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Technical and economic analysis of photovoltaic plant investment at Maribor district heating facility

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The research analyses the technological and economic dimensions of developing a modular solar power plant at Maribor district heating facility, including rooftops and parking lots. The main goal is to enhance the company's energy self-sufficiency, reduce power expenses, and facilitate the shift to renewable energy sources. The research project seeks to enhance energy production by the application of solar photovoltaic technology, ensuring both cost-effectiveness and long-term sustainability.
Multiple design and implementation alternatives have been examined utilising the PV*Sol software package, which facilitates comprehensive simulations and performance assessments of solar power systems. The study concentrated on determining the most economically viable configuration, including variables such as energy output, capital expenditures, and operational efficacy. A comparison of various modular system designs was conducted to identify the most effective strategy for scalability and optimal performance.
The legal and regulatory frameworks pertinent to the planning and construction of a solar power plant were examined, including adherence to national and EU energy policies, grid connection stipulations, and accessible financial incentives.
The research has evaluated the long-term economic viability of the project, identified potential risks and problems, and provided the most profitable and sustainable implementation strategy.
Keywords: Photovoltaic solar modules; renewable energy sources; energy self-sufficiency; investment economic evaluation

1 INTRODUCTION

The increasing demand for sustainable energy solutions has led to a significant shift towards renewable energy sources, particularly solar energy. This work is focused on the financial viability and technical requirements of solar energy investment on the site of Energetika Maribor company, with the net present value (NPV) being used as a critical metric for assessing investment decisions. The rationale for this research is based on the need for a comprehensive evaluation of solar energy projects, which are often influenced by various economic and regulatory factors.

In the light of rising energy costs and environmental concerns, understanding the financial implications of solar energy investments is essential for both individual investors and organizations. The NPV of a solar project at Energetika Maribor, considering both rooftop and parking lot installations, has been evaluated, with an emphasis on selecting appropriate discount rates and considering long-term operational costs, such as maintenance and degradation of solar modules. By analysing these factors, the work aims to guide potential investors in making informed decisions aligned with their financial and sustainability goals.

Furthermore, the research addresses the technical requirements for self-supply systems that utilize renewable energy sources, ensuring that installations comply with safety and operational standards. This aspect is critical for fostering confidence in solar energy solutions and promoting their adoption across various sectors. Overall, this work contributes to the growing body of knowledge on renewable energy investments, providing valuable insights to help stakeholders navigate the complexities of the solar energy market.

1.1 Goals and objectives

The primary goal of this paper is to evaluate the feasibility and optimal design of a solar power plant on the premises of Energetika Maribor company [6]. As renewable energy becomes a cornerstone of modern energy policies, the most effective approach for implementing a photovoltaic (PV) system that enhances energy self-sufficiency and reduces electricity costs for the company is identified.

To achieve this, the focus is on:

1. **The potential and economic viability of a solar power plant** – Different installation scenarios on available surfaces (e.g., warehouse rooftops and parking spaces) are analysed to determine the most cost-efficient setup.
2. **A technical and economic analysis of different solar panel configurations** – Multiple photovoltaic module types and installation methods are evaluated using simulation tools like PV*Sol to optimize performance and return on investment.
3. **Regulatory and financial considerations** – Slovenian and EU legislative frameworks, potential subsidies, and incentives for solar energy adoption, particularly in the context of self-consumption, are reviewed [1][2][3], [4].
4. **A comparison of various investment models** – Profitability, payback periods, and the overall sustainability of the proposed PV system under different financing and operational strategies are examined.

The core objective of this study is to determine whether the construction of a solar power plant at Energetika Maribor is an economically and technically viable investment. Solar simulation models and financial projections are leveraged to present the most efficient and profitable setup while considering constraints such as shading, surface availability, and installation costs.

The paper follows a structured methodology that includes:

- Introduction to the problem and background on solar energy.
- Technical and economic evaluation of photovoltaic systems.
- Regulatory analysis and available incentives [2].
- Investment evaluation and financial feasibility study.
- Comparison of different installation setups and cost-benefit analysis.
- Final recommendations on the optimal solar plant configuration.

By integrating technical feasibility and economic justifications, the paper provides a comprehensive decision-making framework for implementing a sustainable and profitable solar energy project.

The solar power plant was integrated into the electricity consumption system based on 15-minute electricity consumption readings and adjusted through multiple iterations of increasing and decreasing the plant's capacity [3].

