensive framework to address the complex challenges posed by the increasing penetration of renewable energy sources (RES) into power systems. Although this review offers an in-depth overview of power system stability (PSS) methods for high RES integration, it is important to highlight that there are still very few real-world applications of these techniques. Most of the studies in the literature rely on simulation case studies to test the proposed methods. The challenges of implementation, fluctuating grid conditions, and the high resource requirements are some of the reasons for this gap in practical applications. (Jana Sheikh Ali, et al., 2025)

Experimental work

A plan has been developed to implement solar energy consumption systems within a metal products factory.

Due to the continuous increase in electricity consumption costs and the shift of many companies towards sustainable and energy-efficient solutions, a detailed analysis was conducted on energy consumption costs in the factory using three different systems:

1- Electricity Only
2- Electricity with Solar Panels (On Grid)
3- Solar Panels Only (Off Grid)

The goal of this plan is to determine the most cost-effective system in the short and long term while ensuring sustainable energy consumption within the factory. This implementation aims to reduce overall energy costs and achieve sustainability in electricity consumption.

The table below (1) presents the cost breakdown for the electricity-only system, including the necessary electrical capacity, daily operational hours, number of working days per year, current electricity price, and the total cost after 5 years and 30 years. It is important to note that the cost of solar panels will be paid only once every 30 years.

Table (1) - Energy Consumption Costs for Electricity Only

Cost of energy consumption when using electricity only	
Required electric power per hour	70 kw
Daily working hours	8.5 H
Required electric power per day	595 kw
Required electric power per year (296 days)	176120 kw
Electricity consumption cost per kilowatt	2.3 L. E
Total annual cost	405076 L. E
Total cost over 5 years (assuming stable prices)	2025380 L. E
Total cost over 30 years (assuming stable prices)	12152280 L. E

Phase 1: Determining the Current Energy Status in the Factory (Electricity Only)

1- Initial Energy Consumption Evaluation:

- Determining the daily and annual electricity consumption (595 kw per day, 176,120 kw per year).
- Calculating the current total cost of electricity consumption for one year and 30 years.
- Determining the annual electricity consumption cost (405,076 EGP annually).

2- Determining the Potential Benefits of Using Solar Panels:

- Analyzing the initial investment cost for solar panels.
- Comparing the total cost of solar panels with the cost of electricity over 5 years and 30 years.

Phase 2: Implementing Alternative Systems

The table below (2) outlines the cost details for the on-grid system, including the required electrical capacity, daily operating hours, the number of working days per year, the current electricity price, the cost of solar panels, and the total cost after 5 years and 30 years. This total includes both the cost of the solar panels and the cost of the portion of electricity drawn from the grid, which is a quarter of the amount used in the previous system.

Table (2) - Energy Consumption Costs for On Grid

Cost of energy consumption when using electricity with solar panels (On Grid)	
Required electric power per hour	70 kw
Daily working hours	8.5 H
Required electric power per day	595 kw
Required electric power per year (296 days)	176120 kw
Electricity consumption cost per kilowatt	2.3 L. E
Quarter of the annual electricity consumption costs	101296 L. E
Cost of solar panels per kilowatt	22000 L. E
Total cost of solar panels (30 years)	1540000 L. E
Electricity consumption cost over 5 years	506345 L. E
Total cost of electricity and solar panels over 5 years (assuming stable prices)	2046345 L. E
Electricity consumption cost over 30 years	3038070 L. E
Total cost of electricity with solar panels over 30 years (assuming stable prices)	4578070 L. E

1- Electricity with Solar Panels (On Grid):

- Installing solar panels that are connected to the local electricity grid.
- Configuring the system so that solar energy covers a significant portion of the factory's consumption, while continuing to use electricity when needed.
- Calculating the total costs of solar panels with electricity over 5 years and 30 years.
- Analyzing cost savings compared to using electricity only.

2- Solar Panels Only (Off Grid):

- Installing solar panels with batteries to store energy.
- Supplying the factory entirely with solar energy, which requires a high initial investment, especially for batteries and their maintenance.
- Calculating the total cost over 5 years and 30 years.
- Comparing these costs with the traditional electricity system and the on-grid solar panel system.

