Electricity Supply in the Garment Industry through Photovoltaic Plants: Performance and Cost Analysis

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Abstract

This paper presents a sustainable solution for meeting the energy needs of a garment factory through the installation of a photovoltaic (solar) plant. In the context of unstable electricity supply, rising energy costs, and the need to reduce environmental impact, solar energy emerges as a strategic and beneficial alternative, especially for manufacturing businesses.

Due to the factory's continuous energy consumption from intensive production processes, a detailed analysis of its daily, monthly, and annual energy use was conducted to ensure the accurate sizing of the photovoltaic system. The study covers all main components, including solar panels, inverters, mounting structures, protective devices, and their integration with the existing grid. Technical options were carefully evaluated, focusing on efficiency, durability, and cost-effectiveness.

Special attention is given to practical installation aspects, such as optimal panel positioning based on geographic orientation and the use of simulation software for energy production and performance analysis. The economic evaluation includes installation, maintenance, and depreciation costs, while also highlighting the project's positive environmental impact in alignment with global sustainability goals.

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The study focuses on a garment factory located in Lezhë, Albania, providing a real-case application of photovoltaic system implementation in an industrial context. The results confirm that investing in a photovoltaic plant significantly reduces grid dependency, lowers operational costs, and enhances the factory's environmental profile. This project serves as a replicable model for other industries aiming to adopt clean energy and support sustainable development.

Key words: *photovoltaic systems; on-grid systems; hybrid systems; energy efficiency; industrial energy; Albania.*

Introduction

The textile industry is one of the largest sectors in the world and has a significant environmental impact due to its high energy consumption. Textile factories require large amounts of energy for processes such as raw material cleaning, fabric dyeing, and the use of machinery for drying finished products. These processes often rely on electricity from non-renewable sources, which are harmful to the environment. Installing solar panels on factory rooftops could provide a sustainable and clean energy source. The generated energy could be used to power production machinery, various processes, or to illuminate factory spaces.

> This study addresses the following research question: How does the installation of photovoltaic systems influence electricity supply performance and cost efficiency compared to traditional energy sources?
> Hypothesis: The installation of photovoltaic systems leads to long-term financial savings and environmental benefits compared to traditional energy sources.

To carry out this paper, a structured methodology was applied, combining technical, practical, and economic analysis for the implementation of a photovoltaic system in the city of Lezhë. The methodology is divided into several phases:

Theoretical research and data collection
This includes a literature review on photovoltaic technologies and their principles of operation. Data was gathered from electricity bills and the annual consumption profile. Climatic data and environmental factors affecting PV system performance were also analyzed.

System sizing
Professional software such as PV*SOL Premium was used to simulate energy production and model the system's performance under real-world conditions.

System design
The design phase involved the development of electrical diagrams and the layout of the photovoltaic installation.

Economic analysis
Conducted using PV*SOL Premium, this phase evaluated the financial feasibility and return on investment of the project.

Environmental impact assessment and conclusions
The reduction of carbon dioxide (CO_2) emissions was calculated based on data from scientific articles, providing a measure of the system's environmental benefits.

Literature Review

In recent years, the importance of photovoltaic panels has significantly increased. In many cases, solar panel installations can cover up to 80% of the annual electricity consumption of a household or business, depending on solar radiation levels and system size. Users typically utilize the energy for self-consumption, which greatly reduces reliance on the power grid and lowers electricity bills. This approach is considered an effective way to reduce energy consumption and aligns with the need to diversify energy sources in the face of climate and geopolitical crises (Luthander, 2015).

Photovoltaic Technology and System Components

Photovoltaic devices are used to convert solar radiation into electrical energy. The basic unit of these devices is the photovoltaic cell. These cells are small and typically generate about 1–2 watts of power. They are made from semiconducting materials, which are relatively thick to ensure durability for prolonged outdoor exposure. Photovoltaic cells are protected by transparent materials such as glass or plastic, which shield them from environmental factors.

