Sustinere
Journal of Environment and Sustainability
Volume 8 Number 1 (2024) 29-43

Print ISSN: 2549-1245 Online ISSN: 2549-1253
Website: https://sustinerejes.com E-mail: sustinere.jes@uinsaid.ac.id

RESEARCH PAPER

Techno-economic needs assessment for a sustainable novel solar panel production system

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Article history:
Received 5 November 2023 | Accepted 1 April 2024 | Available online 20 May 2024

Abstract. Techno-economic needs assessment for an automated solar panel production system is presented. Solar energy, a rapidly growing renewable energy source, has the potential to meet a significant portion of the world's energy needs. Solar panels, the key component of solar energy systems, there are produced in a major industry. Automated solar panel production systems offer the potential to increase production efficiency and reduce costs. The study outlines key factors necessary for successful establishment and operation of an automated solar panel production factory, including market analysis, financial projections, operational strategies, and sustainability initiatives. The market analysis through examination global trends in the solar energy market, identifying growth trends, potential competitors, and target customer segments. The study used a five-step methodology to assess needs, identifying major requirement such as the application of high-speed and precision manufacturing equipment, investment in reliable and efficient manufacturing processes, and development of cost-effective manufacturing methods. The study's results highlight several key economic benefits of automated solar panel production, including increased production efficiency, reduced labor costs, and improved product quality. The findings are valuable to various stakeholders, including government officials, business leaders, and community members, informing decisions regarding solar industry development and new manufacturing facilities in specific regions. The paper recommends the use of eco-friendly manufacturing processes, utilization of recyclable materials, and adoption of energy-efficient automated technologies to minimize the carbon footprint of solar panel production.

Keywords: solar panel production; techno-economic needs; cost-effective; carbon footprint; sustainable production

1. Introduction

The global transition toward sustainable and renewable energy sources is no longer a mere aspiration but an imperative in the face of climate change and the dwindling availability of fossil fuels (Mani & Goniewicz, 2023). Solar energy, harnessed through photovoltaic solar panels, has emerged as a pivotal component of this transition, offering a clean and abundant source of electricity (Alsharif et al., 2023). However, the widespread adoption of solar power is contingent upon the cost-effectiveness, efficiency, and scalability of solar panel production (Su et al., 2023).

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DOI: https://doi.org/10.22515/sustinere.jes.v8i1.362

Solar energy stands out as one of the most promising renewable energy sources, potential to play a pivotal role in meeting the world's ever-growing energy demands (Kumar et al., 2023). The solar panel industry has experienced rapid growth in recent years, a trend expected to continue in the future (Al-Shetwi, 2022). Automated solar panel production factories offer several advantages over traditional counterparts (Akram et al., 2020). These automated factories are more efficient and productive, capable producing higher -quality solar panels at reduced cost (Myyas et al., 2022).

The solar energy sector has experienced remarkable growth in recent years, driven by advancements in technology, increased environmental consciousness, and the decreasing cost of solar panels (Nguyen et al., 2021). Solar power hold the promise to revolutionize energy generation by providing clean and sustainable electricity, reducing greenhouse gas emissions, and enhancing energy security (Owusu & Asumadu-Sarkodie, 2016). Nevertheless, to fully realize this potential, the solar industry must address challenges related to the cost and efficiency of solar panel manufacturing processes. The integration of automation and advanced manufacturing technologies presents a promising solution to these challenges (Xia et al., 2020). Automated solar panel production factories can significantly enhance the efficiency, precision, and cost-effectiveness, thereby accelerating the global adoption of solar energy (Xia et al., 2020). As result, automated solar panel production factories are becoming increasingly common, offering numerous advantages over traditional production factories.

The production of solar panels, as a key component of the renewable energy landscape, has garnered significant attention from researchers and industry experts alike (Oudes et al., 2022). The global solar panel market is experiencing rapid growth, and is projected to reach $230 billion by 2027 (He et al., 2021). This expansion is driven by several factors, including the declining cost of solar panels, rising demand for renewable energy, and government subsidies (Nishtar & Afzal, 2023).

