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Economic Feasibility and Technical Assessment of Solar Photovoltaic System Implementation for District Heating Infrastructure in Maribor

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Abstract:This study examines the economic feasibility and technical specifications for implementing a modular photovoltaic solar energy system at the Maribor district heating infrastructure, including both rooftop installations and parking area facilities. The primary objective is to enhance the organization's energy independence, reduce electricity procurement costs, and accelerate the transition to sustainable renewable energy use. By deploying solar photovoltaic technology, this research aims to optimize energy generation while ensuring financial viability and environmental sustainability throughout the project lifecycle.
Various design configurations and deployment strategies were evaluated using the PV*Sol simulation platform, which enables detailed modeling and performance assessment of photovoltaic energy systems. The investigation focused on identifying the most economically advantageous configuration by analyzing factors such as power generation capacity, initial investment requirements, and system operational efficiency. A comparative analysis of different modular system architectures was conducted to determine the optimal approach for system expandability and peak performance.
The study also addresses the legal and regulatory framework relevant to solar power plant development and deployment, including compliance with national and European Union energy directives, electrical grid interconnection requirements, and available subsidy mechanisms.
The analysis determined the project's long-term financial sustainability, identified potential implementation challenges and risk factors, and recommended the most cost-effective and environmentally responsible deployment strategy.
Keywords: Solar photovoltaic systems; sustainable energy sources; energy autonomy; financial investment analysis

NOMENCLATURE

ARSO	Slovenian Environment Agency
BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CHP	Combined Heat and Power
EF_{CO2}	CO_2 Emission Factor
E_{PV}	Electricity Production from PV
IRR	Internal Rate of Return
NPV	Net Present Value
OPEX	Operational Expenditure
PV	Photovoltaic
PV*Sol	Simulation Software
RES	Renewable Energy Sources

1 INTRODUCTION

The global transition to sustainable energy systems has accelerated the adoption of renewable energy technologies, with solar photovoltaic systems emerging as a leading solution. This research evaluates the economic viability and technical implementation requirements for a solar energy installation at the Energetika Maribor facility, using net present value (NPV) as the primary financial assessment metric. The motivation for this study arises from the need to conduct thorough evaluations of solar energy initiatives, which are significantly influenced by various economic variables and regulatory frameworks.

With rising energy costs and increasing environmental awareness, understanding the financial implications of solar energy investments has become crucial for both corporate entities and private investors. The NPV analysis for the solar project at Energetika Maribor includes both rooftop-mounted and parking lot-integrated installations, with particular attention to the selection of appropriate discount rates and consideration of long-term operational expenditures, such as system maintenance and photovoltaic module performance degradation. By examining these parameters in detail, this study aims to provide prospective investors with evidence-based guidance for making strategic decisions that align with financial objectives and sustainability commitments.

This research also examines the technical specifications for self-consumption systems powered by renewable energy sources, ensuring that installations meet established safety protocols and operational benchmarks. This aspect is essential for building stakeholder confidence in solar energy technologies and encouraging their widespread adoption across various industries. In summary, this work contributes to the existing literature on renewable energy investments by offering practical insights to assist decision-makers in navigating the complexities of the solar energy marketplace.

1.1 Goals and objectives

The primary objective of this research is to evaluate the technical feasibility and identify the optimal configuration for a solar photovoltaic installation at the Energetika Maribor facility [2]. As renewable energy is a cornerstone of modern energy strategies, determining the most effective approach for deploying photovoltaic systems on existing infrastructure is a significant challenge. This study addresses several key objectives:

1. Technical evaluation: Conduct a comprehensive assessment of the site's solar energy potential by analyzing available surface area, solar irradiation levels, shading patterns, and structural load-bearing capacity for both rooftop and parking lot installations.

2. Economic analysis: Perform detailed financial modeling to assess the project's economic viability, including capital expenditure, operational costs, revenue projections from energy generation, and available financial incentives or subsidies.

3. System design optimization: Use advanced simulation software (PV*Sol) to model various system configurations, comparing different photovoltaic module technologies, inverter specifications, and mounting solutions to identify the optimal design that maximizes energy yield while minimizing costs.