To increase their power output, these cells are combined to form larger units known as photovoltaic panels or modules. These modules can be connected together in strings to create larger systems or can be used individually. Photovoltaic systems, which vary in size depending on the energy demand, can be grid-connected or operate off-grid.

Such systems also include mounting structures that help orient the panels toward the sun to maximize solar radiation capture. In addition, they utilize components to convert the electricity produced from direct current (DC) to alternating current (AC), which is more suitable for powering standard electrical devices. This enables photovoltaic systems to meet a wide range of energy needs, from small-scale residential applications to large industrial installations (Electrical4U, 2023; U.S. Department of Energy, n.d.).

FIGURE 1. View of a house using solar systems

Advantages

- Solar systems require minimal maintenance, as they are highly durable and have a long lifespan.
- These systems do not require fuel and their capacity can be easily expanded if more energy is needed in the future.
- They can operate independently without the need for connection to the provincial power grid.
- They can be installed in remote areas, making them a very efficient and affordable option for electricity supply in isolated locations.

Disadvantages

- Solar energy production can be negatively affected by factors such as cloud cover, rainfall, or air pollution.
- The initial investment in solar systems can be high due to the cost of semiconductor materials used in their construction.
- The efficiency of solar systems depends on sunlight exposure, but this issue can be addressed by installing tracking mechanisms that move the solar panels to maximize solar capture.

Energy Surplus in Photovoltaic Systems

In photovoltaic systems, energy surplus occurs when production exceeds immediate consumption. According to current legislation, excess energy is fed into the grid and balanced monthly by comparing energy taken from and sent to the grid. This is common during low-consumption periods, like nighttime. In the case of factories, where energy use is highest during the day, surplus energy can be:

a) Stored in industrial batteries for later use,
b) Sent to the grid under an agreement for bill compensation, or
c) Used to power secondary systems like heating or air filtration.

Companies that use clean energy and demonstrate energy efficiency gain higher recognition in international markets, which increasingly demand environmental standards (International Renewable Energy Agency [IRENA], 2021, 2020; Armentrout, 2009).

Design and Selection of the Photovoltaic System

For the installation of photovoltaic systems, data is first generated using PVSOL Premium, a professional software used for designing, simulating, and analyzing PV systems. By entering the required data, the software creates a preliminary simulation to visualize the potential installation. PVSOL models the PV system in both 2D and 3D and uses location-based meteorological data to calculate energy production on a daily, monthly, or yearly basis. It also estimates ROI, total cost of ownership, annual savings, and investment return. The software supports On-grid, Off-grid, Hybrid systems, EV chargers, and large-scale installations. It includes a database of over 20,000 certified panels and inverters. This preliminary study serves as a foundation for further reporting and energy auditing (Valentin Software, 2023; Maturi, 2020).

Description of the Garment Factory Project

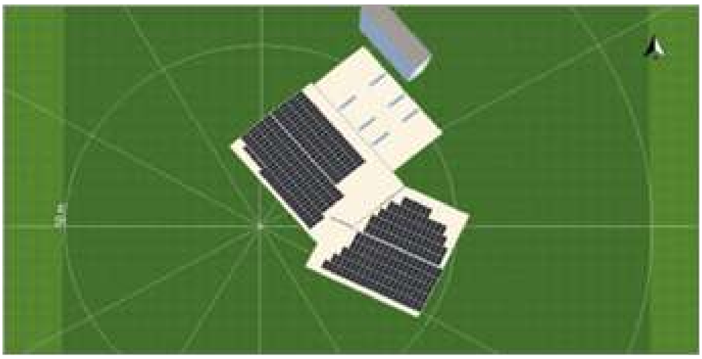
This is a Preliminary Feasibility Study assessing the profitability of investing in a 218.24 kWp-DC / 200 kW-AC photovoltaic system with a grid connection point for self-consumption. The project includes the installation of 352 photovoltaic modules (620 Wp each) and 2 inverters (2x100 kW).