Solar panel production involves intricate processes aimed at converting sunlight into electrical energy (Zhang et al., 2013). Traditionally, this production has heavily relied on manual labor, raising concerns regarding cost, quality consistency, and scalability. Researchers have explored various aspects of solar panel production (Swartwout et al., 2019). According to Swartwout et al. (2019) the solar panel production process can be divided into four main stages. Cell manufacturing, this stage involves the production of solar cells, which are the basic building blocks of solar panels. Solar cells are typically made from semiconductor materials such as silicon or cadmium telluride. Module assembly, here, solar cells are assembled into modules, with modules usually consisting of either 36 or 72 solar cells. Quality control, this stage focuses on testing the solar modules to ensure they meet specified quality standards. Packaging and shipping, the final stage involves carefully packaging the solar modules and shipping them to customers.

A study by Kumar et al. (2021) provides a detailed analysis of solar panel manufacturing processes, including wafering, cell manufacturing, and module assembly, emphasizing the need to optimize these processes for cost reduction. Quality control is paramount in ensuring the reliability and performance of solar panels. Research by Jiang et al. (2021) focuses on the implementation of automated inspection and testing techniques to enhance quality control in solar panel manufacturing, with a particular emphasis on the material used, The choice of materials significantly impacts the efficiency and durability of solar panels (Lu et al., 2021). Ramanujam et al. (2020) investigated advances in materials science, highlighting developments use of perovskite materials and thin-film technologies.

Automation is revolutionizing solar panel production, addressing challenges associated with manual labor and improving overall efficiency (Gorjian et al., 2020). Robotic systems are increasingly employed for tasks such as soldering, tabbing, and stringing in solar cell manufacturing (Chen et al., 2023). Furthermore, machine learning and artificial intelligence (AI) are being leveraging to optimize production processes (Fahle et al., 2023). A study by Ledmaoui et al. (2023) demonstrate the application of AI algorithms for predictive maintenance and process optimization in solar panel factories. The concept of smart manufacturing, integrates automation, data analytics, and IoT technologies (Shahbazi & Byun, 2021). Research by Huang et al. (2021) discusses the implementation of smart manufacturing systems to enhance the flexibility and responsiveness of solar panel production lines.

Solar panel production is intricately connected to several related technologies and innovations (Nazir et al., 2023). One growing trend is integration of energy storage systems with solar panels (Tan et al., 2021). Research by Min et al. (2019) explores the synergy between solar panels and energy storage technologies, highlighting the role of automation in managing and optimizing energy storage. Sustainability considerations are increasingly vital in solar panel production. IPCC (2021) examines sustainability practices, such as recycling and eco-friendly manufacturing processes within the solar industry. Understanding market dynamics is crucial for assessing the economic feasibility of solar panel production. Sharma et al. (2022) provide insights into global market trends, demand projections, and pricing strategies.

The continued development of these technologies is expected to make solar energy even more affordable and accessible in the future (Bogdanov et al., 2021). Automated solar panel production is a relatively new and rapidly developing field (Wilson et al., 2020), which has revealed several knowledge gaps. One such gap is the process optimization. Automated solar panel production factories employ a variety of complex processes and machines, requiring optimization to increase efficiency and reduce costs. Therefore, there is a need to develop new and improved methods for optimizing these processes.

Another knowledge gap lies in quality control. Automated solar panel production factories produce a large number of solar panels within a short period of time, posing challenges in ensuring that all panels meet quality standards. This underscores the necessity to develop new and enhances quality control methods tailored for used in automated solar panel production factories.

Lastly, a critical knowledge gap exists in the area of sustainability within automated solar panel production. These factories consume significant amount of energy and resources, highlighting the urgent need to develop new and improved methods for enhancing their sustainability. While ongoing research efforts in some of these identified areas of knowledge gaps, and new knowledge is continuously being gained, there is still much to be learned about automated solar panel production. By addressing these knowledge gaps, researchers can contribute to making automated solar panel production more efficient, affordable, and sustainable. This, in turn, will accelerate the adoption of solar energy and contribute significantly to the fight against climate change.

The objective of this research paper is to conduct a well-researched Techno-Economic Needs Assessment to determine the viability and prerequisites for establishing an Automated Solar Panel Production Factory. This assessment encompasses a multifaceted investigation, including market analysis, technology evaluation, site selection, regulatory compliance, financial modeling, risk assessment, and sustainability considerations. Specifically, the paper aims to analyze the current and projected market demand for solar panels and assess the economic feasibility of a establishing a solar panel production factory. Secondly, evaluate the technological requirements and potential suppliers or partners for automated solar panel production. Thirdly, identify suitable factory locations based on logistical, infrastructural, and labor-related factors.