Phase 3: Financial Analysis and Evaluation

The table below (3) presents the cost details for the off-grid system, including the required electrical capacity, daily operating hours, the number of working days per year, the current electricity price, the cost of solar panels, and the cost of batteries

used to store solar energy for nighttime use or during periods without sunlight. Additionally, it shows the total cost after 5 years and 30 years.

Table (3) - Energy Consumption Costs for Off Grid

Cost of energy consumption when using solar panels only (Off Grid)	
Required electric power per hour	70 kw
Daily working hours	8.5 H
Required electric power per day	595 kw
Required electric power per year (296 days)	176120 kw
Cost of solar panels and cables per kilowatt	40000 L. E
Total cost of solar panels (30 years)	2800000 L. E
Total battery costs over 5 years	700000 L. E
Total cost of solar panels and batteries over 5 years	3500000 L. E
Total battery costs over 30 years (6 replacements)	4200000 L. E
Total cost of solar panels and batteries over 30 years (assuming stable prices)	7000000 L. E

1- Conducting a Financial Comparison Between Systems:

- Comparing costs over the short term (5 years) and long term (30 years) for the different systems.
- Estimating the expected cost savings after implementing the alternative solar systems.

2- Evaluating Financial Returns:

- Calculating the financial returns from reducing traditional electricity consumption.
- Estimating the returns from using sustainable systems, considering maintenance costs and the lifespan of solar panels.

Phase 4: Implementation and Monitoring

1- Implementing the Chosen System:

- If the most suitable system (solar panels with grid connection or off-grid solar panels) is selected, solar panels will be installed according to studies and designs.
- Identifying the team responsible for implementing the system and ensuring it meets the required technical specifications.

2- Setting Up a Maintenance Plan:

- Developing a regular maintenance plan for the solar panels and related equipment.
- Setting maintenance schedules for inspections and replacements when needed (e.g., batteries in the off-grid system).

3- Monitoring Performance:

- Monitoring energy consumption after implementing the new system and documenting cost savings.
- Conducting regular assessments of the solar system's performance, verifying energy savings, and making continuous improvements.

Phase 5: Final Evaluation and Recommendations

1- Evaluating Actual Costs After Implementation:

- Comparing actual consumption costs after implementing the new system with the expected costs.
- Evaluating the system's effectiveness in reducing energy consumption costs and achieving environmental sustainability.

2- Future Recommendations:

- If the system proves successful, the use of solar panels can be expanded to cover more of the factory's energy needs.
- Exploring other options such as improving the efficiency of electrical devices in the factory to further reduce energy consumption.

RESULTS & DISCUSSION

1- Electricity Only:

- The total annual cost of electricity consumption is 405,076 EGP.
- The total cost over 5 years is 2,025,380 EGP.
- The total cost over 30 years is 12,152,280 EGP.
- Using electricity only in this case, as part of traditional energy systems, is one of the most costly options in the long term.
- Over 30 years, the total cost is substantial, mainly due to the continuous reliance on the electricity grid, which causes costs to accumulate over time.

2- Electricity with Solar Panels (On Grid):

- The total cost of solar panels over 30 years is 1,540,000 EGP.
- The total cost of electricity consumption over 5 years is 506,345 EGP.

- The total cost of solar panels with electricity consumption over 5 years is 2,046,345 EGP.
- The total cost of solar panels with electricity consumption over 30 years is 4,578,070 EGP.

Using solar panels with electricity provides significant cost savings compared to traditional electricity consumption, especially when considering the cost of electricity consumption alone.

- The on-grid solar system offers a reasonable balance between initial investment costs (solar panel costs) and long-term energy savings.
- After 30 years, the analysis shows that the total costs will be significantly lower than using electricity only.

3- Solar Panels Only (Off Grid):

- The total cost of solar panels with batteries over 5 years is 3,500,000 EGP.
- The total cost over 30 years is 7,000,000 EGP.
- This case represents the most costly option in the short and long term, as the cost of solar panels and batteries is very high compared to other options.
- The need to replace batteries every 5 years significantly increases the total costs, making this system more expensive over the long term compared to the other two options.
- This option is the most expensive in the case of price stability due to the high costs of solar panels with batteries.