The solar panels are from AIKO, currently the most efficient in the world (up to 23.5% efficiency), with warranties ranging from 15 to 30 years. The inverters are from SofarSolar with a 10-year warranty. The mounting structure is aluminum, and the AC panel and breakers are from Schneider Electric. Technical datasheets of the main components are attached.

Thanks to AIKO's patented ABC technology, the system is expected to produce approximately 322,438 kWh annually, resulting in savings of around ALL 7,100,000 (including VAT) per year. While AIKO panels are not the cheapest on the market, their unmatched performance allows for a payback period of just 2 years. All prices mentioned include VAT.

The factory's annual electricity consumption is 407,000 kWh, and the system is projected to cover 79% of its energy needs. On-site measurements were conducted during the preparation of this study. The study is prepared by the first photovoltaic implementer in Albania, with over 9 years of experience. The AC grid connection infrastructure also allows for a future system expansion of an additional 100 kW.

FIGURE 2. 3D design of the photovoltaic system layout

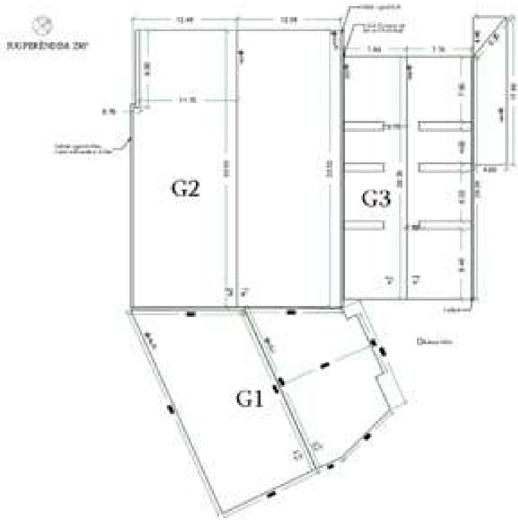


Project Scope

The garment factory under review is located in the city of Lezhë and has undergone several development phases. Initially, the business operated from a single building that served as the main production facility. As demand increased and operations expanded, two additional buildings were constructed to increase production capacity, optimize production lines, and separate key processes such as cleaning, dyeing, and packaging.

Currently, the factory consists of three interconnected buildings that operate in coordination to ensure a continuous production process. These buildings are equipped with modern technology and advanced machinery, improving efficiency and reducing operational costs. Each building includes dedicated spaces for various departments, such as design, production, storage, and logistics.

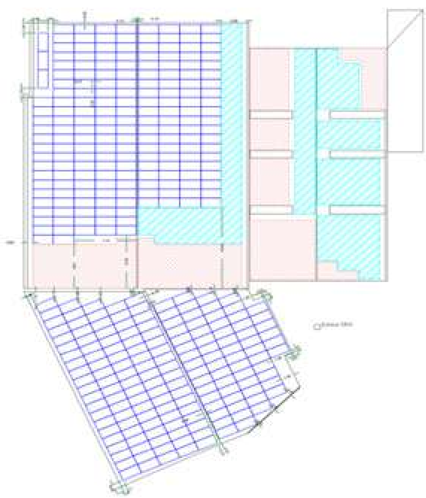
FIGURE 3. Project Layout



Photovoltaic Module Placement

This is a crucial process to ensure that solar energy is efficient and sustainable. When placing photovoltaic modules, several factors are evaluated, including the geographic location, sun exposure, and the supporting structure, whether it's a rooftop or a flat surface. To install the photovoltaic system, it is mandatory to submit an application to OSHEE, as well as through the e-Albania platform to obtain a permit from the local municipality. The project must be licensed and prepared by certified engineers and technicians.

