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Determining Optimal Alternative Strategies for Solar Panel Machine Productions at PT Len Industry (PERSERO)

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ABSTRACT

Purpose: This study aimed to identify the root causes of low annual production capacity and propose optimal alternative strategies to enhance efficiency and output.

Methodology/approach: This study integrates Porter's analysis, stakeholder analysis, and AHP across phases from planning to full-scale operation, aiming at modernization, compliance, competitiveness, and customer satisfaction.

Results/findings: The study finds that low production capacity is caused by outdated equipment, weak stakeholder coordination, lack of performance monitoring, and limited adoption of digital technology. Porter's analysis and AHP conclude that technological modernization is the most effective strategy, with new equipment projected to increase production capacity by 35–45% and improve operational efficiency.

Conclusions: Improving production capacity requires a multidimensional approach, including strategic planning, modern technology adoption, and stakeholder engagement. A phased implementation model proves effective in addressing systemic issues while maintaining operations, enhancing competitiveness, and boosting customer satisfaction.

Limitations: The study is limited to a specific industry context, so the results may not be widely generalizable. The long-term impact of the strategy remains unclear, and the AHP method involves expert judgment, which introduces subjectivity.

Contribution: This study offers a structured framework combining Porter's analysis, stakeholder analysis, and AHP, showing that phased implementation and technology investment can greatly enhance production performance.

Keywords: *5 Porter Analysis, Optimization Strategies, PT Len Industry, Solar Panel Production, Stakeholder Analysis*

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1. Introduction

Solar energy has gained significant attention as an alternative to tackle the energy crisis, particularly the dependence on petroleum since the 1970s. Many countries have recognized this potential. Solar energy is abundant, and does not pollute the environment. Sunlight can be converted into electricity using solar cells or panel technology. Indonesia, being located on the equator, has a high potential for solar energy production, with an average potential of 4.8-5.1 kWh/m²/day and reaching up to 6 kWh/m²/day in eastern Indonesia. Solar panels are the primary components of solar power plant technologies. Solar panel manufacturers in Indonesia are members of the Indonesian Solar Panel Manufacturers Association, which was established on August 17, 2010 (Dang, 2017).

Currently, Apamsi is comprised of 12 domestic companies as solar panel manufacturers in Indonesia. To drive the growth of domestic industry, the Ministry of Industry has introduced regulations under the Increased Use of Domestic Production (P3DN) program. These regulations specify the minimum local content level (TKDN) required for solar panels used in each PLTS development (Tasliman, Adicahya, & Wijaya, 2024). For Solar Power Plants, amendments have been made as per Regulation Ministry of Industry Number 05 of 2017, which revises Regulation Ministry of Industry Number 54/M-IND/PER/3/2012 concerning Guidelines for the Use of Domestic Products for Electricity Infrastructure Development. The combined local content value for the Solar Home System is 53.07%, while for centralized or communal solar power plants, it is set at 43.85%.

The Ministry of Industry is promoting the development of the national solar panel industry through a roadmap outlined until 2025 (Table 1.1). This effort aims to support the realization of a national new and renewable energy (NRE) mix, particularly regarding energy use in power generation. The Ministry of Industry has developed a roadmap to support the growth of the national solar panel industry backed by various strategic policies (Sitompul et al., 2022). The Ministry of Industry in Indonesia has set ambitious targets for the local content (TKDN) of solar panels in the country. The goal was 40% from 2016 to 2018 and increased to 76% from 2019 to 2020. For the period from 2020 to 2022, the target was 85%, and 90% was reached from 2023 to 2025. Despite these ambitious goals, the highest local content achieved in Indonesian solar panels by 2024 is approximately 48%. This shortfall can be attributed to supply chain disruptions, technological gaps, investment shortfalls, policies, and competitive market dynamics. Overcoming these challenges is crucial for the domestic industry to meet TKDN targets and boost the local content in the solar panel industry (Akar & Lotfizadeh, 2017).

Indonesia has a great potential for solar energy development because it is located near the equator and receives abundant sunlight throughout the year. The country's average solar irradiation is approximately 4.8 kWh/m²/day, making it one of the most solar-rich regions globally. This high solar exposure creates a significant opportunity to harness solar energy, meet the increasing energy demand, and reduce the dependence on fossil fuels. Expansive land areas, including urban rooftops and open rural fields, provide ample opportunities for solar panel installation (Ghaleb Al-Aqqad & Menyhart, 2023). Indonesia's numerous islands offer unique locations for decentralized solar power solutions, particularly for remote and off-grid areas. With the government's focus on renewable energy, there is a solid foundation for expanding the solar power capacity, which can contribute to energy security and sustainability goals. The growth in solar energy has increased rapidly from 2018 to 2023. In 2018, the installed solar-energy capacity was 67.6 MWp. By 2023, this capacity had increased significantly to a total of 573.8 MWp. The most substantial growth occurred in 2023, with 290.6 MWp of solar energy being installed in a single year. This increase supports the target of having 196 MWp of installed solar energy in 2024 (Dinçer, Demir, & Yılmaz, 2025).

1.1 Research Questions

To ensure business continuity and production for panel manufacturing facilities in the future, decision making is needed to find the best alternative. This research highlights the following questions for further recommendations for solar panel machine production at PT. Len Industry (PERSERO):

1. What is the root cause of the low annual solar panel production in PT? Len Industry (PERSERO)?

2. What are the relevant available scenarios for solving the current conditions of solar panel production at the PT? Len Industry (PERSERO)?
3. What is the best alternative for addressing the current condition?

1.2 Research Objective

The Objectives of this study were as follows.

1. To identify the root cause, solar panel production is not maximally utilized in PT. Len Industry (PERSERO).
2. After identifying the root cause, relevant alternative scenarios are provided to resolve the existing issue.
3. Determine the best alternative for facing the current conditions.

2. Literature review

2.1 Theoretical Foundation

2.1.1 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is designed to cope with both rational and intuitive methods to select the best among several alternatives evaluated with respect to several criteria (Tavana, Soltanifar, & Santos-Arteaga, 2023). AHP is a basic approach to decision making and a popular method for multi-criteria decision making (Alzahmi & Ndiaye, 2025). The AHP objective is to develop a hierarchy of decision criteria and define alternative courses of action. The AHP method was first introduced by Saaty and Vargas (2012). AHP uses qualitative and quantitative criteria for evaluation. Both qualitative and quantitative information can be compared using appropriate judgments to obtain weights and priorities (Alzahmi & Ndiaye, 2023). The AHP method consists of two steps:

- a. The relative weights of the decision criteria were determined.
- b. Determine the relative rank (priority) of alternative solutions.

