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Zero Energy Production Center: Integration of Photovoltaic Systems and Energy-Efficient Technologies

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ABSTRACT
To meet the requirements of net-zero energy production while cutting costs at the same time, this paper studies the feasibility of converting an existing small food production facility into a zero-energy production center by incorporating photovoltaic solar panels, solar water-heating panels, energy-efficient machines, and renewable-energy management practices. The targeted facility is a processing plant for three fast-food restaurants, with an approximate electric power consumption of 10 kW. It is equipped with solar water-heating panels, and a photovoltaic system has already been installed to increase the amount of renewable electricity generated on site. The installed system comprises of 120 LR5-66HPH-500M G2 Longi Solar Monocrystalline modules with a total direct current (DC) output of 60.0 kWp and Growatt New Energy MAX 50KTL3 LV inverter with a 50 kW alternating current (AC) output. According to the calculations, the projected annual electricity production of the photovoltaic power plant is 62,314 kWh, which equals 1,039 kWh/kWp and a performance ratio of 87.67%. It was found that the installed system is technically viable because it can fulfill the electricity needs of the production facility while providing the surplus for the grid. The paper explores the concept of net-zero energy production, the targeted building, and alternative energy sources, including their costs and barriers to adoption, and evaluates the impact on employees and the community. The findings highlight the ability of the studied approach to make the small production center independent from traditional electricity sources to some extent and promote economic and environmental sustainability in the long run. However, the photovoltaic system has not yet completed one full year of operation, and a complete operational dataset is not available. Therefore, the calculated annual production and performance indicators cannot yet be treated as measured results, and the final net-zero-energy status of the facility remains subject to verification through a complete annual energy balance.

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I. INTRODUCTION

Electricity is an essential requirement for the functioning of any food-production facility, as most processes require continuous operation of various machines such as refrigerators, ovens, lights, ventilating systems, water heaters, and others. Therefore, the price of electricity directly affects the production costs and the final price of the goods. Accordingly, the rising energy prices and global initiatives for sustainability are prompting organizations to consider innovative approaches and alternative sources of energy.

In Bosnia and Herzegovina, there is a growing interest in renewable energy projects among firms and households to meet the rising demand for reliable electricity supplies. Another driving force for promoting alternative energy resources is the growing concern about greenhouse-gas emissions and the environmental impact of traditional power plants. From an economic perspective, switching to renewable energy resources offers a mechanism for significantly reducing power costs in the long run. However, the success of such a project depends on numerous factors, including the location, energy needs, financial constraints, regulatory framework, and other characteristics. Thus, this paper aims to design a concept for a zero-energy production facility based on an alternative source of energy.

The production facility under consideration is a small-scale center that produces meat products, cakes, and pastries for three local fast-food restaurants in the area. It is currently equipped with solar panels that are used for heating water, and a photovoltaic system has been installed for electricity production. In this project, the electricity produced by the photovoltaic system is intended to be used first within the production facility, while the surplus may be distributed to the main electricity grid in accordance with the regulator's requirements and the electricity distributor.

First, this paper will address the question of how the production facility can become a net-zero energy producer. Second, the possible alternative energy source will be determined; besides, the number of kilowatts that can be generated there will be calculated. Third, the project's impact on the economic sustainability of the production facility will be discussed. Furthermore, the current or potential barriers to the project's implementation in the local community will be addressed. Finally, the question whether engaging employees and other stakeholders in the decision-making process will promote the greater sustainability of the project will be considered.

The main hypothesis of this paper is that implementing renewable energy sources and energy-efficient technologies in the zero-energy production facility will ensure its zero-energy status and promote sustainability.

II. METHODOLOGY

2.1 Research Design

The research was conducted using a case-study method supported by technical and literary research on net-zero buildings, renewable energy, energy-efficient technologies, and small-scale production facilities. The case study concerns a food production center in Bosnia and Herzegovina that produces meat products, cakes, and pastries for three fast-food restaurants. The analysis is focused on the installed photovoltaic electricity generation system in combination with an existing solar water-heating system.