In the model, the 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 handed over to the supplier, as seen on 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.

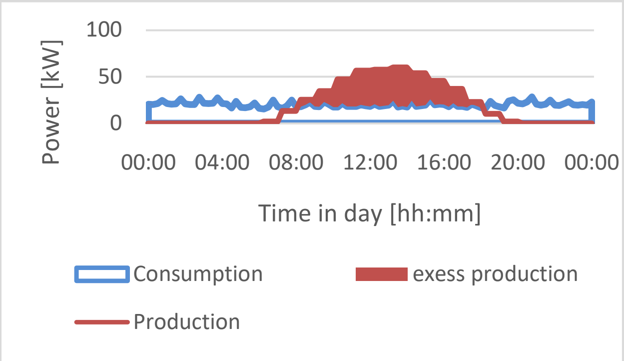

Figure 1 Daily display of electricity consumption and production

2 METHODS

Several possible ways to install a solar power plant at the company's location were examined, as well as the possibility of using bifacial solar panels on carports. Focusing on the strategic planning and design aspects that contribute to its functionality and efficiency, here are the key points of designing of PV power plant:

- **Location Selection:** The proposed location for the solar power plant includes functional surfaces within the place that have the potential for solar energy generation. This includes parking lots and building rooftop, which receive ample sunlight throughout the day. The idea is to cover these spaces with photovoltaic modules, thereby generating electricity while providing shaded parking for vehicles.
- **Modular Design:** The project aims to create a modular design for the solar power plant, allowing it to be adaptable for various locations and uses. This design approach not only serves the needs of Energetika Maribor but can also be replicated in similar urban settings across the city.
- **Construction Specifications:** The construction of the solar power plant on parking lots involve a steel structure designed to support the photovoltaic modules. The inclination of the structure is set at 6 degrees, which is optimal for maximizing solar exposure and energy production with provided shade and shelter for cars during the day. Design can be seen on Figure 2.
- **Environmental Considerations:** The project emphasizes the use of renewable energy sources to minimize environmental impact. By integrating solar energy production into the urban landscape, the initiative aims to contribute to energy self-sufficiency while reducing carbon emissions.

The construction and location of the solar power plant are carefully planned to optimize energy production, enhance urban living conditions, and promote sustainability using renewable energy sources. Several possible variants of the solar power plant were studied and analysed. At the same time, installation of bifacial modules in the parking lots were planned, which also utilize the portion of light reflected from cars underneath. According to the specifications, these panels should have a slightly higher efficiency than ordinary ones.

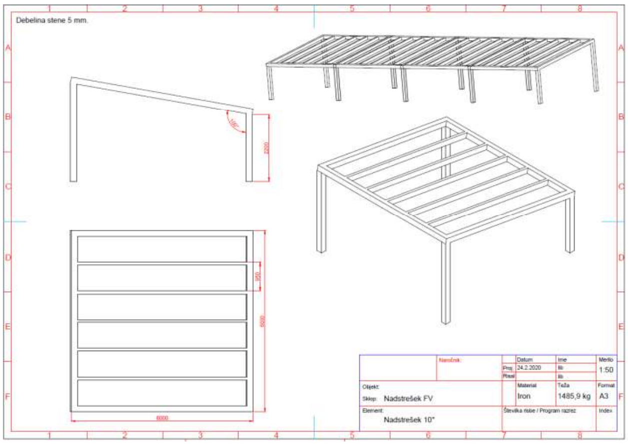

Figure 2: *Modular design for PV on parking lots*

2.1 PV system design using the PV*Sol program

The design of the photovoltaic system using the PV*Sol program involves several critical steps and considerations. The design process begins with the input of relevant data into the PV*Sol program. This includes information about solar radiation, climatic conditions, and specific characteristics of the site where the solar power system will be installed. The software utilizes data from the company Energetika Maribor and ARSO (Slovenian environmental agency) regarding annual solar radiation and climate conditions in the region. The PV*Sol program simulates the expected energy production of the solar panels [7]. For instance, it was found that the annual energy production could reach approximately 189.164 kWh, with a significant portion contributing to the reduction of the company's electricity consumption. PV*Sol allows for a comparative analysis of different PV module types and configurations. This includes evaluating various installation methods and the performance of different photovoltaic (PV) modules, which helps in selecting the most efficient setup for the specific site conditions. The design also incorporates technical specifications for the selected modules and inverters. For example, the use of classic modules and bifacial modules, along with optimizers. Results of the expected energy production of the solar panels on hourly basis were exported into MS excel where we further processed the data.