The Analytic Hierarchy Process (AHP) decision-making phase sequence is as follows.

1. Construct structure a hierarchy

We define the problem, determine the decision criteria, and identify alternatives. The structural hierarchy of the AHP is shown in Figure 1.

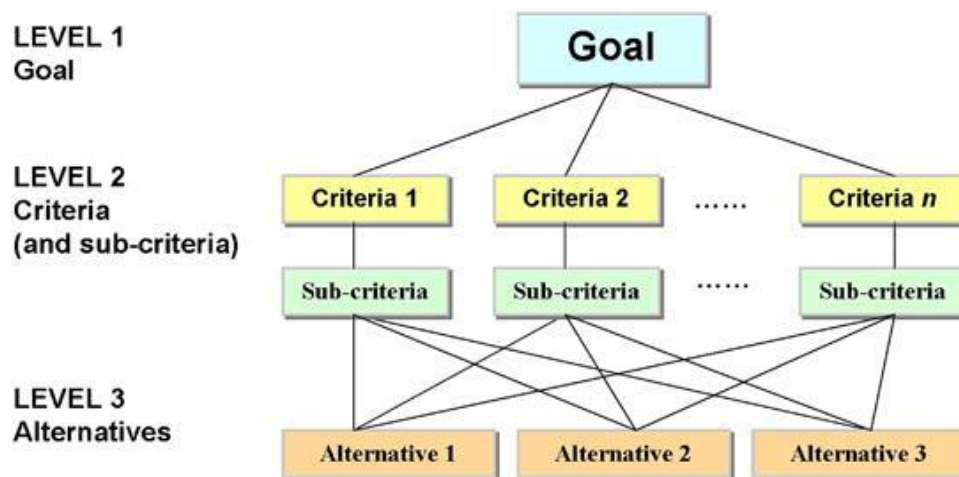


Figure 1. Structure Hierarchy of AHP
Source: Saaty and Vargas (2012)

2. Create Pairwise Comparisons

The relative importance between each pair of decision alternatives and criteria is assessed. A survey was conducted to determine the importance of one element compared to another to create a pairwise comparison. Subject Matter Experts (Rosmeli) as decision makers could be interviewed in the prioritization process to make judgments in decision making. SMEs can use the fundamental scale of

value (Pairwise Numerical rating) to represent the intensities of their judgements, as shown in Figure 2.4

3. Synthesizing Procedure

The results were integrated to determine the most effective solution. The results and output of the AHP are the set of alternative priorities. The procedure for synthesizing the pairwise comparison matrix is as follows:

- a. Step 1: Sum the values in each column
- b. Step 2: Each element of the matrix is divided by its total column. All columns in the normalized pairwise comparison matrix have a sum of one (one).
- c. Step 3: Average the elements in each row (priority vector / eigen vector)
 - a. Values in the normalized pairwise comparison matrix were converted to decimal forms.
 - b. The result is usually represented as a (relative) priority vector (eigenvector).

4. Consistency Measurement

AHP provides a measure of the consistency of pairwise comparison judgments by computing the consistency ratio. AHP provides a method for measuring the degree of consistency among the pairwise judgments provided by the decision maker to answer the consistency question. The rules of the degree of consistency in AHP are as follows:

- a. The decision process can continue if the degree of consistency is acceptable
- b. The decision maker should reconsider and revise the pairwise comparison judgments before proceeding with the analysis if the degree of consistency is unacceptable.

5. Development of Priority Ranking

The procedure for priority ranking calculation is as follows.

- a. Priority ranking is obtained by calculating the priority vector (eigenvector) of alternative solutions for each criteria matrix.
- b. Criteria ranking is obtained by calculating the priority vector (eigenvector) for the criteria matrix.
- c. An alternative ranking calculation is obtained by multiplying the priority vector of alternative solutions for each criteria matrix (priority matrix) with the priority vector of the criteria matrix (criteria weights).
- d. Ranking these priority values from the alternative ranking calculation, the author will obtain an AHP ranking of the decision alternatives. From the results of the alternative ranking calculations, an alternative ranking matrix was obtained, where the highest score from the matrix indicates the best solution.

2.2 Conceptual Framework

The conceptual framework to facilitate the determination of optimal alternative strategies for solar panel production facilities using the Double Diamond design process model. This model, popularized by the British Design Council in 2005, has become synonymous with a structured four-phase approach to design and decision-making (Aliyuddin, 2024). The foundation of this model can be traced back to the divergence- convergence principle proposed. As a Hungarian-American linguist, Bánáthy introduced an early iteration of this concept, emphasizing the cyclical exploration and refinement of solutions (Fan, Zhang, & Bohemia, 2024). These historical milestones establish the Double Diamond as an influential model in design thinking and problem-solving spaces (Gustafsson, 2019).

Adapting the Double Diamond model to the context of optimal alternative strategies for solar panel production at PT. Len Industry involves a detailed exploration and refinement process across four distinct phases (Khan, Hanna, Sun, & Alam, 2017). By following these phases, the author can systematically explore, define, develop, and deliver optimized production strategies. The Double Diamond model ensures that all aspects of production are thoroughly analyzed and refined, leading to improved efficiency, cost-effectiveness, and technological advancement in solar panel production. This structured approach not only addresses immediate production challenges but also sets the foundation for sustainable growth and competitive advantage in the renewable energy sector.

3. Research method

3.1 Research Design

The research approach and methodology are fundamental aspects in designing and conducting this research. When deciding on an appropriate research approach, researchers must consider the research purpose and data sources that will be utilized. In this case, the purpose of this research is to assist the PT. Len Industry management in decision making regarding issues with low annual production of solar panels. The research began by conducting a thorough analysis of the current situation to identify existing issues through a gap analysis (Keisang, Bader, & Samikannu, 2021). This study primarily focuses on evaluating the annual solar panel production, as it significantly influences the solar panel production division, particularly in terms of plant physical availability and maintenance costs. After recognizing the existence of a gap signifying a problem, the researcher will refer to pertinent literature to address this issue. Following this, the researcher will formulate following provided stages as a research design (Abdulla, Sleptchenko, & Nayfeh, 2024)

3.2 Data Collection

Interviews were conducted either in person or via video conferencing, depending on participants' preferences and availability. This flexibility ensures that the data collection process is convenient and comfortable for participants, which can enhance the quality of the data collected. The primary data-collection process involved several key steps.