The research design is primarily descriptive and analytical, as the collected project information was structured into several technical indicators. These indicators include the estimated electricity demand, the roof area, the photovoltaic modules' type, the photovoltaic power capacity, the inverter's power capacity, the expected annual electricity production, the specific yield, and the performance ratio. This information was used to understand the project's technical, economic, environmental, and operational characteristics.

2.2 Materials Used

The materials used for the research include the project description of the analyzed production center, the information on the installed photovoltaic power system, the description of an existing solar water-heating system, and the literature on zero-energy buildings and renewable energy technologies. The main technical materials for analysis include the specifications of Longi Solar LR5-66HPH-500M G2 photovoltaic modules and Growatt New Energy MAX 50KTL3 LV inverter. The materials used for interpreting the technical, economic, and environmental characteristics of the power system include academic articles, technical literature, and materials on renewable energy.

2.3 Method Used

The method used for the research is based on the comparison of the energy condition before and after the installation of the photovoltaic power system. The energy condition before refers to the electricity provided by the grid and the existing solar water-heating system. The energy condition after considers the use of photovoltaic electricity generation, solar water-heating system, energy-efficient technologies, and the possible export of electricity to the grid.

The analysis includes the calculated annual electricity production of the installed photovoltaic power system, its specific yield, and performance ratio. The specific yield was calculated using the following formula:

$$Y_f = \frac{E_{annual}}{P_{PV}}$$

where Y_f is the final specific yield, E_{annual} is annual energy production, and P_{PV} is installed PV capacity. For the proposed system:

$$Y_f = \frac{62{,}314 \text{ kWh/year}}{60.0 \text{ kWp}} \approx 1{,}039$$

The research also includes the analysis of seasonal variations in the electricity production of the installed photovoltaic power system. It is expected that the production will be higher from May to September and lower from November to February. Therefore, the analysis is focused on the grid connection, the possibility of electricity storage, demand management, and the comparison of predicted and actual annual electricity production.

2.4 Model Formulation Assumptions

Several assumptions were made to ensure the accuracy and reliability of the produced results. First, the photovoltaic modules have been installed on the roof of the production center. For the purposes of the technical calculations, the roof was considered to be minimally shaded by surrounding buildings. Second, the installed photovoltaic power system includes 120 photovoltaic modules with 500Wp, meaning that the installed capacity of the photovoltaic power system is 60.0kWp. Furthermore, the production center includes one Growatt New Energy MAX 50KTL3 LV inverter with 50kW AC nominal power.

The annual electricity production of the photovoltaic power system is 62,314kWh/year, the calculated specific production is 1,039kWh/kWp/year, and the performance ratio is 87.67%. The connection to the electric grid was assumed to be appropriate to ensure the electricity import during demand and electricity export during oversupply. The annual electricity demand was not assumed to be constant due to the nature of the production process, as the production center only operates during the working hours of the fast-food restaurants, and the 10 kW indicates the approximate electrical power requirement of the facility.

The existing solar water-heating panels were assumed to be used to provide the production center with hot water and reduce the demand for electricity. Wind turbines were considered as an optional addition to the energy supply system, as their installation requires a detailed assessment of wind characteristics, including wind direction, speed, turbulence, and noise, as well as their economic and visual impact. Finally, the final zero-energy verification was assumed to require one year of electricity production and demand data.

III. CASE STUDY

3.1 Case Study of the Investigated Production Center

The investigated production center is a small food-production facility in Bosnia and Herzegovina. It produces meat products, cakes, and pastries for three fast-food restaurants in the surrounding area. The facility uses approximately 10 kW of electrical power and already has solar panels for water heating. The proposed improvement is the installation of a photovoltaic system for electricity generation.

The photovoltaic system consists of 120 Longi Solar LR5-66HPH-500M G2 modules. Each module has a nominal power of 500 W, producing a total installed capacity of 60.0 kWp. The modules occupy approximately 285 m² of roof area, while the usable cell area is approximately 264 m². The system uses one Growatt New Energy MAX 50KTL3 LV inverter with a nominal output capacity of 50 kWac.

The installed photovoltaic capacity is higher than the nominal AC capacity of the inverter. This configuration can improve inverter utilization during the annual operating period because photovoltaic modules do not continuously operate at their maximum rated power. The final electrical design would nevertheless need to confirm string configuration, voltage limits, current limits, protection equipment, cable sizing, grounding, structural capacity, fire safety, and the requirements of the local distribution network.