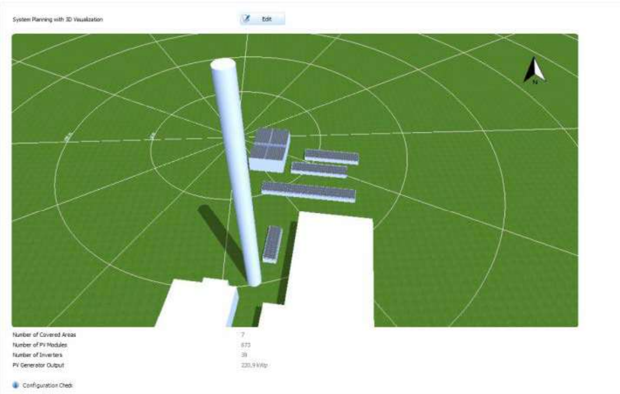

Figure 3: *Planning in PV*Sol*

In conclusion, the technical results of the optimal configuration for the PV system demonstrate a well-thought-out design that combines efficient module selection, strategic installation, advanced optimization technology, and robust inverter systems to achieve high performance and economic benefits. Desing uses high-efficiency PV modules (classis on rooftop and bifacial at parking lots). Each module is paired with Solar Edge power optimizer and utilized with three-phase Solar Edge inverters. Thus, considering the different possible module and layout variants, we looked for a variant where the yield of the solar power plant is as high as possible, while the excess energy produced remains low.

2.2 Economic viability and long -term sustainability

The economic viability of the photovoltaic (PV) project is assessed through various financial metrics and methodologies, as outlined in the provided contexts. Here are the key results:

- **Net Present Value (NPV)**: The NPV is a critical measure used to evaluate the project's economic viability. It is calculated using a discount rate of 7.2% [1]. A positive NPV indicates that the project is expected to generate more cash than the costs incurred, making it a worthwhile investment. The methodology for calculating NPV considers the investment value, project returns over time, and the appropriate discount rate based on business conditions and risks.
- **Internal Rate of Return (IRR)**: The project aims for the highest internal rate of return, which is a key indicator of profitability. The IRR is compared across different configurations to identify the most financially advantageous setup. The optimal configuration is expected to have the shortest payback period and the highest NPV after 25 years of operation, indicating strong economic performance.
- **Financing Structure**: The project financing is structured with 20% of the investment funded through equity and 80% through loans. This mix influences the expected return rates and the overall financial risk associated with the project. The desired return on investment is assessed based on this financing structure, which is crucial for determining the project's feasibility.
- **Electricity Pricing**: The price for electricity was set at 74,06 €/MWh in high tariff and 49,37 €/MWh in lower tariff (as in Table 1). A large share of electricity costs is also represented by the network fee, which is considered in the calculations. As a comparison, we have made calculations of the economic feasibility if all the electricity from the solar power plant were sold on the market. The reference price for electricity was set at 48.04 €/MWh [5].

In conclusion, the economic viability of the PV project is supported by a positive NPV, a favourable IRR, a well-structured financing plan, operational support, and strategic pricing of electricity. These factors collectively indicate that the project is financially sound and likely to yield significant returns over its operational lifespan.

Table 5 Energy tariffs used

	Price without tax [€/kWh]
Energy higher tariff	0.07406
Energy lower tariff	0.04937
Network fee higher tariff	0.01146
Network fee lower tariff	0.00883
Energy Efficiency tax	0.0008
RES and CHP fee	1.84450
Market Operator fee	0.00013
Excise duty	0.00305

For the analysis, the losses due to shading and the consumption of the inverters were taken into account. For each variant, the compensated electricity based on 15-minute measurements of consumption and production was calculated. The 2,5 % efficiency loss due to degradation of the modules is considered. This assumes a linear decline in module efficiency to 80.7% of nominal power in the 25th year of operation [8], [9]. Maintenance costs were estimated as 0.35 % of investment per year. The calculation also considers the costs of replacing inverters after 15 years of operation.

3 RESULTS

The study evaluates six different PV system configurations, each with varying initial investment costs, expected energy yields, and operational efficiencies. The primary cost considerations include:

- **Capital expenditure (CAPEX)**: Initial investment required for purchasing PV panels, inverters, and installation.
- **Operational expenditure (OPEX)**: Recurring maintenance costs estimated at 0.35% of the initial investment per year.