A successful execution of these objectives will provide valuable insights and recommendations to stakeholders, including investors, policymakers, and industry professionals, regarding the feasibility and prerequisites for establishing an Automated Solar Panel Production Factory. The findings of this study are expected to contribute to the advancement of sustainable energy solutions and the accelerate the global transition to renewable energy sources.

2. Material and research methodology

2.1. Materials and methods

The materials used for the study include: camera, calculator, field notebook and pen, engineering measurement and evaluation bill of a solar panel production facility, laptop, and Microsoft Excel software.

The study was carried out using a five steps methodology proposed by Adigio and Ohwofadjeke (2016). The details of each step are described as follows. Step 1 is intensive literature search, that was conducted using thirty-three research papers to identify gaps in current knowledge regarding the automation of solar panel production process. Step 2, detailed need assessment of panel production process. This step encompassed various considerations including market analysis, financial and human resources requirements, technology and equipment evaluation, materials and consumables assessment, infrastructure and facilities analysis, running cost, energy and environmental considerations, regulatory compliance, research and development needs, and training, conferences and publication of research outcome/results. Step 3 is data collection. Cost data were extracted from Bill of Engineering Measurement and Evaluation (BEME) of a solar panel production factory, serving as the primary data source for the research. Step 4 is data classification and analysis. In this step, the collected data were organized and classified for analysis. The last step is writing and publication of final report/paper.

2.2. Needs identification and assessment

A need assessment was carried out to identify equipment, tools/machineries, and manpower required for establishing an automated solar panel production factory. Various necessary resources were identified, including financial capital, human resources, technology, equipment, and materials, to ensure the successful establishment and efficient operation of the factory. Resource allocation of the proposed project follows principles of sustainability, profitability, and overall business objectives.

- *Sources of financing*

The initial investment required for acquiring land, building, infrastructure, and equipment procurement has been carefully considered and outlined in this section. Funds have been allocated for product design, prototyping equipment, and operational expenses such as salaries, utilities, maintenance, and marketing to achieve our objectives.

According to Torrado (2023), sources of funding include self-funding, equity investment, loans, grants, and donations from partners or venture capital. The initial investment, operational costs, maintenance, and future expansion of the factory will be funded through combination of the following sources: self-funding and grants, bootstrapping, and strategic partnerships. Utilizing self-funds and seeking grants from government agencies, private foundations, or corporations to support our objectives. Bootstrapping, generating revenue and reinvesting it into the factory's growth without external financing, offering more control albeit at a potentially slower pace. Strategic partnerships, collaborating with other businesses or individuals willing to provide capital and resources through partnership arrangements.

- *Human resources need*

Key personnels needed for the factory, such engineers, technicians, researchers, production staff, quality control experts, and administrative staff, have been identified and carefully allocated. Their roles and responsibilities have been clearly defined within the organizational structures presented in this section. The required workforce size and skills sets for different stages of production and operation are being planned through recruitment, training, and retention strategies aimed at cultivating a competent and diverse workforce across various discipline (multidisciplinary), inclusive of both male and female employees. A 'top-down methodology' was adopted to assess the manpower skills and training needs of the proposed factory. The first step involved broadly categorizing the solar process into 'manufacturing' (solar PV modules) and 'nonmanufacturing' (solar PV projects) sectors. This primary level of classification outlines the segments and value chain of the proposed solar panel production process.

- *Quality control and testing*

The factory requires a robust quality control processes to monitor and ensure the performance and durability of solar panels produced. Standard and globally recognized testing procedures are needed for incoming materials, in-process production, finished products, sales/distribution, transportation/haulage, installation, maintenance/servicing, and application/use of all our products. In order to operate effectively, the factory will need to obtain necessary certifications, including local, national and international standards such as ISO quality systems and certifications from relevant Standard Organizations in the country where the plant is located.

- *Environmental considerations*

The factory needs to design all its processes to prioritize sustainability, aiming to minimize waste generation, energy consumption, and environmental impact. Additionally, the factory will implement recycling and scientifically accepted waste management programs and procedures for materials used in production in order to comply with its zero-tolerance policy toward negative environmental impact and pollution.