1. Participant Selection Purposive sampling will be used to select participants who have been directly involved in the migration process. This method ensures that the data collected are relevant and informative for our research objectives.
2. Interview Preparation: Before interview, the author reviewed the interview guide and any relevant background information about the participant. This will help me ask informed and relevant questions during the interviews.
3. Conducting the Interview: During interview, the author will use active listening skills to facilitate conversation and ensure understanding. The author will also take brief notes about the interview context and participants' non-verbal cues.

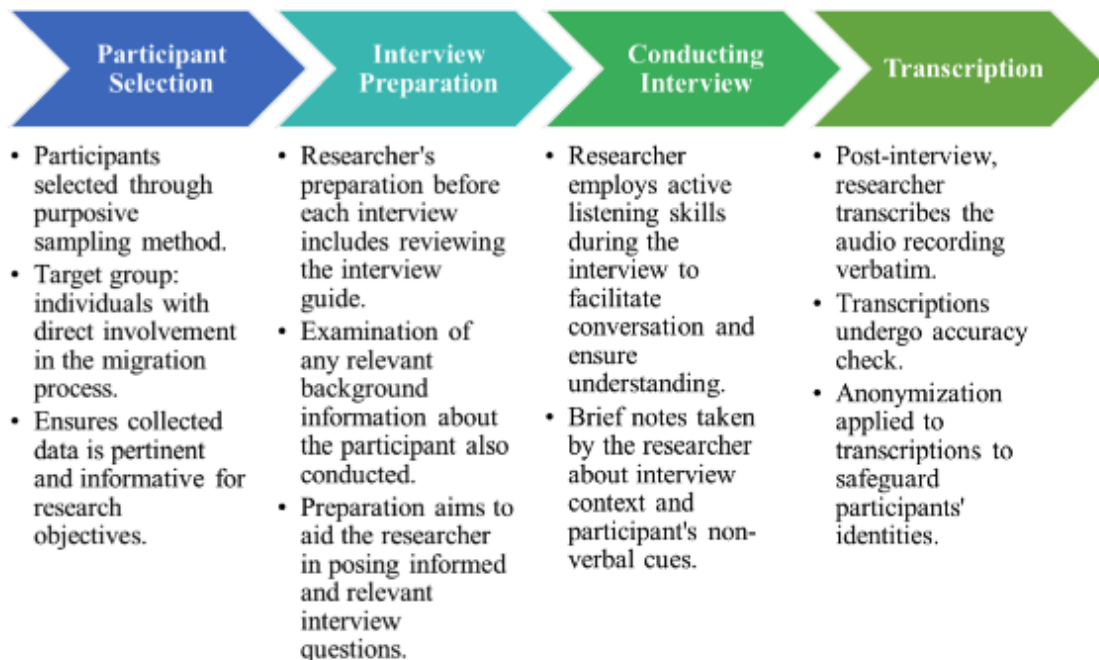


Figure 2. Primary Data Collection Process

The primary data collection method for this study was designed to provide a comprehensive and in-depth understanding of the network migration process. Semi-structured interviews offer a flexible and adaptable approach, enabling the collection of rich and detailed data that can provide valuable insights.

3.3 Data Analysis

The data analysis in this study employs a blend of qualitative and quantitative methodologies, providing a comprehensive understanding of the process.

1. **Qualitative Data Analysis:** The qualitative data gathered through interviews and document review were subjected to thematic analysis. This process involves coding the data, identifying themes, reviewing themes, defining and naming themes, and producing a report (Braun and Clarke, 2006). Thematic analysis allows for in-depth exploration of the data, offering insights into the experiences, perceptions, and decision-making processes of the participant.
2. **Quantitative Data Analysis:** The quantitative data collected through research on company reports, radio equipment catalogs, and product specifications were analyzed using Analytic Hierarchy Process (AHP) statistical methods. Descriptive statistics were employed to summarize the data, while differential statistics were used to identify the relationships between the variables and test the hypotheses. Quantitative analysis provides a numerical representation of the data, facilitating objective comparison and evaluation (Tsai, Chen, & Yang, 2021).

The integration of qualitative and quantitative data analysis methods allows for a comprehensive and robust analysis of the data, thus enhancing the reliability and validity of the research findings.

4. Results and discussions

4.1 Analysis

To thoroughly investigate the context of determining optimal alternative strategies for solar panel machine production at PT. Len Industry, we embarked on a multifaceted exploration process. Various methods have been employed to gain a comprehensive understanding of production strategy optimization.

1. **Stakeholder interviews:** Engaging with PT. Len Industry management, technical teams, customers, and regulatory authorities provided direct insights into the practical challenges and expectations related to solar panel machine production facilities. These interactions helped us to understand the operational, technical, and regulatory nuances that could influence this strategy.
2. **Brainstorming Sessions:** Through Brainstorming with diverse teams within the PT. Len Industry, we fostered an environment of creative problem-solving and idea generation. This collaborative effort was instrumental in strategizing solar panel machine production, highlighting the company collective intelligence and innovative potential.
3. **Technological Review:** A comprehensive review of the current production infrastructure and technical requirements for optimizing solar panel machine production was conducted. This review and stay informed on broader technological trends ensured a well-rounded understanding of the technical landscape of PT. Len Industry would navigate during the optimization process.
4. **Integrated Approach:** This integrated approach of stakeholder interviews, brainstorming sessions, and technological reviews allows us to develop a detailed and nuanced understanding of the production context. This thorough exploration ensured that PT. Len Industry solar panel machine production strategy is aligned with immediate operational needs and long-term strategic objectives, facilitating successful optimization.

Our exploration revealed that determining the optimal alternative strategies for solar panel machine production is driven by a complex interplay of factors:

1. **Technological Advancements:** The need to optimize production is primarily driven by the demand for increased efficiency and output, with advancements in solar technology offering the necessary capabilities for improved energy production and cost-effectiveness.
2. **Regulatory Environment:** The global trend towards renewable energy highlights the importance of aligning with regulatory changes to secure PT. The Len Industry's operational legitimacy and future growth emphasize the necessity of compliance with national and international standards.
3. **Market Dynamics:** The competitive landscape in the solar panel industry necessitates strategic optimization of production facilities, which enables the PT Len Industry to improve product quality, penetrate new markets, and sustain its competitive advantage.