4. Regulatory compliance: Review applicable legal and regulatory requirements for solar installations, including grid connection standards, building permits, environmental assessments, and adherence to national and EU renewable energy directives.

5. Risk assessment: Identify and evaluate potential technical, financial, and operational risks associated with the project, and develop mitigation strategies to ensure long-term project success.

6. Implementation strategy: Create a practical roadmap for project execution, including phasing strategies, technology selection criteria, procurement recommendations, and performance monitoring protocols.

By achieving these objectives, this research provides a comprehensive framework for solar energy project development that can be adapted to similar district heating facilities and industrial applications, thereby contributing to the broader transition to sustainable energy systems.

The solar power plant was integrated into the electricity consumption system based on 15-minute electricity consumption readings and was adjusted through multiple iterations of increasing and decreasing the plant's capacity [4].

In the model, 15-minute energy consumption was compared with the projected hourly electricity production of the new solar power plant. Hourly production was divided into 15-minute intervals for further analysis. Compensation, deficits, and electricity sales were calculated for each 15-minute interval throughout the year.

When designing a self-sufficient power plant, care must be taken to avoid oversizing the system, as excess electricity produced is transferred to the supplier, as shown in Figure 1. Calculations were collected at monthly and annual levels. The economic analysis used annual consumption and production data, assuming the same levels of consumption and production for 25 years, despite changing weather conditions. Annual degradation of the solar modules, as provided by the manufacturer, was considered in the financial analysis. The energy flow scheme is shown in Figure 4.

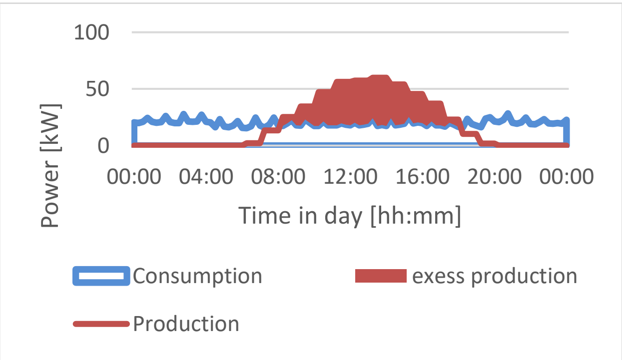

Figure 1: Daily display of electricity consumption and production.

2 METHODOS

Several alternatives for installing a photovoltaic (PV) power plant at the company's premises were analyzed, including the use of bifacial solar modules on parking structures. The study focused on strategic planning, architectural integration, and technical design elements to ensure both high performance and long-term functionality of the system.

2.1 Site assessment and data collection

The main principles of the PV plant design are outlined below:

• **Site Selection:** The designated area for the PV installation includes functional surfaces within the company's property that have strong solar potential. These areas include rooftops and parking lots with unobstructed sunlight exposure for most of the day. Installing photovoltaic modules on these surfaces allows the system to generate clean electricity while providing shaded, weather-protected parking for employees and visitors.

• **Adaptable and Modular Concept:** The PV plant design uses a modular and scalable approach, enabling easy adaptation to different spatial conditions and energy demands. While the project primarily serves the needs of Energetika Maribor, the same structural and design solutions can be replicated at other municipal or commercial sites throughout the city, promoting a unified and flexible model for urban solar infrastructure.

• **Structural and Technical Design:** For the carport installation, a robust steel support structure is proposed, optimized to hold photovoltaic panels at an inclination of approximately 6 degrees. This angle balances aesthetic integration, efficient solar capture, and practical considerations for shading vehicles. The design ensures durability and easy maintenance while enhancing the architectural quality of the surrounding space. The conceptual visualization is shown in Figure 2.

• **Sustainability and Environmental Aspects:** The initiative supports the transition to renewable energy and sustainable urban development. By integrating solar energy generation into everyday functional areas such as parking spaces, the project reduces dependence on fossil fuels, lowers greenhouse gas emissions, and increases local energy autonomy.

Several alternative configurations of the PV system were evaluated to determine the optimal combination of surface use, energy output, and investment cost. Special attention was given to the use of bifacial photovoltaic modules on carports, which can convert both direct solar radiation and reflected light from vehicles and pavement below. This feature allows for a measurable increase in overall energy yield compared to conventional single-sided panels.