FIGURE 4. Photovoltaic Module Layout



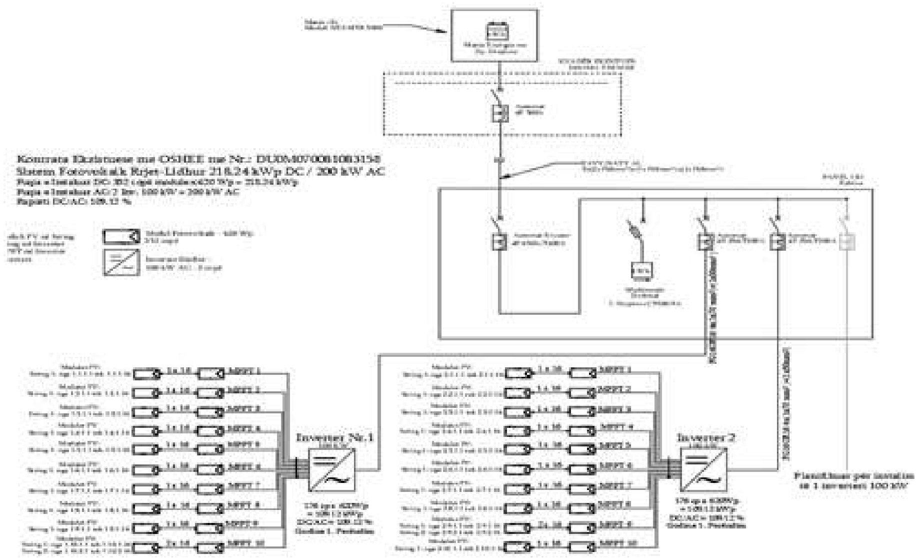
Single-Line Electrical Diagram

A single-line electrical diagram is used to represent the electrical connections within a system using just one line to illustrate the path of energy flow. It simplifies the layout of key electrical components and connections, making it easier for engineers and technicians to understand without unnecessary detail. These diagrams are commonly used in the design and analysis of medium and high-voltage systems, including energy transmission, distribution, and industrial power systems.

In the context of photovoltaic energy, the single-line diagram shows how solar power is integrated into the factory's electrical system to supply production processes and machinery. It clearly illustrates the connection between the solar panels and the power distribution lines, ensuring efficient energy flow within the facility.

This type of diagram also plays a critical role in troubleshooting, allowing for quick identification of issues. In industries like garment manufacturing, it contributes to better energy management, cost reduction, and improved operational efficiency.

FIGURE 5. Single-Line Electrical Diagram



DC Cabling and Electrical Pathways

In a photovoltaic system, electrical pathways and DC cabling are essential for transferring energy from the solar panels to the inverter and connecting system components. The electrical pathway includes junction boxes, panel connection points, cable trays, and routing channels. These must ensure safety, be protected against fire risks, and prevent short circuits.

DC cabling connects the photovoltaic panels to the inverters, carrying the direct current (DC) generated by the panels. Since most electrical systems operate on alternating current (AC), the inverter converts DC to AC for use in homes or industries. DC cables must be weather-resistant and capable of handling high voltages and outdoor conditions (Boxwell, 2010; International Electrotechnical Commission [IEC], n.d.; Institute of Electrical and Electronics Engineers [IEEE], 2003; National Fire Protection Association [NFPA], n.d.).

Configuration of PV Modules to the Inverter

The configuration of photovoltaic (PV) modules to the inverter is a critical step to ensure the system operates safely and efficiently. PV panels generate direct current (DC), which is then converted into alternating current (AC) by the inverter for use in electrical devices or for feeding into the power grid.

The modules are connected in groups called "strings" (nV in series) and linked to the inverter's input. Each string must have identical electrical characteristics, current, voltage, and orientation. Protection devices such as fuses are used to guard against short circuits, overheating, and UV exposure, especially for cabling.