4. **Strategic Imperatives:** Optimization is identified as a strategic realignment with PT. Len Industry long-term business goals focus on expanding product offerings, enhancing customer satisfaction, and securing market leadership.
5. **Operational Considerations:** The transition involves significant changes in infrastructure, technology procurement, and workforce training, necessitating a detailed plan to manage these operational shifts smoothly.

In summary, the exploration process, characterized by stakeholder engagement, brainstorming, and technological assessment, laid the foundation for understanding the multifaceted aspects of PT. Len Industry optimization of solar panel production facilities. This comprehensive exploration informed the development of an optimization strategy intricately aligned with the company's operational realities and strategic aspirations, setting the stage for seamless and successful production enhancement.

4.2 Problem Definition and Objectives

In the process of defining the problem and objectives for optimizing the PT. Len Industry's solar panel production facilities have identified a unique set of challenges and opportunities. This definition is crucial to outline the specific issues that the company will encounter during this optimization and to establish clear, measurable goals for the transition.

4.2.1 Problem Definition

Principal challenges for PT. Len Industry in optimizing solar panel production, lies in managing the technological, financial, and regulatory complexities of the transition while ensuring uninterrupted production and customer satisfaction, The critical challenges pinpointed are:

1. **Technological Integration:** We must ensure that the existing production infrastructure can be upgraded or replaced to support advanced solar panel technologies. This requires a significant technological investment and system reconfiguration.
2. **Capital and Operational Expenditure:** The Optimization requires substantial financial investment in new equipment, technology, and training. Additionally, we anticipate potential increases in operational costs owing to the complexities of managing the transition period.
3. **Regulatory Compliance:** We must navigate the evolving regulatory landscape to secure the necessary licenses and approvals for optimized production facilities, adhering to stringent technical and operational standards.

4.2.2 Objectives Setting

To address these challenges, we established clear and actionable objectives.

1. **Technological Modernization:** Our goal is to successfully upgrade production facilities to operate efficiently using advanced solar panel technologies by integrating cutting-edge equipment to enhance product quality and production performance.
2. **Financial Management:** We aim to develop and implement a financial strategy that ensures that optimization is cost-effective, focusing on optimizing investment in infrastructure and technology to achieve a favorable return on investment within a defined period.
3. **Regulatory Alignment:** We strive to fully comply with all regulatory requirements for solar panel production, ensuring legal and operational adherence to facilitate smooth transition.
4. **Market Competitiveness:** We plan to leverage enhanced production capabilities to strengthen our market position, responding effectively to competitive pressures and customer expectations in the renewable energy market.
5. **Customer Continuity and Satisfaction:** We are committed to ensuring uninterrupted production during the optimization process with minimal impact on customers, while also improving the overall product quality and customer experience post optimization

By precisely delineating problems and setting strategic objectives, we are confident that PT. Len Industry can effectively navigate the optimization of solar panel production facilities. These objectives are designed not only to address the immediate challenges of optimization, but also to align with the company's broader strategic goals of technological leadership, financial stability, regulatory

compliance, market competitiveness, and customer satisfaction. The successful realization of these objectives will empower PT. Len Industry to capitalize on the opportunities presented by the production optimization, positioning the company for sustained growth and success in the evolving renewable energy landscape.

4.2.3 Strategic 5 Porter Analysis of Solar Panel Production Facilities

Five Porter analyses of PT were conducted. Len Industry optimization of solar panel production facilities is essential for mapping a company's strategic direction and positioning in the competitive landscape. This analysis incorporates an in-depth review of the PT. Len Industry internal strengths and weaknesses, alongside external opportunities and threats, using data from company annual reports, sector-specific studies, and the latest trends in technology (Porter, 1990).

4.3 Threat of New Entrants

The threat of new entrants to the solar panel production industry for the PT Len Industry is moderate to high. Entry into this market requires significant capital investment in advanced manufacturing technologies, R&D, and compliance with stringent environmental and safety regulations. These high entry barriers protect established companies such as the PT Len Industry, which benefit from economies of scale, established supplier relationships, and brand recognition. However, the growing demand for renewable energy and the global push towards sustainable solutions make this market attractive to new players, particularly those with innovative approaches or substantial financial backing.

Despite these barriers, technological advancements and decreasing solar technology costs have lowered entry thresholds over time. New entrants can leverage innovative production techniques and materials to differentiate themselves. Supportive government policies and incentives for renewable energy projects can facilitate market entry. For the PT Len Industry, this means that, while the threat of new entrants is mitigated by its established position and resources, it must be bold. Continuous innovation and investment in cutting-edge technologies are crucial to maintain a competitive edge.

To address this threat, the PT-Len industry must focus on strengthening its core competencies and enhancing its value proposition. This includes investing in research and development to improve the efficiency and cost-effectiveness of solar panels, as well as exploring strategic partnerships and collaborations to expand technological capabilities. By maintaining high standards of product quality and customer service, the PT Len Industry can create strong brand loyalty and overcome entry barriers that new competitors will find challenging.

4.4 Bargaining Power of Suppliers

The bargaining power of suppliers in the solar panel production industry in the PT Len Industry is notably high because of several critical factors. First, the production of solar panels relies heavily on specific raw materials and advanced components such as silicon wafers, solar cells, and specialized manufacturing equipment. These materials and components are often sourced from a limited number of suppliers, with significant control over their supply chains. This concentration of suppliers increases their leverage over pricing, delivery schedules, and terms of sale, placing the PT Len Industry in a potentially vulnerable position.

Moreover, the high specialization and technological expertise required to produce high-quality solar components further intensify supplier power. Suppliers who can provide cutting-edge materials and technologies are indispensable for maintaining the efficiency and competitiveness of the PT Len Industry production facilities. Dependence on a select group of suppliers for these critical inputs means that any disruption in the supply chain, whether due to geopolitical issues, natural disasters, or supplier-specific problems, can significantly impact production schedules and costs.

To mitigate suppliers' bargaining power, the PT Len Industry must adopt several strategic measures. One effective strategy is to diversify the supplier base, reducing dependency on any single supplier and thus diminishing their negotiating power. Building long-term partnerships and strategic alliances with

key suppliers can also help secure more favorable terms and ensure a stable supply of essential materials. Additionally, investing in in-house capabilities to produce certain components or developing alternative materials can reduce reliance on external suppliers and enhance control over the production process.