In summary, the proposed design concept demonstrates how thoughtful integration of photovoltaic technology into the urban environment can improve energy efficiency, environmental performance, and overall quality of life in the city.

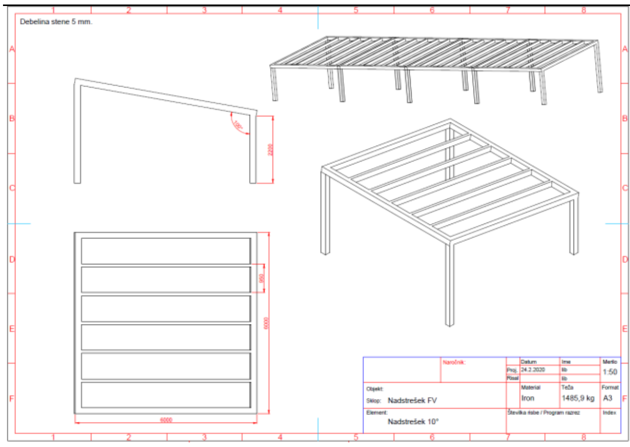

Figure 2: Modular design for PV on parking lots.

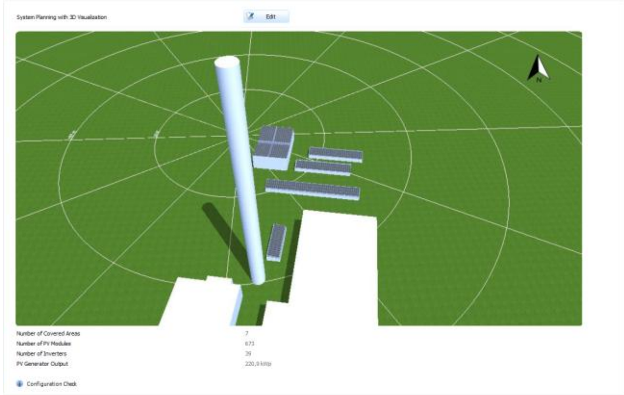

Figure 3: Designing in PV*Sol.

2.2 System design and simulation

The photovoltaic (PV) system was designed using PV*Sol simulation software, which offers a comprehensive environment for modeling and optimizing solar installations. The process began by entering detailed input parameters into the program, including site-specific data on solar radiation, climatic conditions, and the physical characteristics of the intended PV installation location. The simulation used information from Energetika Maribor and the Slovenian Environment Agency (ARSO), ensuring accurate representation of local meteorological conditions and annual solar irradiation.

Using these datasets, PV*Sol simulated the expected annual electricity generation of the proposed solar power plant. The results estimated an annual production of approximately 189,164 kWh, making a substantial contribution to the company's energy self-sufficiency and reducing grid electricity consumption.

The program also enables comparative performance analysis of different PV technologies and installation layouts. Various module types, including conventional monofacial and bifacial photovoltaic panels, were evaluated for output efficiency, spatial configuration, and shading effects. This comparative approach identified the most effective design for the given site and operational conditions.

Technical specifications for selected system components were incorporated into the design. The final configuration combines high efficiency monofacial modules on building rooftops with bifacial modules on parking structures. Each module is equipped with a SolarEdge power optimizer and connected to three-phase SolarEdge inverters, ensuring maximum energy harvest and system reliability. Hourly simulation data on expected PV output were exported to Microsoft Excel for further data processing and performance evaluation.

In conclusion, the optimized system configuration represents a technically robust and economically sound design. It incorporates precise site modeling, advanced simulation tools, and state-of-the-art components to achieve high energy yield with minimal surplus production. By evaluating multiple design variants, the selected layout offers the best balance of efficiency, cost-effectiveness, and energy utilization, supporting the broader goal of sustainable energy management within the company.

2.3 Economic evaluation framework

The economic feasibility of the photovoltaic (PV) project is evaluated using several financial indicators and analytical methods. The main findings are summarized below:

• **Net Present Value (NPV):** NPV is the primary metric for assessing the economic viability of the investment. It is calculated using a discount rate of 7.2% [2]. A positive NPV indicates that the projected cash inflows from the PV system exceed the initial investment and associated costs, confirming the project's financial attractiveness. The NPV calculation includes the total investment cost, anticipated returns over the project's lifetime, and the discount rate, which reflects market conditions and business risk factors.