The calculated annual electricity production is 62,314 kWh. The specific production is approximately 1,039 kWh/kWp/year, and the performance ratio is 87.67%. The highest production is expected during the sunnier months, particularly from May to September, while electricity will also be generated during sunny winter days at a lower level.

The proposed system can supply electricity to the production center during periods of photovoltaic generation. When production exceeds instantaneous demand, surplus electricity may be delivered to the electrical grid, subject to applicable regulations. When photovoltaic production is insufficient, the facility can continue receiving electricity from the grid. The actual annual energy balance must be established through electricity bills and monitoring data.

3.2 Case Study of Industrial Energy Management

Salonit Anhovo is a large cement-production factory in Slovenia that demonstrates the importance of energy management in industrial facilities. The factory consumes more than 90 GWh of electricity annually, more than 8 GWh of gas, and approximately 400,000 m³ of technological water. Its industrial environment includes high moisture, extreme temperatures, and widely distributed production areas, making the installation of conventional wired monitoring infrastructure difficult and expensive.

Solvera Lynx implemented a smart energy-management solution based on wireless LoRaWAN technology. The system used ComBox.L devices to collect information from gas, water, compressed-air, and electricity meters, while the GemaLogic software platform gathered and analyzed the data. The example demonstrates that renewable-energy production should be supported by accurate monitoring and analysis. Although the investigated production center is much smaller, a similar principle can be used through a simpler monitoring system that records electricity production, consumption, peak demand, export to the grid, and the performance of major equipment.

The relevance of this example is not the direct transfer of industrial equipment to a small food-production facility. Instead, it demonstrates the importance of connecting energy generation with operational data. A photovoltaic system can reduce electricity consumption, but monitoring is necessary to determine whether the system is achieving its intended economic and environmental performance.

3.3 Comparative Interpretation of the Case Studies

The investigated production center and the industrial energy-management example differ significantly in size, energy demand, equipment, and operational complexity. However, both cases demonstrate that energy performance depends on the interaction between energy generation, energy consumption, monitoring, and management. The industrial example uses an advanced wireless monitoring system because of its large scale and difficult operating environment. The smaller production center would require a simpler system, but it would still benefit from the recording of electricity production, electricity consumption, peak demand, and equipment performance.

The investigated production center represents a small-scale application in which photovoltaic generation and solar water heating can reduce dependence on conventional energy. The Salonit Anhovo example represents a large industrial application in which energy monitoring is necessary to manage multiple utilities and geographically distributed equipment. Together, the cases demonstrate that the scale of the monitoring system should correspond to the scale and complexity of the facility, while the basic principle of measuring and managing energy remains applicable in both situations.

IV. RESEARCH QUESTIONS

Research Question 1: The first research question focuses on determining the combination of the renewable-energy sources, which would be most appropriate for achieving zero-net energy consumption at the production center. The most viable option, in this case, is to use the existing solar water-heating panels in combination with the installed 60.0 kWp photovoltaic system. The wind turbines could be considered as a possibility since the terrain is rather favorable for capturing winds coming from specific directions; however, it is essential to evaluate the wind potential more closely. The use of photovoltaic electricity and solar water-heating seems to be the most reasonable one based on the information at hand.

Research Question 2: As for the second research question, it is related to projecting possible reductions in energy consumption after the implementation of renewable-energy sources and measures enhancing energy efficiency. The installed 60.0 kWp photovoltaic system is calculated to produce 62,314 kWh of electricity per year, corresponding to approximately 1,039 kWh/kWp and a performance ratio of 87.67%. Based on the available calculations, the photovoltaic system may cover a substantial part of the facility’s electricity demand. However, the exact proportion cannot yet be determined because the system has not completed one full year of operation and a complete annual electricity-consumption dataset is not available. The actual electricity consumption, photovoltaic production, electricity imported from the grid, and electricity exported to the grid must be measured before the annual energy contribution of the system can be confirmed.