Furthermore, the PT Len Industry can leverage bulk purchasing and long-term contracts to negotiate better terms with its suppliers. By committing to large-volume purchases over an extended period, a company can secure discounts and more stable pricing, thereby improving cost management. Engaging in continuous market research to remain informed about emerging suppliers and new technologies can also provide opportunities to switch to more cost-effective or innovative suppliers. By implementing these strategies, the PT Len Industry can better manage the bargaining power of suppliers and strengthen its position in the solar panel production industry.

4.5 Bargaining Power of Buyers

The bargaining power of buyers in the solar panel production industry in the PT Len Industry is relatively high and is significantly influenced by the competitive landscape and the availability of alternative suppliers. Buyers, ranging from large-scale commercial clients to government entities and individual consumers, have numerous options, making them price sensitive and demanding in terms of quality, efficiency, and service. This multitude of choices empowers buyers to negotiate better prices, enhanced product features, and superior after-sales service, forcing manufacturers such as the PT Len Industry to innovate and maintain competitive pricing continuously.

Moreover, buyers are well informed and increasingly sophisticated, often conducting extensive research and comparisons before making purchasing decisions. The rise of digital platforms and global connectivity has further enhanced access to information about different suppliers and product specifications. This heightened awareness and access to market information allow buyers to exert considerable pressure on the PT Len Industry to meet high standards and deliver value. To address this, the PT Len Industry must focus on building strong relationships with its customers, offering exceptional customer service, and continually improving its product efficiency and cost-effectiveness to differentiate itself from competitors and reduce buyers' bargaining power.

4.6 Threat of Substitutes

The threat of substitutes in the solar panel production industry for the PT Len Industry is moderate to low, primarily because of the unique advantages solar energy offers over other renewable energy sources. Solar energy is highly versatile, scalable, and suitable for various applications, from residential rooftops to large-scale solar farms. Its decreasing cost over the years, driven by technological advancements and economies of scale, further strengthens its position in the renewable-energy market. However, other renewable energy sources such as wind, hydro, and geothermal energy present viable alternatives, each with its own benefits and limitations.

Wind energy is a well-established substitute that can produce significant amounts of electricity, particularly in regions with strong and consistent wind patterns. However, it requires substantial land and specific geographical conditions, which limits its applicability compared with the more flexible installation options of solar panels. Similarly, hydroelectric power is a reliable and mature technology capable of generating large-scale power; however, it depends heavily on the availability of water resources and can have significant environmental impacts. Geothermal energy offers continuous power generation but is geographically restricted to areas with suitable subterranean heat sources.

Despite the existence of these alternatives, the threat they pose to solar panels is mitigated by the broader adoption and lower costs of solar technology. Additionally, the versatility of solar installations, which can be deployed in various settings including urban areas, rooftops, and even portable applications, gives solar energy a competitive edge. The PT Len Industry can capitalize on these strengths by continuing to innovate in solar technology, improving the efficiency and affordability of its solar panels, and expanding its product range to address diverse market needs.

To mitigate the threat of substitutes further, the PT Len Industry should focus on enhancing the overall value proposition of its solar panels. This includes investing in R&D to boost the efficiency and durability of solar panels, thereby increasing their appeal to cost-conscious and environmentally aware consumers. Additionally, providing comprehensive customer support and integrated solutions, such as energy storage systems and smart grid compatibility, can make solar energy more attractive than other renewable energy sources. By leveraging these strategies, the PT Len Industry can strengthen its market position and reduce the potential impact of substitute products.

4.7 Industry Rivalry

The solar panel production sector in Indonesia is characterized by intense rivalry driven by several factors that amplify competition among existing players. The PT Len Industry faces significant competition from both domestic and international manufacturers, who employ various strategies to capture market share, including price competition, technological advancements, and brand differentiation. The rapid growth of the industry and increasing demand for renewable energy solutions have attracted numerous players, further intensifying competition.

Price competition is the major driver of this intense rivalry. Solar panel manufacturers are under constant pressure to reduce costs and offer competitive pricing because of commoditization of solar panels. As technology advances and production techniques become more efficient, companies can lower their prices and create a highly competitive pricing environment. To remain competitive, the PT Len Industry must continuously seek ways to reduce production costs without compromising quality. This could involve investing in more efficient manufacturing processes, sourcing cheaper materials, or innovating product design to reduce overall costs.

Technological advancements have played a crucial role in intensifying industrial rivalry. Companies that can innovate and introduce more efficient, durable, and cost-effective solar panels have gained a significant competitive advantage. The PT Len Industry needs to invest heavily in R&D to stay ahead of technological trends and offer superior products. Collaborating with research institutions, adopting the latest manufacturing technologies, and continuously improving product efficiency can help a company maintain its competitive advantage in the face of rapid technological changes.

The regulatory environment adds another layer of complexity to the industry rivalry. Regulations for local and imported solar panels can significantly affect the competitive landscape. The Local Content Requirement (TKDN) policy and Ministry of Energy and Mineral Resources (ESDM) regulations on the implementation of SNI IEC 61215 demonstrate the government's efforts to increase the use of domestic components and ensure the quality of solar panels in the Indonesian market. Manufacturers and importers of crystalline silicon photovoltaic modules are required to comply with the SNI IEC 61215 standard of 2016, which involves recertification or endorsement for uncertified modules. These regulations aim to protect consumers and ensure high performance and durability of solar panels in PLTS projects.

Local manufacturers face challenges in that the minimum local content requirement of 60%, according to the Ministry of Industry regulation number 54/M-IND/PER/3/2012, will take effect on first January 2025. Domestic industry currently has limited production capacity and technology, leading to higher prices for locally made solar panels compared to imported products. The government needs to consider adjusting the local content policy to encourage investment and development of domestic industries. Proposals to lower the local content to 40% and provide a relaxation period of 3-4 years can give local manufacturers time to increase their capacity and production efficiency.

The PT Len Industry produced solar panels with a total capacity of 3.80 MWp in 2023, derived from the production of solar panels with outputs of 300Wp and 330 Wp. Compared to the total installed capacity of solar power plants (PLTS) in 2023, which reached 290.69 MWp, PT Len Industry production contribution was only 1.3% (Figure 4.1). This clearly indicates that the PT Len Industry solar panel production is relatively small compared to the total installed capacity. To increase its

contribution to national installed capacity, the PT Len Industry must implement strategies to boost production and adopt more efficient technologies.