• **Internal Rate of Return (IRR):** The project's profitability is also assessed using the internal rate of return (IRR), which enables comparison between different system configurations. By analyzing multiple scenarios, the configuration with the highest IRR can be identified, corresponding to the shortest payback period and the largest NPV over a 25-year operational horizon. This approach ensures selection of the most economically efficient layout.

• **Financing structure:** The PV project is planned to be financed with 20% equity and 80% debt, directly affecting both expected returns and financial risk. This capital structure is a key consideration in assessing project feasibility, as it defines the required return on investment and the associated cost of capital.

• **Electricity tariffs and market considerations:** Electricity prices were set at 74.06 €/MWh during peak periods and 49.37 €/MWh during off-peak hours (see Table 1). Network fees, which make up a significant portion of electricity costs, were included in the calculations. For comparison, an alternative scenario considered selling all electricity generated by the PV system on the open market at a reference price of 48.04 €/MWh [6]. Electricity prices are from the year 2020.

In summary, the project demonstrates strong financial viability, supported by a positive NPV, a favorable IRR, a strategically structured financing plan, and carefully considered electricity pricing. Together, these factors indicate that the PV system is a sound investment expected to generate substantial economic benefits throughout its operational life.

Table 1 Energy tariffs used.

	Price without tax	Unit
Energy higher tariff	0.07406	€/kWh
Energy lower tariff	0.04937	€/kWh
Network fee higher tariff	0.01146	€/kWh
Network fee lower tariff	0.00883	€/kWh
Contracted power	2,28278	€/kW
Energy Efficiency tax	0.0008	€/kWh
RES and CHP fee	1.84450	€/kW
Market Operator fee	0.00013	€/kWh
Excise duty	0.00305	€/kWh

2.4 Methodology for calculating useful energy from solar panels compared to building electricity consumption

For the analysis, losses due to shading and inverter consumption were taken into account. For each variant, the compensated electricity was calculated based on 15-minute measurements of consumption and production. The 2.5% efficiency loss due to module degradation is considered. This assumes a linear decline in module efficiency to 80.7% of nominal power in the 25th year of operation [9], [10]. Maintenance costs were estimated at 0.35% of the investment per year. The calculation also includes the costs of replacing inverters after 15 years of operation.

For the techno-economic analysis, a comprehensive analytical model was developed to quantify and evaluate the proportion of useful electrical energy generated by the photovoltaic system relative to the total electricity demand of the facility. The analysis is based on 15-minute interval measurements of electricity flows and considers both high and low tariff rates during the day, as well as different day types (working days, weekends, and public holidays).

The input dataset contains time-stamped measurements for:

- **Electricity consumption** – total energy used by the building
- **Electricity production** – energy generated by the photovoltaic system
- **Tariff information** – indicates whether each time interval falls under the high or low tariff period
- **Day type** – identifies working days, weekends, and public holidays

Each 15-minute record represents the measured energy in kilowatt-hours (kWh) for the corresponding time interval.

Calculation logic:

For each 15-minute interval, the following steps are applied:

1. **Data alignment:**
Consumption and production values are matched by timestamp to ensure direct comparison for the same interval.
2. **Compensation (self-consumption):**
Electricity produced by the solar panels is first used to meet the building's immediate consumption. The portion of production used on-site represents compensated energy.
    - If production is less than or equal to consumption, all produced energy is self-consumed.
    - If production exceeds consumption, only part of the produced energy is self-consumed.
3. **Energy deficit:**
When the building's consumption exceeds solar production, the difference represents energy drawn from the grid (deficit).
4. **Energy surplus:**
When solar production exceeds the building's consumption, the excess energy is considered a surplus and can be exported or sold to the grid.
5. **Aggregation and classification:**
The calculated values for each interval (consumption, production, compensation, deficit, and surplus) are aggregated by:
    - **Tariff period** (high, low)
    - **Day type** (working day, weekend, public holiday)
    - **Time frame** (daily, monthly, annual summaries)

The final output provides a comprehensive overview of total electricity consumed, produced, and self-consumed; the amount of energy purchased from the grid (deficit); the amount of energy sold or exported (surplus); and the distribution by tariff and day type for detailed performance and cost analysis. This methodology enables consistent and transparent assessment of solar energy utilization and supports the evaluation of energy efficiency, grid dependency, and the potential for increased self-consumption.