- *Marketing and distribution*

The factory requires a robust marketing strategy and experienced sales personnels to promote sales of its solar panels and attract customers. Additionally, the factory needs to establish production distribution channels and a customer service unit to consistently reach its target markets. This includes forming partnerships with distributors, retailers, or direct sales to end users of our products.

- *Technology and equipment*

The technology and machinery required for various stages of solar panel production (e.g., wafer fabrication, cell manufacturing, and module assembly) are carefully selected following global best practices. Resources were allocated for purchasing, installing, and maintaining the required equipment. Automation and digitalization to optimize the production processes were also taken into consideration. Details of the technology and equipment needed are presented using a process flow chart in Figure 1.

- *Materials and consumables*

The raw materials required for solar panel production, such as silicon wafers, encapsulation materials, backing sheets, and frames, were identified and budgeted for. Establishing a strong business relationship with suppliers is crucial to secure a stable supply chain to the factory. Resources for inventory management and procurement strategies are allocated. Additionally, an enterprise resource management software will be procured and installed to ensure prudent management of resources.

- *Infrastructure and facilities*

A suitable location for the factory should be chosen considering factors such as proximity to suppliers, transportation networks, and target markets. Although the university management has allocated an existing building for the factory, some upgrades and expansions will be necessary to ensure efficient utility setup optimize facility layout.

- *Running cost, energy and environmental considerations*

The fully operational plant requires sustainable energy solutions, such as on-site solar power generation and energy-efficient lighting systems. These initiatives should ideally be supported by a diesel generator as a backup power source. Additionally, sustainable waste management and recycling processes are essential to minimize environmental impact.

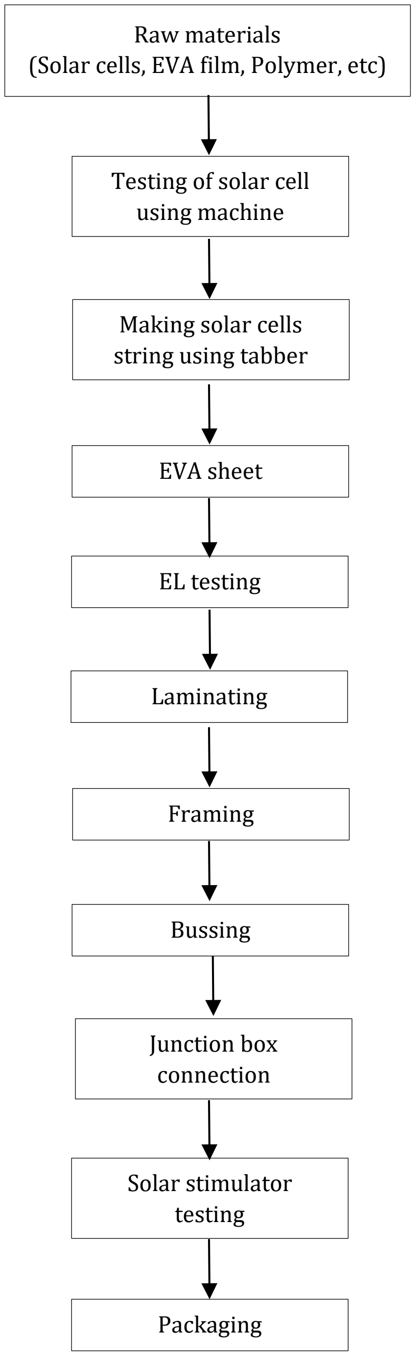

Figure 1. Process flow chart

- *Regulatory issues and compliance*

Resources are needed to obtain necessary permits, licenses, and certifications for the factory's operation at both local, national and international levels. Furthermore, resources are essential for legal and regulatory compliance activities, including obtaining relevant ISO certifications for its processes and products.

- *Research and development*

Resources are required for research and development, including the procurement of state-of-the-art laboratory equipment to support research on automated solar panel production process. It is essential for companies and research institutions involved in solar panel production to remain up-to-date with the latest technological advancements and market trends to effectively address these Research and Development (R&D) needs. Additionally, collaboration with academic institutions, government agencies, and industry partners can help accelerate progress in these areas. Investor should keep in mind that the solar industry is rapidly evolving, and new R&D priorities may emerge in response to changing market dynamics and technological breakthroughs.