To address this issue, it is essential to develop products that meet market standards at lower prices per watt peak (/Wp). Our internal analysis shows that increasing the production of 330 Wp panels to outputs exceeding 445 Wp can significantly reduce production costs. Customers are highly interested in solar panels with higher Watt peak outputs and lower prices per Watt peak. By making this strategic shift, the PT Len Industry can enhance its competitiveness in the market and attract more customers in need of cost-effective and efficient solar solutions. Focusing on producing high-output panels at reduced costs will allow the PT Len Industry to improve its market position and make a more substantial contribution to the national installed capacity of solar power.

RUPTL PLN data for the years 2024 to 2029 (Table 4.2) shows significant growth in both Independent Power Producers (IPP) and non-IPP solar power projects. There is a specific focus on IPP, driven by the mandatory implementation of Domestic Component Level (TKDN). The IPP market for solar power (PLTS) is expected to add 1,746 Mw over the six-year period. In 2024, there will be a substantial addition of 358 Mw, followed by a significant increase of 858 Mw by 2025, accounting for nearly half of the total forecasted capacity. The growth stabilizes in the following years, with annual increments of 110–140 Mw from 2026 to 2029. This pattern suggests front-loaded expansion, which highlights the strategic importance of enhancing facilities to increase the market share.

Failing to capture a significant market share in the IPP solar power sector presents a critical cost issue, largely owing to the high price per watt peak (Wp) of solar panels, which hampers competitiveness and increases the project costs. By enhancing the solar panel capacity per watt peak (Wp) and reducing the cost per Wp, companies can optimize the overall cost of solar power systems. Moderate forecasting suggests that such improvements could boost the market share by 25% (Figure 4.2), driven by strategic investments in advanced manufacturing technologies, automation, and robust quality control systems. These improvements not only ensure compliance with TKDN regulations but also make the products more competitive by meeting high-quality standards (Patel, Khan, Sun, & Alam, 2019). To achieve this, the PT Len Industry must upgrade its production facilities. There are two primary evaluation options:

1. **Partial Upgrade:** Partial upgrade of PT. Len Industry solar panel production facilities can enable the production of solar panels with outputs exceeding 445Wp while utilizing a full-cell configuration. This upgrade not only boosts the energy production capabilities of the panels but also reduces production costs by 15%. By implementing this targeted enhancement, the PT. Len Industry can achieve higher efficiency and output without the need for a complete overhaul of its existing infrastructure.
2. **Full Upgrade:** Full upgrade of PT. Len Industry solar panel production facilities can enable the production of solar panels with outputs exceeding 445 Wp by using a half-cut cell configuration. This comprehensive enhancement not only maximizes the energy production capabilities of the panels but also significantly reduces production costs by 25%. The adoption of half-cut cell technology is a strategic move for future-proof PT. Len Industry production facilities. This technology is expected to remain relevant and in demand in the foreseeable future because of its superior performance metrics and cost-effectiveness. As advancements in solar technology continue, the modular nature of half-cut cell panels allows for easier integration with emerging technologies such as bifacial panels and advanced inverter systems, further extending their technological viability and market appeal.

Comparison of partial and full upgrade options for PT. Len Industry solar panel production facilities have distinct advantages and strategic implications. This partial upgrade enables the production of solar panels with outputs exceeding 445 Wp using a full-cell configuration, offering a 15% reduction in production costs (Song et al., 2017). This option enhances energy production capabilities and efficiency without necessitating a complete overhaul of the existing infrastructure, making it a cost-effective and less disruptive solution. By contrast, the full upgrade employs a half-cut cell configuration, achieving the same output levels while reducing production costs by 25%. This comprehensive upgrade

maximizes energy production capabilities, enhances panel durability and performance, and provides future-proof facilities by aligning with the ongoing advancements in solar technology. Half-cut cell technology, with its superior performance metrics and cost-effectiveness, is expected to remain relevant and in high demand, providing a competitive edge (Dallaev, Pisarenko, Papež, & Holcman, 2023). Additionally, its modular nature facilitates integration with emerging technologies, such as bifacial panels and advanced inverter systems, extending technological viability and market appeal. Ultimately, while the partial upgrade offers immediate cost savings and efficiency improvements, the full upgrade presents a more robust future-oriented solution that ensures long-term competitiveness and adaptability in the rapidly evolving solar industry (Hwang & Kang, 2023).

4.8 Stakeholder Analysis

The optimization of PT. Solar panel production facilities in the lens Industry involve many stakeholders, each with specific interests, influences, and expectations. A stakeholder analysis can better understand these aspects, inform strategies for managing and engaging with each stakeholder group effectively, and systematically analyze the multifaceted stakeholder landscape surrounding PT. Len Industry strategic initiative to optimize solar panel production facilities (Widya Yudha & Tjahjono, 2019). This stakeholder analysis is critical for aligning the optimization process with a diverse array of interests and influences that permeate the PT ecosystem (Reynolds, 2024). Len Industry. By dissecting the stakeholder grouping ranging from internal entities such as management and employees to external forces such as regulatory bodies and market competitors, we uncover the core interests, gauge the power and influence of each stakeholder, and assess their potential impact. The subsequent engagement strategies are customized to each group’s unique positioning, aimed at fostering cooperative relationships and mitigating risks to ensure seamless transition (Ezeh, Ogbu, Ikevuje, & George, 2024).

This in-depth analysis adheres to the tenets of stakeholder theory and serves as a strategic compass, guiding the company through the complex interplay of expectations and influences that define the optimization journey by understanding and strategically engaging with stakeholders, PT. Len Industry can navigate the challenges and opportunities presented by the market and regulatory environment, ensuring that the optimization of its solar panel production facilities is successful and aligned with its long-term strategic goals.

Table 1. Stakeholder Analysis PT. Len Industry Solar Panel Production

| Stakeholder Group | Interests | Influence /Power | Potential Impact | Engagement Strategy |
|---------------------------|--|------------------|------------------|--|
| Management & Employees | Cost reduction, efficiency, profitability, strategic growth, working condition | High | Direct | Regular updates, decision-making involvement, Training programs, Transparent communication |
| Regulatory Bodies | Compliance with environmental and safety standards | High | Direct | Regular compliance reporting, active participation in policy discussions |
| Investors and Shareholder | Return on investment, business growth, risk management | High | Direct | Financial reporting, investor meetings, risk management strategies |
| Customers | Product quality, price, reliability, after-sales support | High | Direct | Customer service excellence, regular feedback, loyalty programs |
| Suppliers | Long-term contracts, timely payments, business growth | Medium | Direct | Long-term partnerships, Clear communication, diversified sourcing |
| Competitors | Market share, technological | Medium | Indirect | Market analysis, competitive benchmarking, innovation focus |

| Stakeholder Group | Interests | Influence /Power | Potential Impact | Engagement Strategy |
|-----------------------|--|------------------|------------------|---|
| | advancements, pricing strategies | | | |
| Industry Associations | Industry standards, networking, advocacy | Medium | Indirect | Active participation, collaboration on industry initiatives |

Based on the stakeholder analysis framework provided in the table, this is an explanation of PT. Len Industry Solar Panel Production is shown on Table 1:

Management: Management focuses primarily on cost reduction, improving efficiency, ensuring profitability, and driving strategic growth. Given their high influence and impact on the company, keeping them well informed and involved in decision making is crucial. Regular updates and strategic meetings ensure that management can guide the company effectively through the optimization process, aligning operational activities with the company’s strategic goals.