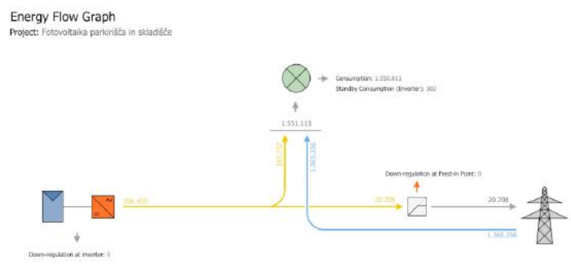

Figure 4: Self consumption energy flow scheme.

3 RESULTS

The analysis considered six distinct configurations of photovoltaic (PV) systems, each defined by different initial investment levels, projected energy generation, and operational performance. The financial evaluation included the following key components:

- **Capital expenditure (CAPEX):** The upfront cost of PV modules, inverters, mounting structures, and installation.
- **Operational expenditure (OPEX):** Annual maintenance expenses, estimated at 0.35% of the total initial investment.
- **Economic return:** Calculated over a 25-year system lifetime, accounting for revenues from electricity sales to the grid or savings from on-site self-consumption.

Among the analyzed alternatives, Variant 5 offered the most favorable balance between cost and performance. This configuration consists of 384 PV modules installed on 22 carport structures, each measuring 6 × 6 meters. The system has a total installed capacity of 169 kWp, corresponding to a module surface area of 921.9 m².

Simulation results from PV*Sol software estimate annual electricity generation at 189,164 kWh. Of this total, approximately 176,762 kWh would be directly used to offset the facility's internal electricity demand. In the first year of operation, this is expected to result in a cost reduction of 14,801.47 € (excluding VAT).

3.1 Key findings

1. **Net Present Value (NPV)**
   The NPV analysis indicates that self-consumption-based systems achieve significantly higher profitability than configurations that rely solely on electricity export. This result reflects current market electricity prices and relatively low feed-in tariffs.
2. **Internal Rate of Return (IRR)**
   The IRR values confirm the superior financial performance of self-consumption models, driven by greater cost savings and increased energy autonomy compared to grid-dependent schemes.
3. **Payback Period**
   The shortest payback period – approximately 9.81 years– is achieved with Variant 5. Other system configurations reach the break-even point between 10 and 11 years. After this period, all variants yield net positive returns, reinforcing their potential as long-term profitable investments.

A detailed comparison of the analyzed system variants is provided in Table 2.

Table 2 Comparison of different variants by payback period and internal rate of return.

SE exploitation method / Layout variant	Payback period [years]		Internal rate of return [%]	
	Sale	Self-consumption	Sale	Self-consumption
Layout 1	10.98	10.82	6.11	8.15
Layout 2	10.63	10.35	6.59	8.94
Layout 3	10.56	9.96	6.67	9.63
Layout 4	10.72	10.31	6.47	9.00
Layout 5	10.32	9.81	7.02	9.92
Layout 6	10.79	10.64	6.41	8.48

3.2 Energy savings and environmental benefits

Based on the PVSol simulation results, the proposed photovoltaic system would generate approximately 189,164 kWh of electricity per year. Of this amount, 176,762 kWh would be used directly to offset the company's internal electricity demand. These results are based on average climatic and solar radiation data from the PVSol database. Actual energy production may vary depending on weather conditions, which are the most significant variable affecting PV system performance.

In addition to reducing electricity consumption from the grid, the generated solar energy leads to a measurable decrease in greenhouse gas emissions. The reduction in CO_2 emissions was calculated using the methodology developed by the Centre for Energy Efficiency of the "Jožef Stefan" Institute [11].