Research Question 3: The third research question is concerned with assessing how zero-net energy consumption impacts the economic competitiveness and sustainability of the production center. The installed photovoltaic system may reduce monthly electricity costs and reduce the facility’s exposure to increases in electricity prices. Surplus electricity may also be supplied to the local electricity grid if permitted by the applicable regulatory framework. The initial economic analysis indicated a possible payback period of approximately 2.5 years. However, this estimate should be interpreted as a calculated result based on the assumptions used in the original analysis, because the final economic outcome will depend on actual electricity consumption, electricity prices, grid compensation, operating costs, administrative costs, and the legal framework.

Research Question 4: Finally, the fourth research question is focused on examining how employees can be engaged and whether community support plays a significant role in the success of the project. In this case, employees are key stakeholders since their behavior determines the level of electricity consumption at the production facility. They can be motivated to engage in energy-saving behaviors by educating them on the project’s goals and encouraging their active participation in implementing the proposed measures. The most significant steps will involve adjusting the use of production equipment, lighting, heating and air conditioning, and water heating. The support of the community can be garnered by promoting the project as an example of how sustainability-conscious initiatives benefit both the business and the community at large. It will be essential to make the process of adopting similar initiatives easier for other businesses and homeowners in order to facilitate their proliferation.

V. HYPOTHESIS EVALUATION

The hypothesis states that the use of renewable-energy sources and energy-efficiency measures in the production facility will contribute to achieving zero-energy status and improving sustainability. The calculations presented in this paper support the technical feasibility of the installed photovoltaic system and the existing solar water-heating system. The photovoltaic system is calculated to produce approximately 62,314 kWh of electricity annually, while the solar water-heating system can reduce the facility's dependence on conventional energy for hot-water production.

However, the hypothesis cannot yet be considered fully verified. The photovoltaic system has not completed one full year of operation, and no complete annual dataset is available. Verification requires measurements of electricity consumption, photovoltaic electricity production, electricity imported from the grid, electricity exported to the grid, thermal-energy consumption for water heating, system losses, and equipment operating time.

Therefore, the hypothesis is conditionally supported at the design and calculation stage. The final conclusion regarding the zero-energy status of the facility can be made only after the results of a complete operating year have been collected and analyzed using a clearly defined energy-accounting boundary.

VI. CONCLUSION

This paper examined the possibility of transforming a small-scale food-production facility in Bosnia and Herzegovina into a zero-energy production center. The facility produces meat products, cakes, and pastries for three local fast-food restaurants and has an approximate electrical power requirement of 10 kW. It is equipped with a solar water-heating system, and a photovoltaic system has been installed for electricity generation. The installed photovoltaic system consists of 120 Longi Solar LR5-66HPH-500M G2 monocrystalline modules with a total capacity of approximately 60.0 kWp and one Growatt New Energy MAX 50KTL3 LV inverter with a nominal capacity of 50 kW AC.

According to the calculations, the photovoltaic system is expected to produce approximately 62,314 kWh of electricity annually, with a specific production of approximately 1,039 kWh/kWp and a performance ratio of 87.67%. These results indicate the technical potential of the installed system to reduce the facility's dependence on electricity from conventional sources and to provide surplus electricity to the grid, subject to applicable requirements.

Nevertheless, the photovoltaic system has not yet completed one full year of operation, and no complete annual dataset is available. Consequently, the calculated annual production, specific production, and performance ratio cannot yet be treated as measured operational results. The actual energy balance must be determined after collecting data on facility consumption, photovoltaic production, electricity imported from the grid, electricity exported to the grid, thermal-energy production, and system losses.

The initial economic analysis indicated a possible payback period of approximately 2.5 years. This result should be treated as an estimate based on the assumptions used in the analysis. The actual payback period will depend on electricity prices, grid compensation, facility consumption, maintenance costs, administrative expenses, and the applicable legal framework.

The main barriers to achieving verified zero-energy status are financial, procedural, and technical. These include the initial investment, administrative requirements, grid-connection procedures, seasonal variation in photovoltaic production, the operating characteristics of production equipment, maintenance requirements, and the need for reliable energy monitoring.

Overall, the installed photovoltaic system and existing solar water-heating system provide a technically promising basis for reducing the facility's conventional energy consumption. However, the facility should be described as a potential or intended zero-energy production center until a complete year of operational data confirms its annual energy balance.

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