Regulatory Bodies: Regulatory bodies ensure compliance with environmental and safety standards. Their high influence and potential impact make them essential for PT. Len Industry to maintain regular compliance reporting and actively participate in policy discussions. This engagement helps the company stay abreast of regulatory changes and ensures it meets all legal requirements, thus avoiding potential legal and operational disruptions.

Investors seek returns on investments, business growth, and effective risk management. Their high influence and impact indicate that the PT. The lens Industry must provide comprehensive financial reporting, hold regular investor meetings, and implement robust risk-management strategies. Transparent communication and strategic planning are key to maintaining investor confidence and securing continued financial support for companies’ initiatives.

Customers: Customers prioritize product quality, competitive pricing, reliability, and after-sales support. They have a significant influence on and impact company success. Ensuring customer service excellence, obtaining regular feedback, and implementing loyalty programs are critical strategies to maintain customer satisfaction and loyalty. These efforts help PT. Len Industry builds a strong customer base and enhances its market reputation.

Suppliers: Suppliers are interested in securing long-term contracts, timely payments, and business growth. Although their influence is medium, their potential impact is high given their role in the supply chain. Building long-term partnerships, holding regular negotiation meetings, and diversifying sourcing strategies can assist PT. Len Industry stabilizes its supply chain and reduces dependency on individual suppliers, thus ensuring a steady supply of essential materials.

Competitors: They focus on capturing market share, advancing technological capabilities, and implementing effective pricing strategies. With a medium influence and impact, it is crucial for PT. Len Industry conducts a thorough market analysis, engages in competitive benchmarking, and focuses on innovation. Understanding competitor strategies and maintaining a competitive edge through continuous improvement can help a company sustain its market position.

Industry Associations: Industry associations aim to set industry standards, facilitate networking, and advocate for industrial interests. They hold a medium influence and impact, making active participation in these associations significant for PT. Len Industry. Collaborating on industry initiatives and staying involved in industry discussions helps the company align with industry trends, standards, and best practices, thus enhancing its credibility and influence within the sector. In implementing this analysis, these insights form the basis of an approach to stakeholder management during PT. Len Industry

optimization of solar panel production facilities ensures that each group's interests and influences are factored into the process for a balanced and successful outcome.

In the Interest-Power Matrix constructed for the PT. Len Industry stakeholder analysis: Stakeholders are classified into four categories to guide the company engagement strategy: Key Players, Keep Satisfied, Keep Informed, and Monitor (Zhu et al., 2024).

1. Key Player (High Interest, High Power)

Regulatory Bodies (5,5): Regulatory bodies are crucial in determining the optimal alternative strategies for solar panel machine production in the PT Len Industry. Their high interest and power make them significant stakeholders, who can influence or restrict operational processes through policies and regulations. Ensuring compliance with environmental standards and the SNI IEC 61215 regulations is essential for quality production and market acceptance. Engaging with regulatory bodies to align strategies with current and future regulations can facilitate a more sustainable and legally sound production process.

Management and Employees (4,4): The management and employees of the PT Len Industry are pivotal in the implementation of new production strategies for solar panel machines. With their high interest and power, they drive the operational efficiency and innovation capabilities of the company. Effective communication and collaboration between management and employees are vital for adapting to new strategies, improving productivity, and maintaining quality standards. Their involvement ensures that the strategies are practical, feasible, and aligned with the company goals and resources.

2. Keep Satisfied (lower interest, higher power)

Customer (5,3): While having high power owing to its influence on market demand, has a comparatively lower interest in the internal production strategies of the PT Len Industry. However, maintaining customer satisfaction through reliable high-quality solar panel machines is critical. Understanding customer needs and preferences helps refine production strategies to meet market expectations and enhance customer satisfaction. Creating production value for customers can lead to sustained loyalty and a competitive edge in the market.