The CO_2 savings are determined according to the following relationship:

$$CO_{2\,savings} = EF_{CO2} \times E_{Pv} \qquad (1)$$

where:

EF_{CO2} – average CO_2 emission factor [kg CO_2/kWh$_e$]

E_{PV} – annual electricity generation of the photovoltaic system [kWh]

According to the average national emission factor for Slovenia for the period 2002–2018,

$$EF_{CO2} = 0.48 \text{ kg } CO_2 /kWh_e$$

the resulting CO_2 reduction is:

$$CO_{2\,savings} = 0.48 \text{ kg } CO_2/kWh_e \times 189{,}164 \text{ kWh} = 90{,}799 \text{ kg } CO_2$$

Thus, implementing the PV system would result in an annual reduction of approximately 90.8 tonnes of CO_2 emissions. Over its projected 25-year lifetime, the system would prevent the release of more than 2,270 tonnes of CO_2, making a substantial environmental contribution to decarbonization and sustainable energy development. This also helps reduce the primary energy factor within the district heating system of Maribor, as part of the electricity required for heat generation and distribution is supplied from renewable sources.

3.3 Challenges and limitations

While the financial analysis is promising, the study highlights potential risks and limitations, including:

- **Degradation of PV panels:** Efficiency decreases over time, affecting long-term revenue generation.
- **Grid constraints:** Regulatory restrictions on energy export and possible changes in feed-in tariffs may affect profitability.
- **Capital cost fluctuations:** Market variability in PV module prices and installation costs can influence investment decisions.

The investment cost analysis shows that self-consumption is the optimal financial strategy for PV system deployment. System Configuration 5 is the most profitable, offering the highest IRR and the shortest payback period. Future research should examine the effects of battery storage and dynamic pricing models to further enhance financial performance.

Figure 5 indicates that the total return on investment for self-consumption shifts from negative to positive between the 11th and 12th year, while for electricity sales, this transition occurs around the 13th year of operation. Over their lifetimes, all investments would recover the initial capital. The highest total return after 25 years is achieved with Configuration 6, totaling €172,027, while Configuration 5 has the shortest payback period at 9.81 years. The diagrams clearly show a revenue drop in the 15th year, corresponding to inverter replacement and changes in electricity purchase prices after the expiration of operational support. Although the differences between individual configurations are minor, the method of electricity utilization (self-consumption vs. sales) significantly affects financial outcomes. The most profitable photovoltaic power plant setup is self-consumption with Configuration 5, followed by Configurations 3, 4, 2, and 6. The least favorable option is Configuration 1, which uses all available space for the solar power plant but has the highest initial cost. With Configuration 5, the net present value of the project after 25 years is €16,641.

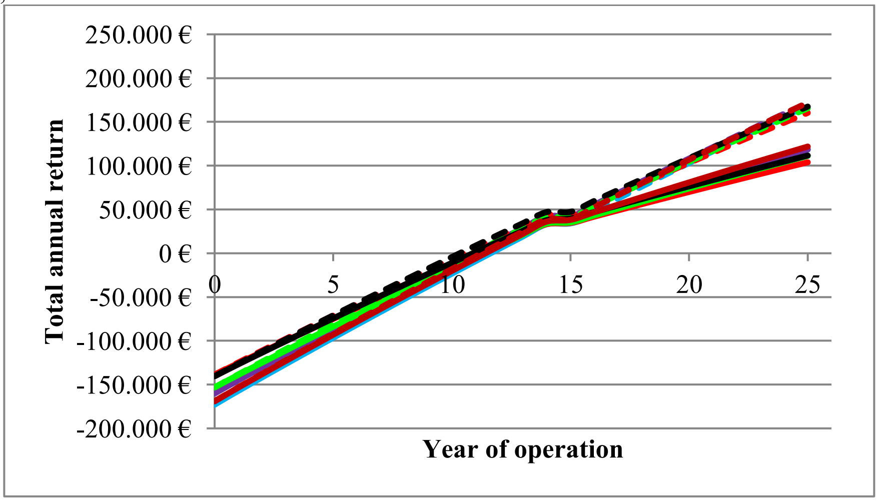

Figure 5: Total annual return of configurations.

