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Techno-Economic Assessment of Solar Photovoltaic System for a Single-Family House in Borrowdale, Harare, Zimbabwe.

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Abstract: Solar photovoltaic (PV) systems are becoming increasingly important for residential energy solutions due to their environmental and economic benefits. This study assesses the techno-economic viability of a grid-connected solar PV system for a single-family house in Borrowdale, Harare, Zimbabwe. Using PVsyst simulation software, the proposed system was designed with 16 PV modules, resulting in a total installed capacity of 5.04 kWp. The performance of the system was evaluated based on energy output, efficiency, and financial returns. The simulation predicted an annual energy production of 8003 kWh, with a performance ratio (PR) of 78.51%. Economic analysis revealed a total installation cost of USD 6.770, an annual operating cost of USD 880.76, and a payback period of 2.8 years. The levelized cost of energy (LCOE) was calculated at USD 0.16 per kWh. Additionally, the system is expected to reduce CO_2 emissions by 158.5 tons over a 30-year lifetime. These results demonstrate that the system is both technically efficient and economically feasible, offering significant environmental benefits.

Keywords: renewable energy, solar photovoltaics, pvsyst, grid-connected, renewable energy, simulation, carbon footprint, economic analysis, sustainability

Citation: To be added by editorial staff during production.

Academic Editor: Wiseman Siriro.

Received: date
Revised: date
Accepted: date
Published: date

1. Introduction

Solar photovoltaic (PV) systems are becoming widely used in both the commercial and residential sectors due to the growing demand for renewable energy. Solar energy, a clean and abundant resource, provides a sustainable alternative to traditional fossil fuels, which contribute to climate change and environmental degradation. Zimbabwe heavily relies on conventional energy sources, such as firewood, coal, thermal power, and hydropower, for meeting its energy needs [6]. In regions with high solar irradiance, such as Zimbabwe, solar PV systems are especially effective at harnessing solar power to meet electricity demands. Nearly all African countries have signed the Paris Agreement and prepared Nationally Determined Contributions, which outline their energy transition agenda [20]. The Zimbabwean Ministry of Energy and Power Development (MEPD) has committed itself to the development and adoption of renewable energy technologies (RETs) in the country [13]. According to ESI Africa Report, the 100MW solar energy project is to be constructed at the Ventersburg Estate in the Zimbabwe capital Harare [23]. At the present moment, Zimbabwe 's electricity generation is mainly through hydroelectric and thermal power stations generating to a national power capacity of 1400MW against a national demand of 2400MW [5].

The objective of this study is to perform a techno-economic assessment of a grid-connected solar PV system for a single-family house located in Borrowdale, Harare City, Zimbabwe. This assessment will determine the feasibility of the system in terms of both technical performance and economic viability. Off-grid solar PV systems are not feasible financially or economically for rural households of Sub-Saharan African countries unless these technologies are subsidized from abroad [4]. Using PVsyst, a modeling tool specialized for solar PV system analysis, this research will investigate important performance metrics, including energy output, system efficiency, and financial returns. The study assesses the system's environmental benefits, including its potential to cut CO_2 emissions. As grid electricity rates rise and solar technology costs decline, domestic solar PV systems are becoming a more attractive option for homeowners seeking long-term cost savings and energy independence. Energy self-sufficiency involves meeting energy needs through renewable sources while reducing dependence on external imports [21]. This report will provide a comprehensive analysis of the proposed system, with recommendations for optimizing performance and maximizing economic returns.