Comparison Between Different Systems:

Over 5 years:

- The electricity-only option requires a total cost of 2.025 million EGP.
- The on-grid solar panel option has a total cost of 2.05 million EGP.
- The most expensive option is the off-grid solar panel system with batteries, totaling 3.5 million EGP. As shown in the figure.

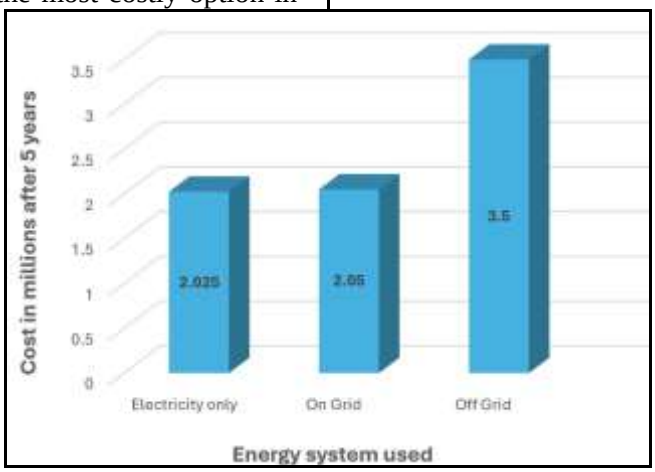

Figure (2) the cost difference between the three systems after 5 years

We conclude that there is a slight difference in cost after five years between using the electricity-only system and the system on-grid. but the on-grid solar panels provide a good balance between initial cost and long-term savings.

Over 30 years:

- The total cost of electricity consumption is 12.15 million EGP.
- The on-grid solar panels have a total cost of 4.58 million EGP.
- The off-grid solar panels with batteries cost a total of 7 million EGP.
- As shown in the figure.

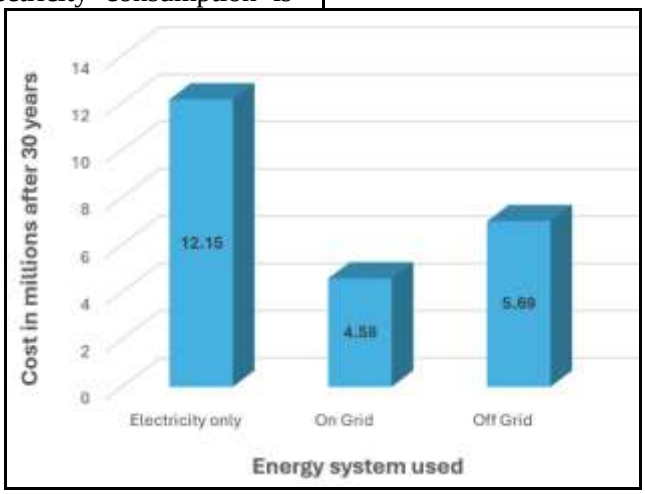

Figure (3) the cost difference between the three systems after 30 years

In this context, the on-grid solar panel system (On Grid) appears to be the best option in terms of long-term cost, significantly reducing costs compared to electricity-only consumption or off-grid solar panels with batteries.

Conclusions:

In conclusion, if the priority is to save on long-term costs, the on-grid solar system is the most cost-effective option and the best for achieving sustainability.

- The electricity-only option is the least costly in the short term but will become very expensive in the long run.
- The on-grid solar system (On Grid) is the most efficient option in terms of balancing initial cost and long-term savings.
- The off-grid solar system (Off Grid) is the most expensive option, primarily due to high battery costs and maintenance.

After implementing this plan, the factory is expected to achieve significant cost savings in the long term, along with reduced reliance on traditional electricity. This step will help enhance environmental sustainability and reduce the factory's ecological footprint.

The world is actively pursuing clean and green energy sources, focusing on environmental preservation and raising awareness about the impacts of climate change and carbon emissions from factories. Renewable energy helps eliminate carbon, a major contributor to climate change, while also reducing costs, especially with rising electricity prices.

Thus, a comprehensive plan is developed to select and implement the appropriate systems within the factory, analyzing all financial and technical aspects, in addition to ongoing monitoring and evaluation of the results.

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