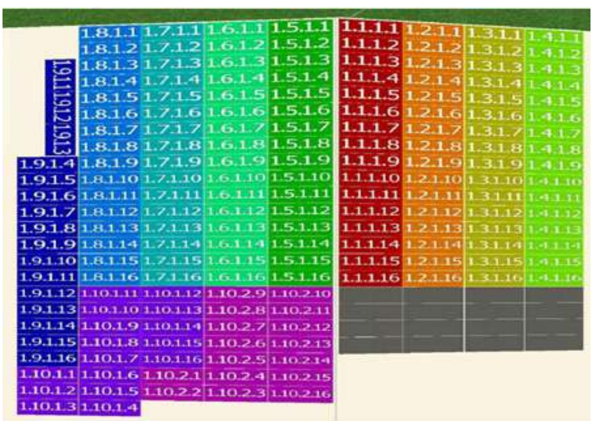
There are two main connection types between panels and the inverter:

Parallel connection: All panels share the same voltage, but the current increases. This setup requires more cabling and space.

Series connection (string): Panels are connected one after another in a single line, maintaining the same current while increasing voltage.

Both methods have their own advantages depending on the system design and energy needs (National Fire Protection Association [NFPA], n.d.; Solar Energy International [SEI], n.d.; SMA Solar Technology, n.d.; Victron Energy, n.d.).

FIGURE 6. Configuration of PV Modules to the Inverter



Minimum Temperature in Lezhë

In PV system design, minimum ambient temperature is critical because lower temperatures increase the open-circuit voltage (Voc) of solar panels. This must be considered when sizing strings and selecting inverters to avoid exceeding voltage limits.

For Lezhë, the lowest recorded temperature is -4°C, which will be used as the reference value in all technical calculations. This ensures safe operation, proper system sizing, and compliance with international standards even under extreme weather conditions.

Economic and Technical Analysis of the Photovoltaic (PV) Investment

As part of sustainable development and the energy transition, a photovoltaic system with a capacity of 218.2 kWp is planned to be commissioned on January 1, 2025. The system is expected to inject 165,207 kWh of electricity into the grid during its first year of operation, accounting for the natural degradation of PV modules.

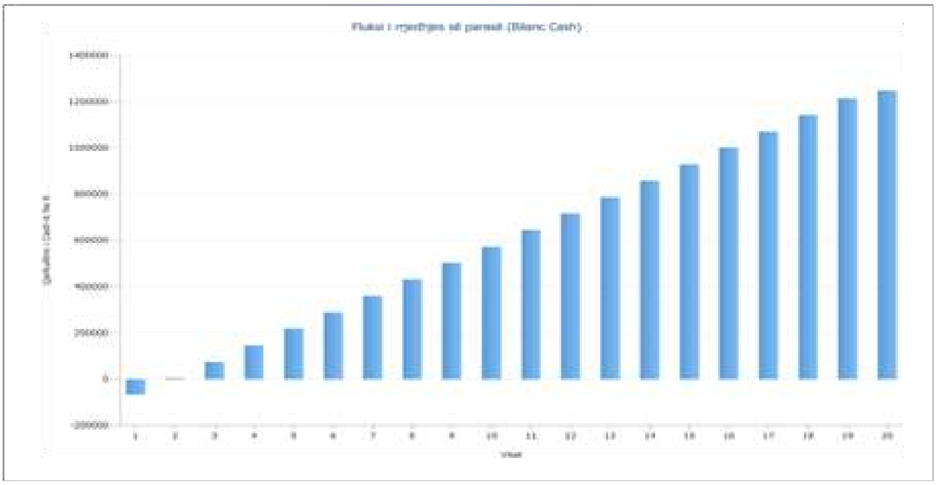
The economic assessment of this investment is highly favorable. With a total investment cost of €138,500, a specific cost of €634.62/kWp, and negligible annual operating expenses (€0/year), the system is projected to generate annual revenues of €36,345.51—primarily through a feed-in tariff of €0.22/kWh. These revenues translate into direct savings for the investor, with €34,867.82 saved in the first year alone.

The financial indicators make the project particularly attractive. The internal rate of return (IRR) of 51.3% is significantly higher than the average for similar projects, while the payback period is just 1.9 years—meaning the initial investment is recovered in less than two years. Over a 20-year period, the project is expected to generate a net cash flow of €1,249,421.02, making it a highly strategic and profitable investment.