- *Training, conferences and publication of research outcome/results*

Resources are needed to facilitate comprehensive trainings for the workforce, attend conferences, workshops, and organize travel for relevant industry tours. Additionally, there is a need publish the outcomes of research on solar panel production in local, national, and international journals.

- *Intellectual property protection*

The factory will implement legal procedures to protect its unique manufacturing processes, technologies, or designs through patents, trademarks, or trade secrets to guard against piracy and unauthorized use.

- *Health, security and safety protocols*

The factory requires the implementation of strict health, safety, and environment protocols and policies to protect employees from potential hazards associated with manufacturing processes, in line with its goal zero harm to people, zero damage to asset, and zero negative impact on the environment.

- *Scaling and expansion*

The factory will integrate scalability into its plans by designing the layout and processes to accommodate future growth and increased production capacity.

- *Partnerships and collaborations*

Partnerships and collaborations are essential for every business to thrive and succeed. We will explore collaborations with research institutions, universities, and industry partners to stay updated on the latest advancements and innovations in solar panel technology. This will ensure that our products remain relevant and incorporate the latest technology.

- *Risk assessment and management in the proposed factory*

Managing risk is a crucial aspect of the needs assessment process for establishing a solar panel production factory. Effective risk management ensures that potential challenges are identified, evaluated, and addressed to enhance the project's success and sustainability. Resources are required to risk assessment and mitigation strategies to address potential operational, financial, and market risks. Mitigation strategies should be adopted to manage effectively throught the project.

- *Risk identification and document*

Proper documentation of all potential risks and uncertainties related to the smooth operation of the solar panel factory will be maintained. Regular engagement with key stakeholders, including experts in solar energy, manufacturing, finance, and regulatory compliance will be a fundamental policy of the factory.

- *Regular risk assessment and prioritization*

Risks identification and review based on potential impact and likelihood will be conducted quarterly. Priority will be given to risks to focus resources and attention on addressing the most significant threats to the success of our project. The factory should adopt and apply qualitative and quantitative methods, such as risk matrices or probability impact assessments, to facilitate in this process.

- *Risk mitigation strategies*

Specific strategies will be implemented to mitigate each identified risk. These strategies will focus on reducing the likelihood of occurrence, minimizing potential impacts, and developing contingency plans to manage adverse outcomes. Key responsibilities for implementing and monitoring these mitigation strategies will be assigned to senior members of staff, including the management team.

- *Risk monitoring and reporting*

A system for monitoring and reporting risks will be established to track the status of identified risks and assess the effectiveness of mitigation measures. Regular updates will be provided to stakeholders on progress and any changes in risk profiles or strategies. Information board will be strategically placed within the factory to facilitate dissemination of risk identification and mitigation efforts.

- *Contingency planning and implementation*

Detailed contingency plans have been developed for high-priority risk areas that could significantly affect the factory's operations or finances. These plans outlined step-by-step and actions to be taken in in response to identified risks.

- *Integration with project schedule*

Risk management activities have been deliberately integrated into the project schedule to minimize the risk of failure. Efforts will ensure that risk assessments, mitigation actions, and contingency plans align with key project milestones and deadlines.

- *Financial risk management*

Conscious efforts have been made to eliminate or mitigate financial risks through thorough financial analyses, regular auditing, sensitivity analysis and stress testing. The factory's financial viability has been assessed under various scenarios, such as changes in material costs, demand fluctuations, or interest rate fluctuations.

- *Supply chain risk management*

The factory has assessed dependence on raw materials and components for solar panel production against supply chain risks. Alternative will be identified and relationships established to ensure a reliable source of materials with cost reduction in mind.

- *Regulatory and compliance risks*

The factory will stay updated with local and national regulations pertaining to solar panel manufacturing processes and procedures. Compliance strategy will be applied to mitigate legal and regulatory risks, including potential fines or project delays.

- *Human resources and skills risks*

Regular evaluation of risks related to workforce availability and skill gaps will be conducted. Strategies have been developed to attract and retain qualified personnel through continuous training programs aimed at enhancing skills, improving productivity, enhancing safety, and maintaining the factory's competitive advantage.

- *Continuous improvement*

The factory will continuously improve its process effectively manage risks. Regular review and updates of the risk assessment as the project progresses and new information becomes available.