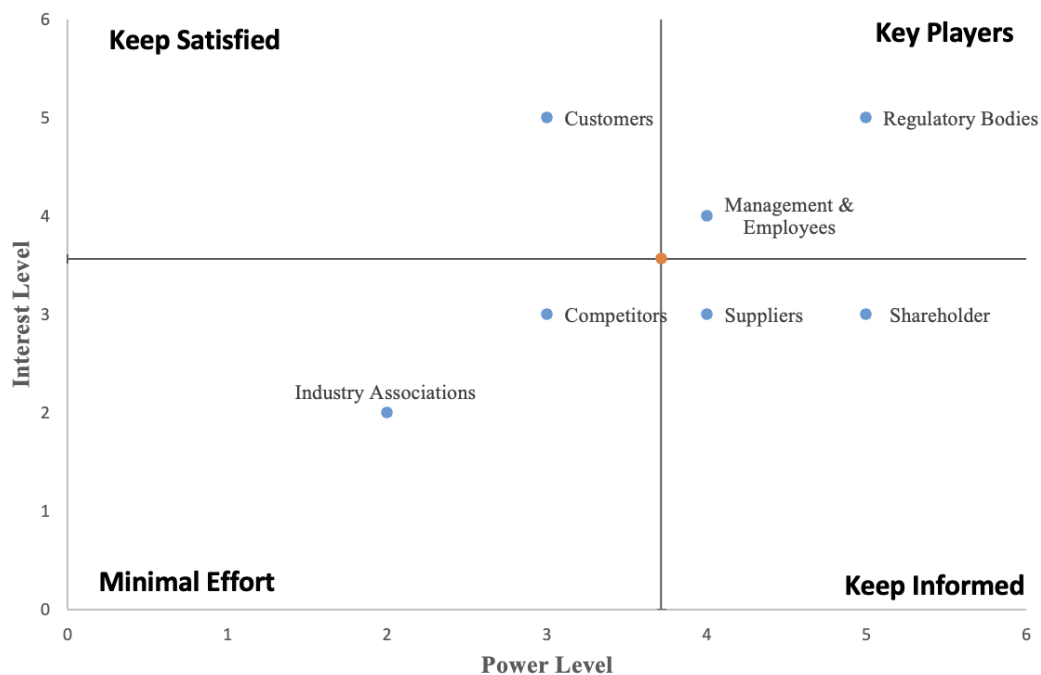


Figure 4. 1 Power Interest Matrix for Solar Panel Production Facility

3. Keep Informed

Shareholder (3,5): Shareholders hold significant power due to their investment in the PT Len Industry, but their direct interest in day-to-day production strategies might be moderate. Keeping shareholders informed about the development and implementation of optimal alternative strategies for solar panel machine production is essential for maintaining their confidence and support. Transparent communication regarding the potential benefits, risks, and expected returns of new strategies can foster trust and ensure continued investments.

Suppliers (3,4): Suppliers are crucial partners in the production process, providing the necessary materials and components for solar panel machines. Their interest in production strategies was moderate, but their power was substantial because of their impact on the supply chain. Keeping suppliers informed about new strategies helps align their operations with PT Len Industry needs, ensuring a steady flow of high-quality materials. Collaborative relationships with suppliers can lead to better coordination, cost efficiency, and innovation in production processes.

4. Minimal Effort

Competitors (3,3): While interested in market dynamics, competitors have limited power over the PT Len Industry production strategies. Monitoring competitors' activities and staying informed about industry trends can provide insights into strategic adjustments. However, direct engagement with competitors is minimal, focusing instead on differentiating PT Len Industry products and maintaining competitive advantage through innovation and efficiency.

Industry associations (2,2): Industry associations have relatively low interest and power in PT Len industry-specific production strategies. Nonetheless, they play a role in shaping the industry standards and fostering collaborative efforts. Participation in industry associations can provide valuable networking opportunities, access to industry-wide knowledge, and advocacy support. Minimal effort in maintaining these connections can yield benefits such as industry insights and potential partnerships.

The average interest and power levels across all stakeholders (3.57, 3.71) suggest a balanced approach, but with an emphasis on those with greater power. The PT Len Industry should implement its engagement strategies accordingly, allocating resources and attention where it can most effectively influence the success of determining optimal alternative strategies for solar panel machine production. The PT Len Industry can ensure a smooth transition to more efficient production processes by focusing on regulatory bodies, management, and employees while keeping customers, shareholders, and suppliers informed and satisfied. This matrix serves as a strategic tool for managing stakeholder relationships throughout the strategy development process, fostering organizational growth and a robust market position in the competitive solar energy industry.

5. Conclusion

5.1 Conclusion

The objective of this research is to enhance annual solar panel production. Various factors affect the performance and operational targets. After investigating the business issue and proposing a solution, research conclusions are presented to address the research questions.

1. What is the root cause of the low annual solar panel production in PT? Len Industry (PERSERO)?

The root cause of the low annual solar panel production in PT. Len Industry (PERSERO) is the uncompetitive pricing driven by high production costs for solar panels with a maximum capacity below 445Wp. These panels incur higher manufacturing costs, leading to elevated overall project expenses, which, in turn, makes the products less competitive in the market. As a result, PT. Len Industry struggles to scale its production and capture a significant market share.

2. What are the relevant available scenarios for solving the current conditions of solar panel production at the PT? Len Industry (PERSERO)?

To address the current conditions of solar panel production at PT. Len Industry (PERSERO), three relevant scenarios are available: not to upgrade, partial upgrade, and full upgrade. Opting not to upgrade would maintain the status quo, continuing with high production costs and uncompetitive

pricing, thereby limiting the market potential and growth. A partial upgrade would involve enhancing existing production facilities to produce solar panels with outputs exceeding 445 Wp using a full-cell configuration, reducing production costs by 15%, and improving competitiveness without a complete overhaul. The full upgrade scenario entails a comprehensive enhancement of production facilities to manufacture panels with outputs exceeding 445 Wp using a half-cut cell configuration, significantly reducing the production costs by 25%. This approach would not only maximize efficiency and output, but also provide future proof of the facilities by adopting advanced, durable technology that meets evolving market demands and integrates easily with emerging innovations.

3. What is the best alternative for addressing the current condition?

The best alternative is to address the current conditions at the PT. Len Industry (PERSERO) is to pursue a full upgrade of the solar panel production facilities. This comprehensive approach involves enhancing the production capabilities to manufacture panels with outputs exceeding 445 Wp using a half-cut cell configuration, which significantly reduces the production costs by 25%. The full upgrade maximizes efficiency, boosts output, and aligns with the latest technological advancements, ensuring that the facilities remain competitive and adaptable to future innovation. By investing in this advanced technology, the PT. Len Industry can offer highly efficient, cost-effective solar panels that meet market demand, thereby improving its market position and contributing more substantially to the national solar capacity.

5.2 Recommendation

The PT Len Industry should proactively engage with regulatory bodies to influence and align with environmental and safety standards. By actively participating in policy discussions, providing feedback on proposed regulations, and demonstrating commitment to compliance and sustainability, the PT Len Industry can help establish favorable regulatory frameworks that support the growth of the solar industry. Building strong relationships with regulators and showcasing the company's adherence to best practices will not only ensure smooth operations but also position the PT Len Industry as a leader in the renewable energy sector.

The PT Len Industry should pursue a full upgrade of its solar panel production facilities to leverage the latest advancements in half-cut-cell technology. This upgrade will enable the production of panels with outputs exceeding 445 Wp, thereby significantly reducing production costs by 25%. The full upgrade maximizes production efficiency, enhances panel performance, and provides future-proof facilities, making them adaptable to emerging technologies. By investing in this comprehensive enhancement, the PT Len Industry can offer more competitive and cost-effective solar panels, thereby increasing the market share and contributing significantly to national solar capacity goals.

To further strengthen its competitive position, PT Len Industry should focus on optimizing production processes and reducing operational costs. This involves implementing lean manufacturing techniques, enhancing supply chain efficiency and investing in workforce training to improve productivity. By continuously monitoring and refining production workflows, a company can minimize waste, reduce downtime, and lower overall production costs. These efforts will ensure that the PT Len Industry not only meets but also exceeds market expectations for high-quality, affordable solar panels, thus driving sustainable growth and profitability.

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