- **Revenue from electricity sales or self-consumption savings**: Modelled over a 25-year period.

The most optimal option was found to be Variant 5, which requires 384 photovoltaic modules. The supporting structure consists of 22 carports, each measuring 6 x 6 meters. The total installed capacity of the entire solar power plant is 169 kWp, with a module surface area of 921.9 m².

According to the PV*Sol simulation, the estimated annual electricity production would be 189,164 kWh. Out of this, 176,762 kWh would be directly offset against the company's annual electricity consumption. This would result in a cost savings of €14,801.47 (excluding VAT) in the first year of operation.

3.1 Key Findings

1. **Net Present Value (NPV)**
   The NPV calculations indicate that self-consumption models outperform pure electricity sales, given the current market conditions and feed-in tariffs.
2. **Internal Rate of Return (IRR)**
   The IRR for self-consumption models is higher than for grid sales, due to better cost savings and energy independence.
3. **Payback Period**
   The shortest payback period is around 9.81 years for option 5, while other configurations take between 10 to 11 years to break even. After this period, the systems generate pure profit, making them a lucrative long-term investment.

Results of comparison of different variants can be seen 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 Challenges and Limitations

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

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

The investment cost analysis demonstrates that self-consumption is the optimal financial strategy for PV system deployment. System configuration 5 emerges as the most profitable, with the highest IRR and shortest payback period. Future research should explore the impact of battery storage and dynamic pricing models to further improve financial performance.

Figure 3 shows that the total return on investment for self-consumption transitions from a negative to a positive value between the 11th and 12th year, while for electricity sales, this occurs around the 13th year of operation. Over their lifetime, all investments would pay off and recover the initial capital. The highest total return after 25 years of operation would be achieved with Configuration 6, amounting to 172,027 €, while Configuration 5 has the shortest payback period of 9.81 years. The diagrams clearly show a drop in revenue in the 15th year, corresponding to the replacement of inverters and the change in electricity purchase prices after the expiration of operational support. While the differences between individual configurations are minor, the method of electricity utilization (self-consumption vs. sales) has a significant impact on 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 favourable option is Configuration 1, which utilizes all available space for the solar power plant but comes with the highest initial cost. With Configuration 5, the net present value of the project after 25 years is 16,641 €.

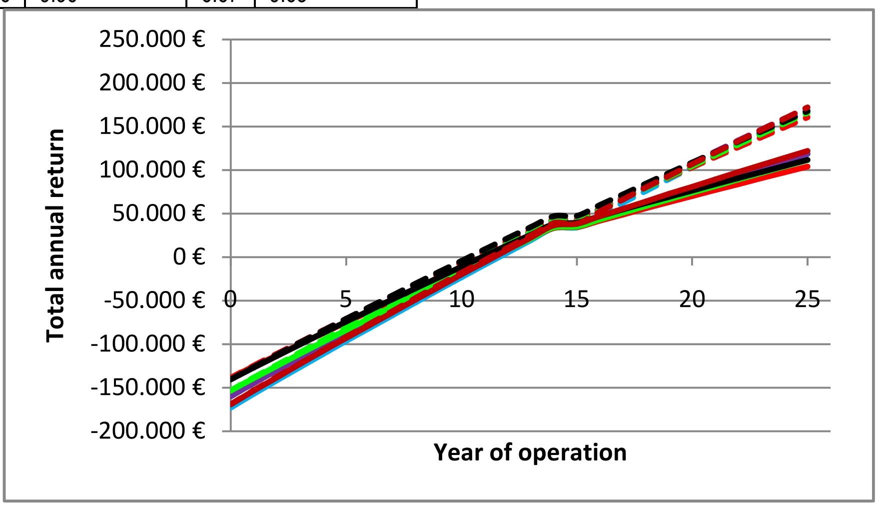

Figure 51: Total annual return of configurations

The figure 4 illustrates the difference between the two approaches to utilizing the solar power plant. It is evident that, in this case, selling electricity is not a viable option, as self-consumption proves to be 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, in the case of 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.