The cost of energy production is just €0.0215/kWh—well below the current market price for business consumers (18.34 ALL/kWh excluding VAT, approximately €0.22/kWh), further strengthening the economic rationale behind the investment.

In conclusion, this photovoltaic project represents an excellent example of smart investment in renewable energy. It combines technical efficiency with high economic returns, while also contributing to reduced dependence on fossil fuels and greater environmental protection.

FIGURE 7. Cash Flow Diagram



Energy Balance and Self-Sufficiency of the Photovoltaic System

The monthly energy balance and self-sufficiency analysis for the 218.24 kWp photovoltaic system show seasonal variations in production and consumption. The system is expected to generate around 322,438 kWh annually, while the total annual consumption is 407,040 kWh.

During summer months (June to September), the PV system produces more energy than consumed, achieving over 100% self-sufficiency—up to 268% in August—meaning excess energy can be fed back to the grid or stored. In contrast, winter months (December, January, February, November) see lower solar production, covering only about 27% of consumption in December due to shorter days and less sunlight.

Overall, the system's annual energy self-sufficiency is approximately 79%, with the remaining energy supplied by the grid. This seasonal pattern aligns with typical Mediterranean climate PV performance models (International Energy Agency [IEA], 2020; Energy Regulatory Authority [ERE], 2024).

Savings from Self-Produced Electricity

Based on the current electricity price in the Free Market, the photovoltaic system produces approximately 322,438 kWh per year. Multiplying this by the price of 22 ALL/kWh (including VAT) results in annual savings of 7,093,636 ALL (with VAT).

This amount represents the monetary value of the electricity generated by the PV system that does not need to be purchased from the grid.

System Maintenance and Potential Issue Diagnostics

Photovoltaic systems require less maintenance compared to traditional energy sources. Regular maintenance and early detection of potential issues are crucial to ensure optimal performance and system longevity. Without these processes, system efficiency gradually declines.

Key maintenance activities include inspecting panels for cleanliness or damage, checking electrical connections, testing inverters, and regular cleaning. Dirt, dust, and urban pollutants can reduce system efficiency by 5% to 25%, depending on the duration and severity of panel coverage.

A well-maintained photovoltaic system can produce 10-20% more energy compared to one that is not properly maintained.

These savings improve the user's financial balance and enhance the overall efficiency and sustainability of the energy system (International Renewable Energy Agency [IRENA], 2016; National Renewable Energy Laboratory [NREL], 2018).

Energy Consumption and Pollution from Photovoltaic System Production

While solar energy itself is very clean, the manufacturing of photovoltaic (PV) modules involves industrial processes that impact the environment negatively. These effects mainly come from raw material extraction, industrial processing, and handling of toxic chemical waste.

Most PV panels are made from crystalline silicon, but other technologies use materials like CIGS (copper-indium-gallium-selenide), CdTe (cadmium telluride), and GaAs (gallium arsenide). These materials require mining rare metals such as:

- Cadmium (toxic and carcinogenic, used in CdTe panels)
- Silicon (requires high energy for purification, causing CO_2 emissions and toxic waste)
- Indium (used in CIGS, limited supply)

Manufacturing consumes significant energy and produces hazardous waste like sulfur dioxide, arsenic, lead, and silicon fluoride, which can pollute air, water, and soil if not managed properly.

Factories use dangerous chemicals such as trichlorosilane, hydrofluoric acid, organic solvents, and industrial cleaners during cell production and doping processes. Poor management can harm workers and nearby communities.

Life cycle analyses show that producing a crystalline silicon panel has a larger environmental impact than its 25-year operation, but this impact decreases significantly if renewable energy powers production.

Recycling is also a challenge since panels contain glass, plastic, semiconductors, and metals. Without proper infrastructure, damaged or old panels may end up in landfills, risking toxic substance leakage.