- *Communication and stakeholders' engagement*

Open communication channels will be maintained with all stakeholders. Regular engagement will involve regular discussions on risk assessment findings, mitigation efforts, and contingency plans to build trust and ensure alignment with core values.

In conclusion, effective risk management across all areas of the factory's operations will enhance the project's ability to navigate potential challenges, make informed decisions, and increase the likelihood of successful and sustainable solar panel production for investors and other stakeholders.

2.3. Management structure of the proposed factory

The factory will be managed by a director and overseen by a board of director, whose role, composition, and functions are essential for the effective and smooth operation of the factory. The board of directors will maintain a close working relationship with the factory director and management team on matters related to operations, programs, management, and finances/budget. The organizational chart for the proposed solar panel production factory is presented in Figure 2.

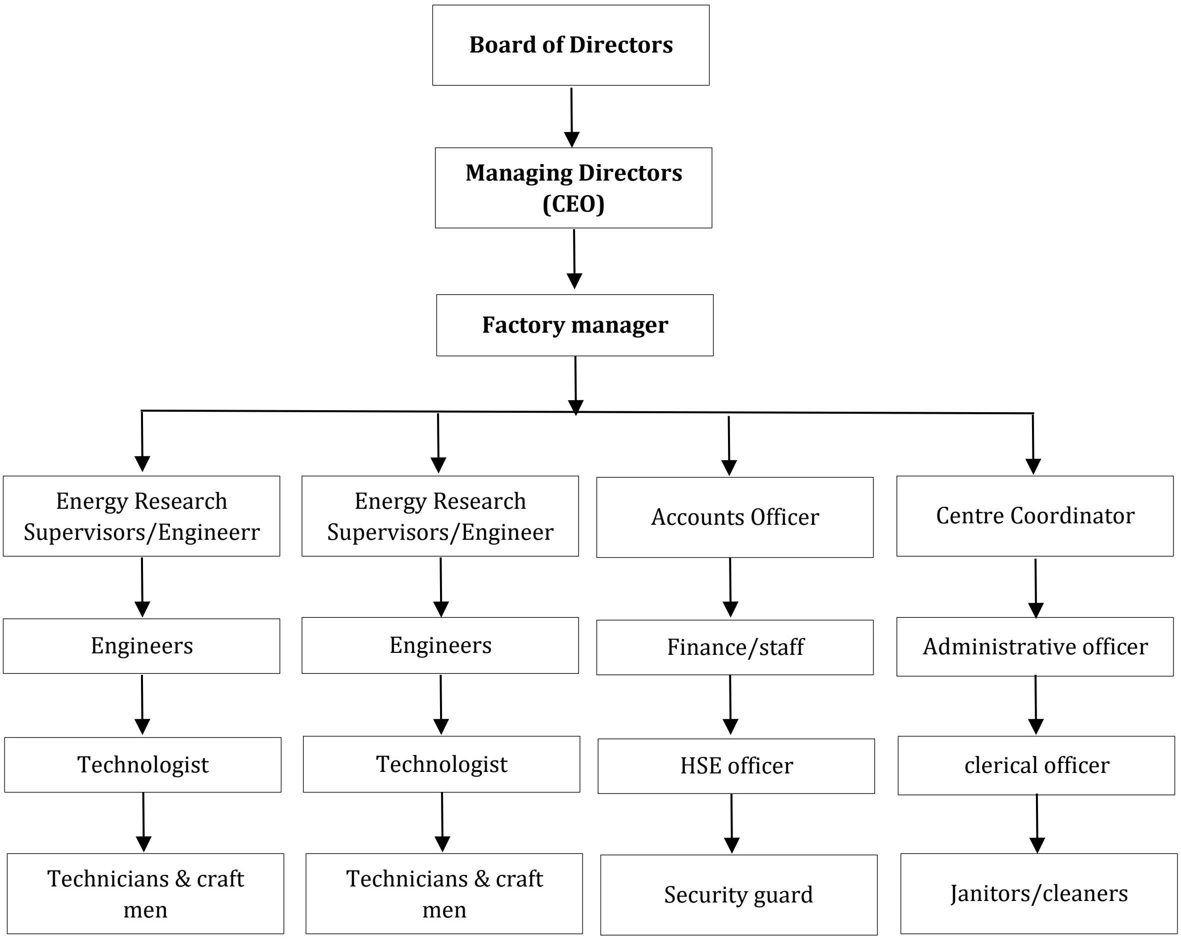

Figure 2. Management Structure of automated solar panel production factory

2.4. Schedule of Project Activities

A detailed project schedule has been developed for solar panel production factory process, outlining specific tasks, timelines and resources requirements. The program implementation is divided into ten phases. Each of the phase is presented in Table 1.