1.1 Literature Review.

Recent studies showcase the feasibility and economic potential of photovoltaic (PV) and photovoltaic-thermal (PV-T) systems across various settings. Patel and Khurana (2023) [15] found that a 20.5 kWp PV-T system saved 2,900 kg of LPG annually for MSMEs in Gujarat with a five-year payback. Poudyal et al. (2021) [16] demonstrated a 3 kWp PV system in Kathmandu could meet household demands, save 10.33 tons of CO_2, and had an 8.6-year payback. Husain et al. (2021) [8] reported an 8.4-year ROI on a 380 kWp PV system in Malaysia, while Dellosa et al. (2024) [7] highlighted a floating PV system in Lake Mainit, Philippines, offering a 4.8-year payback. Aksoy and Ispir (2023) [2] compared PV cell types, finding mono-Si most viable with a 5.8-year payback. Srinivasan et al. (2024) [18] noted a 530 kWp offshore FPV in Abu Dhabi with a 9.5-year payback. At Universiti Teknologi MARA, an 8 MW PV system reduced 149,195 tons of CO_2 with an 8-year payback (Yusri et al., 2023) [14]. Ijeoma et al. (2023) [9] found PV systems in Nigerian supermarkets viable with a four-year payback and 581.7 tons CO_2 savings annually. Tarigan et al. (2015) [19] found Indonesian residential PV feasible with tariffs, reducing the payback to 6.5 years. Aktas and Ozenc (2024) [3] reported a 17.4-year payback for a 416 kWp system in Turkey, and Sam (2024) [17] showed a 10 kW PV system in Nigeria met 26.9% of household needs at a 261 Naira/kWh cost. These studies highlight PV's environmental benefits and economic viability, especially with supportive policies.

2. Materials and Methods.

2.1 Simulation and optimisation software.

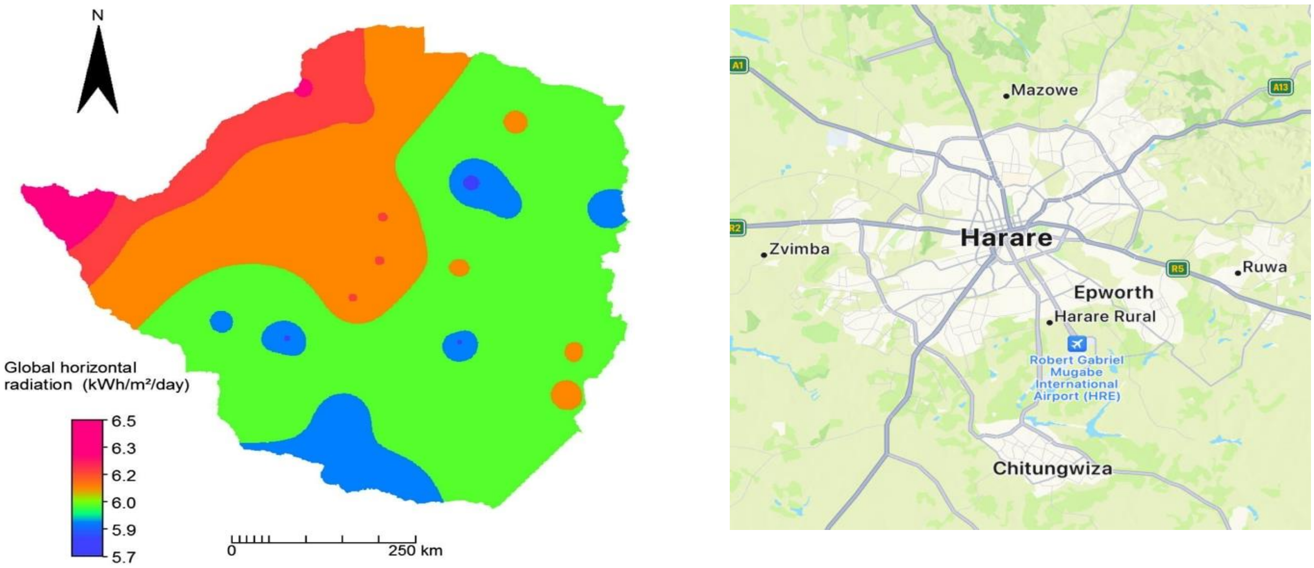
The simulation aimed at designing a 5.04 kWp PV system. Both technical and economic studies were performed using PVsyst software. PVsyst is a simulation software that was first designed in Geneva and helps in calculating the working and operations of PV system [12]. PVsyst simulator is the most well-known software among researchers and PV experts [1]. PVsyst allows users to input a wide range of data and customize their simulations to their needs [11]. The software includes a complete contextual Help menu that defines the techniques and models used, giving an accessible guide for project development. PVsyst can import weather data and personal data from a variety of sources. The software deals exclusively with grid-connected, stand-alone, pumping, and DC-grid (public transportation) PV systems (Irwan et al., 2015) [10] (Poudyal,2021) [16]. However, one of the challenges that designers are now facing is the design of bifacial PV modules installed on single-axis trackers. Reports indicate that PVsyst is working to integrate a more comprehensive analysis of such systems.