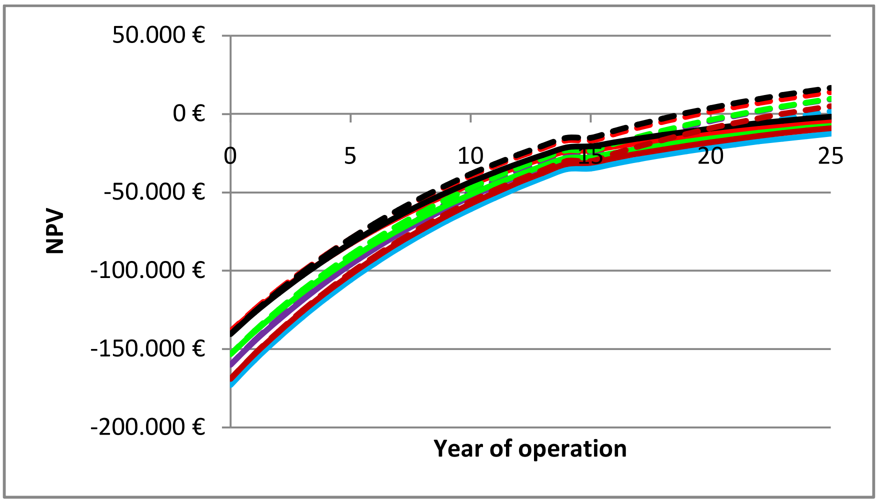

Figure 52: Net present value of configurations

4 CONCLUSIONS

6 different installation variants were analysed with power plants sized between 162 kW and 202 kW. The analysis presented 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 with such a solar power plant would amount to 189,164 kWh, of which 176,762 kWh or 93% could be used for self-supply. The remaining energy is represented by surpluses delivered to the network. On an annual basis, this means a reduction in the cost of electricity of 14,801 € at the existing 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 proves to be the most beneficial model**, as selling electricity to the grid does not yield significant returns under current market conditions.
- **The combination of classic modules on warehouse rooftops and bifacial modules on parking lots** ensures high efficiency and improved energy yield.
- **The optimal tilt angle of 20°** on rooftops further enhances performance of the system.

Additionally, environmental benefits were also considered. The reduction of CO_2 emissions by 91 tons annually underscores the sustainability of the project, aligning with Slovenia's renewable energy objectives.

In conclusion, the study confirms that investing in a solar power plant with a focus on self-consumption is the most economically and environmentally sound decision. Future optimizations could explore the integration of battery storage solutions to enhance energy independence and further improve financial returns.

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 come with certain limitations that must be acknowledged:

- **Sensitivity to Assumptions**: Both NPV and IRR calculations are highly sensitive to the assumptions made regarding discount rates, cash flow projections, and the lifespan of the project. A slight change in these assumptions can lead to significantly different outcomes, which may misrepresent the project's true economic viability.
- **Complexity in Multi-Variant Scenarios**: When comparing multiple investment options or configurations, the complexity increases, making it challenging to derive clear conclusions.

- **Market Fluctuations**: The methods assume stable market conditions, which may not hold true in real-world scenarios. Fluctuations in energy prices, interest rates, and inflation can significantly affect the projected cash flows and, consequently, the viability assessment.

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

- **Renewable Energy Projects**: The methodologies are particularly 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 can be applied 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 utilize these methods to make informed decisions regarding capital allocation, ensuring that resources are directed towards projects with the highest expected returns.

In conclusion, while the methods for assessing economic viability provide essential insights into project feasibility, it is crucial to recognize their limitations and consider a broader range of factors when making investment decisions. Their application in renewable energy and infrastructure development highlights their importance in guiding financial strategies in these sectors.

6 REFERENCES

[1] *The Regulation on support for electricity produced from renewable energy sources and in high-efficiency cogeneration of heat and electricity*. Uradni list RS, št. 74/16 in 74/20.
[2] *The Regulation on Self-Supply with Electricity from Renewable Energy Sources*. Uradni list RS, 2019, št. 17/2019, page 1505.
[3*] The Rules on Technical Requirements for Devices for Self-Supply with Electricity from Renewable Energy Sources*. Uradni list RS, 2016, št. 1/16 in 46/18.
[4] *Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources*.
[5] See https://www.agen-rs.si/poziv2020julij
[6] See: https://www.energetika-mb.si/o-podjetju/o-nas/
[7] Petrijan L. (2017). *Dimenzioniranje omrežno povezane elektrarne v programskem orodju PV*SOL*. Fakulteta za elektrotehniko, računalništvo in informatiko, Univerza v Mariboru.
[8] See: https://www.recgroup.com/en/products/rec-twinpeak-2-mono-en
[9] See: https://www.recgroup.com/en/products/rec-twinpeak-2-mono-en?parent=85&type=product

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