Table 1. The program implementation procedures

Phase 1: Project initiation phase

1. Definition of project scope, objectives, and implementation strategies (one week)
2. Conduct feasibility studies and need assessment, including market analysis and financial projections (two weeks).
3. Secure funding and necessary permits (three months).

Phase 2: Design and planning phase

1. Engage architects and engineers to design the factory layout and infrastructure (one month).
2. Develop a detailed production process flowchart (one day).
3. Source and procure equipment, machinery, and raw materials (three months).

Phase 3: Construction phase

1. Prepare and grade the site (one week).
2. Construct or expand and develop infrastructure (three months).
3. Instal solar panel production lines, machinery, and utilities (one months).
4. Perform quality control and safety inspections during construction (one months).

Phase 4: Production/testing and commissioning phase

1. Test process equipment and production (one months).
2. Conduct quality assurance tests on manufactured equipment (one months).
3. Fine-tune processes for efficiency and quality (one months).

Phase 5: Recruitment and training phase

1. Recruit and train production staff, engineers, and support personnel (one months).
2. Conduct safety and quality training programs (one week).

Phase 6: Production launch phase

1. Gradually increase production volumes (one months).
2. Monitor and optimize production processes (one months).
3. Implement quality control measures to address any issues observed (one months).

Phase 7: Marketing and distribution phase

1. Develop marketing strategies to promote solar panels (one months).
2. Establish distribution channels and partnerships (one months).
3. Commence sales and distribution panels to customers (one months).

Phase 8: Operations and maintenance phase

1. Monitor production output, quality, and process efficiency (one months).
2. Perform routine maintenance on equipment and machinery (one monthly).
3. Continuously improve processes and adopt new technologies as needed.

Phase 9: Sustainability and expansion phase

1. Explore opportunities for sustainable practices and renewable energy sources (continuous).
2. Expand production capacity and launch new product lines (one year after operations commence).

Phase 10: Post-project evaluation phase

1. Assess project success against initial objectives and targets (continuous).
2. Analysis financial performance and return on investment (continuous).
3. Identify lessons learned and areas for improvement throughout the project (continuous).

3. Result and discussion

3.1. Computation of project cost and expected revenue

The financial analysis was carried out on the estimated project cost and revenue using payback period method. The costs of required equipment and materials for the project were obtained from a comprehensive market survey and detailed analysis, including data extracted from the bill of engineering measurement and evaluation of automated solar panel production factory. Market research and human resources needs assessment were carried out in Section 2.3, and the collected data were analyzed in Section 3 using payback period method. The summary of the assessed costs for different sectors of the investment are presented in Table 2. It is important to note that all cost computations are based on exchange rate of 1USD ≡ ₦ 1100 as at October 2023. The detailed computation of payback period is as follows.

Computation of project cost computation

The cost of raw materials will cover production for thirty days. Plus 2,5% allowance for likely price fluctuations in raw material (variable cost) = ₦15,323,069.825.

Monthly operating cost = ₦ 612,922,793 + ₦ 15,323,069.825 = ₦ 628,245,862.825

Initial capital required for investment = Fixed cost + total operating cost for the first month

= ₦ 1,369,052,052.8 + ₦ 628,245,862.825

= ₦ 1,997,297,915.625

Annual cost (first year = Fixed cost + (monthly operating cost * 12)

= ₦1,369,052,052.8 + (₦628,245,862.825 * 12)

= ₦1,369,052,052.8 + ₦7,538,950,353.9

= ₦ 8,908,002,406.7

Computation of expected revenue (return on investment)

The laboratory will produce 16 solar panels/hour with of 550 W capacity each. It is proposed to run three shifts daily (24hours), each of 8 hours; resulting production of 384 panels/day of 550 W capacity, translating to 11,520 panels/month. The selling price of 550W capacity solar panels in Nigeria as of July 2023 is ₦100,000 per piece. Hence, the expected daily sales/production value is ₦38,400,000, which translates to ₦ 1,152,000,000 monthly.