The European Union's WEEE Directive mandates proper recycling and disposal of electrical waste, including solar panels. Many companies have developed dedicated solar panel recycling programs to address this issue (Cucchiella et al., 2015; Fthenakis, 2011; International Renewable Energy Agency [IRENA], 2016; Peng et al., 2013).

Global and Ethical Impact of Photovoltaic System Production

The majority of global solar panel and cell production is concentrated in a few Asian countries, particularly China. China alone controls over 80% of the world's polysilicon supply. Reports from international organizations have raised serious concerns about the use of forced labor in the production process. This raises ethical challenges for companies and governments aiming to promote clean energy without contributing to human rights violations.

Another key ethical issue is the lack of transparency in how solar panel components are produced and distributed. Most companies do not disclose:

- The origin of raw materials,
- Labor practices within supplier factories,
- Toxic waste management procedures in production facilities.

This lack of transparency prevents consumers and investors from making informed, ethical choices. In response, several organizations are advocating for ethical standards and clean supply chain certifications, to ensure that solar panel manufacturing does not involve forced labor or environmental abuse.

Conclusions

This paper aimed to analyze the feasibility of supplying electricity through the installation of a photovoltaic (PV) system in a textile factory located in the city of Lezhë. The analysis incorporated the technical, economic, and practical aspects of implementing such a system. From this study, several key conclusions are drawn:

Firstly, it has been confirmed that Lezhë has favorable climatic conditions for the utilization of solar energy due to a significant level of solar irradiation. This makes the region suitable for photovoltaic installations. This is further supported by the growing national interest in renewable energy and the supportive policies being adopted by the Albanian government.

Secondly, through energy consumption analysis and the use of dedicated simulation software, an optimal PV system configuration was achieved. This system covers a significant portion of the factory's energy needs, particularly during daytime working hours. The installation of the PV system on the rooftop, aligned with the most efficient panel orientation, ensures maximum utilization of solar resources while minimizing the impact on the factory's existing infrastructure.

From an economic perspective, the investment is considerable, but the payback period is justified by the resulting savings on monthly electricity bills. Once the investment is recouped, the PV system continues to generate electricity at near-zero cost, providing direct financial benefits to the business. These benefits can further increase if small renewable energy producers take advantage of government incentive schemes.

From an environmental standpoint, the photovoltaic system significantly reduces greenhouse gas emissions, particularly CO_2, making the factory more environmentally responsible and aligned with global sustainability standards. Given that the textile industry is connected to international markets, where stricter environmental criteria are increasingly applied, such an investment enhances competitiveness and compliance.

This paper demonstrates that implementing photovoltaic systems in the industrial sector represents a replicable model that could be successfully applied to other industries in Albania. Therefore, it is recommended that textile companies explore the transition to clean energy as a step towards sustainability, increased competitiveness, and long-term energy independence.

The findings of this study contribute to the growing body of research on renewable energy adoption in industrial sectors and provide practical insights for policymakers and investors in Albania.

Recommendations

The use of photovoltaic systems is a viable and effective solution not only for households but also for businesses and industrial buildings. Albania, given its strategic geographic position and close ties to Europe, should maximize the use of solar energy. Based on the outcomes of this paper, the following recommendations are made:

Practical implementation of the proposed project by following the technical layout developed in this study to ensure system efficiency and stable operation.

Integration of real-time monitoring systems to track energy production and improve maintenance management.

Utilization of public and international funding and subsidies offered by the Albanian government and international organizations for clean energy projects.

Future expansion of the system, aligned with the factory's growth in production capacity and increasing energy demands.

Replication of this model in other industrial sectors, presenting a practical example for Albania's energy transition and sustainable economic development.

In summary, solar energy is free, affordable, and photovoltaic systems can function as autonomous units, even in areas without access to the electric grid. This study reinforces the belief that solar power is not just a viable alternative—but a strategic necessity for the future of Albania's industrial sector

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