Figure 6 illustrates the difference between the two approaches to utilizing the solar power plant. In this case, it is clear that selling electricity is not a viable option, as self-consumption is more beneficial given the current discount rate and electricity sale conditions. According to the net present value method, an investment is acceptable if the difference between revenues and expenses remains positive at the end of the period. However, for electricity sales, this is not the case. The internal rate of return (IRR) for a solar power plant intended for electricity sales ranges from 6.11% for Configuration 1 to 7.02% for Configuration 5.

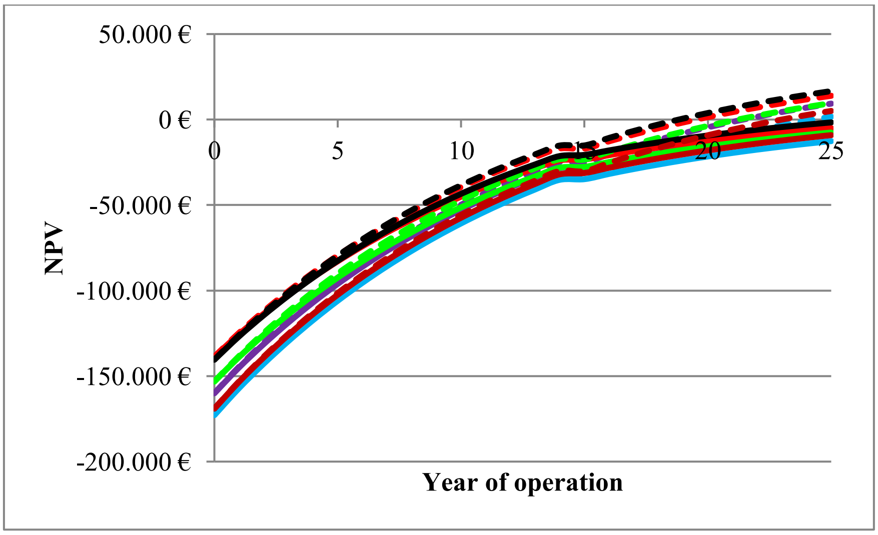

Figure 6: Net present value of configurations.

The most reasonable configuration for the solar power plant is one that avoids excessive electricity surpluses and maximizes self-consumption (compensation) of the generated energy. When the plant is oversized, the Internal Rate of Return (IRR) decreases because selling surplus electricity is less profitable than direct compensation through self-consumption. In cases of continuous electricity surpluses, integrating an energy storage system to store excess energy for later use is advisable. This could generate additional revenue through operational optimization and advanced load management strategies. Battery storage enables peak shaving, using stored electricity during periods of high demand or high tariffs, thereby reducing grid dependency and operational costs under the new grid tariff structure introduced in Slovenia, which charges electricity consumers based on both total energy consumption and peak power demand. However, a detailed simulation and cost-benefit analysis of such a hybrid PV–battery system is beyond the scope of this paper and should be addressed in future research.

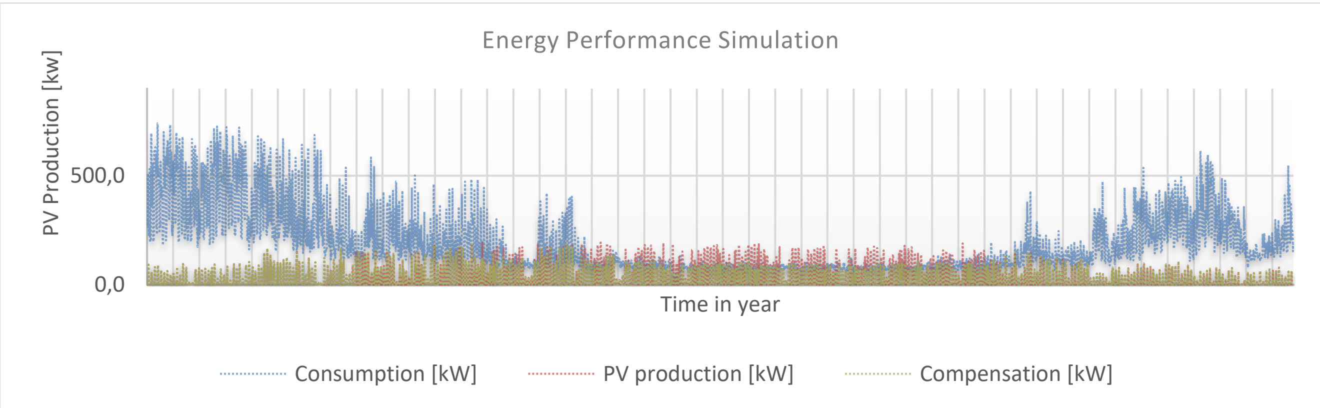

Figure 7: Yearly energy production and consumption simulation.