Yearly expected sales = ₦ 13,824,000,000

Monthly revenue = value of total monthly production output – (total monthly operating cost)

= ₦ 1,152,000,000 – ₦ 628,245,862.825

= ₦ 523,754,137.175

Yearly revenue = monthly revenue * 12

= ₦ 523,754,137.175 * 12

= ₦ 6,285,049,646

The feasibility analysis was conducted using payback period (PBP) as follows:

$$\text{PBP} = \frac{\text{Initial investment } Cost}{Cash\ Inflow}$$

$$PBP = \frac{8,908,002,406.7}{6,285,049,646} = 1.4$$

Therefore, the estimated time to recover initial capital on investment is one year and four months (16 months).

Table 2. Summary of financial analysis

S/N	Financial component description	Amount (₦)
1	Construction cost (Fixed cost)	1,369,052,052.80
2	Monthly operating cost	628,245,862.83
3	Total annual operating cost	7,538,950,353.90
4	Annual cost for first year	8,908,002,406.70
5	Value of expected daily sales/production	38,400,000
6	Value of expected monthly sales/production	1,152,000,000
7	Value of yearly expected sales	13,824,000,000
8	Projected daily profit/benefit	17,219,314
9	Projected monthly profit/benefit	523,754,137.18
10	Projected yearly profit/benefit	6,285,049,646
11	Initial capital required for investment	1,997,297,915

3.2. Discussion

The needs assessment was conducted by a team of experts with experience in solar panel manufacturing, economics, and engineering. The team worked closely with local stakeholders, such as government officials, business leaders, and community members, to gather their input and feedback, which were integrated into the final report. The Initial capital required for this investment is ₦ 1,997,297,915, equivalent of $1,815,725.

The comprehensive analysis presented in section 3 outlines the costs, benefits, and risks involved in the project, derived from the outcomes of the needs assessment. This information facilitates a deeper understanding of the entire study. The needs assessment report will be useful to policymakers, investors, and other stakeholders in making informed decisions about establishing an automated solar panel production system.

The study identified specific benefits for establishing an automated solar panel production system, including increased production efficiency and reduced production costs, improved product quality, job creation, reduced reliance on imported solar panels, contribution to the development of the local economy, and reduction of greenhouse gas emissions promoting sustainable development. However, the study also highlighted some challenges that need to be addressed when establishing an automated solar panel production system. These challenges include high initial investment costs, the need for skilled labor, and compliance with complex environmental regulations.

4. Conclusion

A comprehensive need assessment was carried out prior to the establishment of an automated solar panel production factory, determining that an initial capital investment of ₦ 1,997,297,915 only is required as initial capital for investment into establishing a fully automated solar panel production factory. From the results obtained in section 3, the following recommendation were proposed by the needs assessment team.

Firstly, the prioritize investments in automation technology, such as robotic assembly lines and AI-driven quality control systems, to enhance efficiency, reduce errors, and improve production quality. Secondly, encourage potential investors to conduct comprehensive cost-benefit analyses, including initial setup costs and ongoing operational costs, to highlight the long-term economic benefits of automation. Thirdly, explore government incentives and subsidies for adopting clean and automated technology, as many countries provide tax breaks and grants for renewable energy facilities. Fourthly, collaborate with technology providers and automation experts to ensure selected technologies align with industry standards and best practices.

Fifthly, emphasize sustainable practices in the automated production, such as reducing energy consumption and minimizing material waste, to enhance the environmental footprint of solar panel production. Sixthly, develop risk mitigation strategies, including contingency plans for technology failures, market fluctuations, or supply chain disruptions to manage potential risk effectively. Seventhly, utilize public-private partnerships (PPPs) for financing and developing automated solar panel production systems. The lastly, implement technology transfer schemes from developed to developing countries to promote automated solar panel production development.

In conclusion, implementing these recommendations will effectively address challenges and maximize the benefits of establishing an automated solar panel production system, positively impact the economy, environment, and society at large.

Acknowledgment
I extend my special appreciation goes to my dear wife, Mrs. Bridget Ogheneochuko Ohwofadjeke, and to my daughter Ogheneyeochukome Valerie, for their continuous support for my scholarly research.

Abbreviations

₦	Nigerian Naira
$	United States Dollar
PPP	public-private partnerships

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