Electricity surpluses occur mainly during the summer months, as shown in Figure 7. During this period, market electricity prices are generally lower, especially when surplus generation peaks. Therefore, it is essential to limit or minimize these excesses to improve the overall economic efficiency of the photovoltaic system.

4 DISCUSION

Six different installation variants were analyzed with power plants sized between 162 kW and 202 kW. The analysis identified system Configuration 5, with 169 kW of output power, as the most optimal setup for implementing a photovoltaic (PV) power plant at Energetika Maribor. The annual electricity production from this solar power plant would be 189,164 kWh, of which 176,762 kWh, or 93%, could be used for self-supply. The remaining energy would be surplus delivered to the grid. Annually, this results in a reduction in electricity costs of 14,801 € at the current electricity purchase price.

This conclusion is based on a comprehensive evaluation of financial, technical, and environmental factors, with an emphasis on self-consumption over energy sales.

The key findings highlight that:

- **System configuration 5 achieves the highest internal rate of return (IRR)** and the shortest payback period, making it the most financially viable option.
- **Self-consumption is the most beneficial model,** as selling electricity to the grid does not yield significant returns under current market conditions.
- **Combining classic modules on warehouse rooftops with bifacial modules on parking lots** ensures high efficiency and improved energy yield.
- **An optimal tilt angle of 20°** on rooftops further enhances system performance.

Additionally, environmental benefits were considered. The annual reduction of CO_2 emissions by 91 tons highlights the project's sustainability and aligns with Slovenia's renewable energy objectives.

In conclusion, the study confirms that investing in a solar power plant focused on self-consumption is the most economically and environmentally sound decision. Future optimizations could include integrating battery storage solutions to enhance energy independence and further improve financial returns. Adding a battery energy storage system (BESS) could enable peak shaving and load shifting, allowing excess solar production to be stored and used during periods of higher demand or tariffs. This is especially relevant under Slovenia's new grid tariff structure, where network charges are partially based on peak power demand. Implementing such a system could provide additional cost savings and improve grid stability.

The assessment of economic viability through methods such as Net Present Value (NPV) and Internal Rate of Return (IRR) provides valuable insights into the financial performance of projects, particularly in the renewable energy sector. However, these methods have certain limitations that must be acknowledged:

- **Sensitivity to Assumptions:** Both NPV and IRR calculations are highly sensitive to assumptions regarding discount rates, cash flow projections, and project lifespan. Small changes in these assumptions can lead to significantly different outcomes, potentially misrepresenting the project's true economic viability.
- **Complexity in Multi-Variant Scenarios:** Comparing multiple investment options or configurations increases complexity, making it challenging to draw clear conclusions.
- **Market Fluctuations:** These methods assume stable market conditions, which may not reflect real-world scenarios. Fluctuations in energy prices, interest rates, and inflation can significantly affect projected cash flows and, consequently, the viability assessment.

Despite these limitations, methods for assessing economic viability are widely applicable in various areas:

- **Renewable energy projects:** The methodologies are especially relevant for evaluating investments in renewable energy sources, such as solar and wind power, where long-term cash flows and initial capital investments are critical considerations.
- **Infrastructure development:** These financial metrics apply to large-scale infrastructure projects, helping stakeholders understand the potential returns and risks associated with significant capital expenditures.
- **Investment decision-making:** Investors and financial analysts use these methods to make informed decisions about capital allocation, ensuring that resources are directed to projects with the highest expected returns.

In conclusion, while methods for assessing economic viability offer essential insights into project feasibility, it is important to recognize their limitations and consider a broader range of factors when making investment decisions. Their use in renewable energy and infrastructure development underscores their significance in guiding financial strategies in these sectors.

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