2.2 Site and System Design.

The system is designed for a single-family house in Borrowdale, Harare, Zimbabwe, a region with high solar insolation. **Figure 2** illustrates the solar path, showing the sun's position in relation to the tilt and azimuth angles. Zimbabwe has abundant solar energy available throughout the year. **Figure 1(a)** depicts the hemispherical global horizontal map for Zimbabwe. Global solar irradiance for the country varies from 5.7 to 6.5 kWh/m2/day [22]. **Figure A1** displays monthly weather data for Borrowdale, Harare, with year-to-year global horizontal irradiation recorded at 5.7%.

Table 1. The geographical coordinates of the proposed project.

Parameter	Values
Latitude:	-17,76° S
Longitude	31,11° E
Altitude (m above sea level)	1524 m
Albedo (reflectivity of the ground surface)	0,20
Time Zone	2,0



(a) **(b)**

Figure 1. Geographical locations: **(a)** Shows a global solar radiation map; **(b)** The interactive map of Harare City.

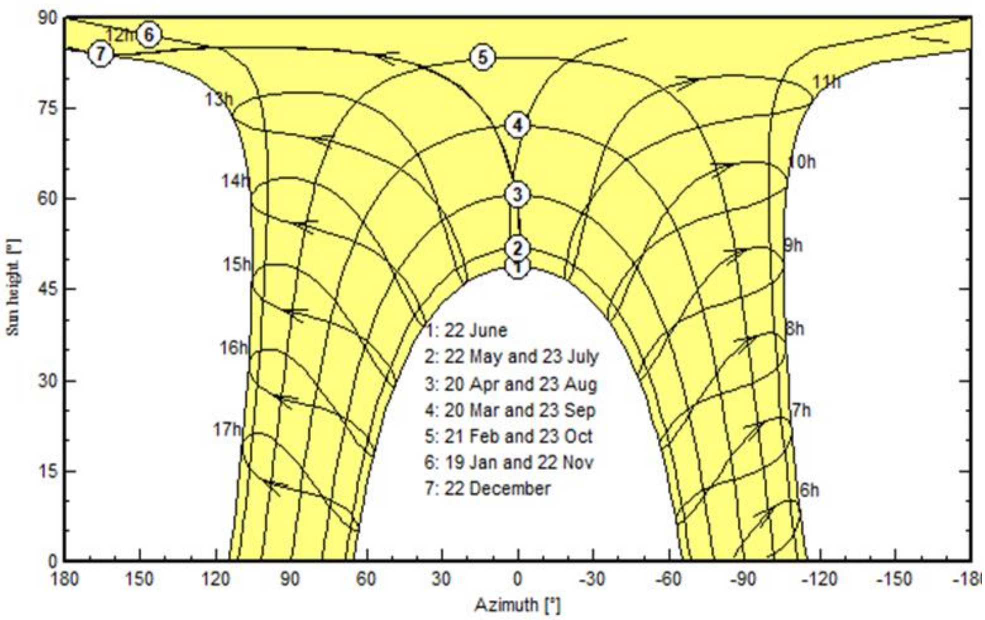


Figure 2. Solar path of Borrowdale, Harare.

2.3 System Specifications.

The PV system consists of 16 PV modules (model: PM318B01_315) connected in a grid-tied configuration. The total installed capacity of the system is **5.04 kWp**. The system is oriented at a tilt angle of 22° and an azimuth of 0° (facing true north) as shown in **Figure A2** and **Figure 3**, with no shading or obstruction. The main components of the system include:

- PV modules: 16 units (total capacity: 5.04 kWp)
- Inverter: SUN2000-4.95KTL-JPL1 (total power: 4.95 kW)

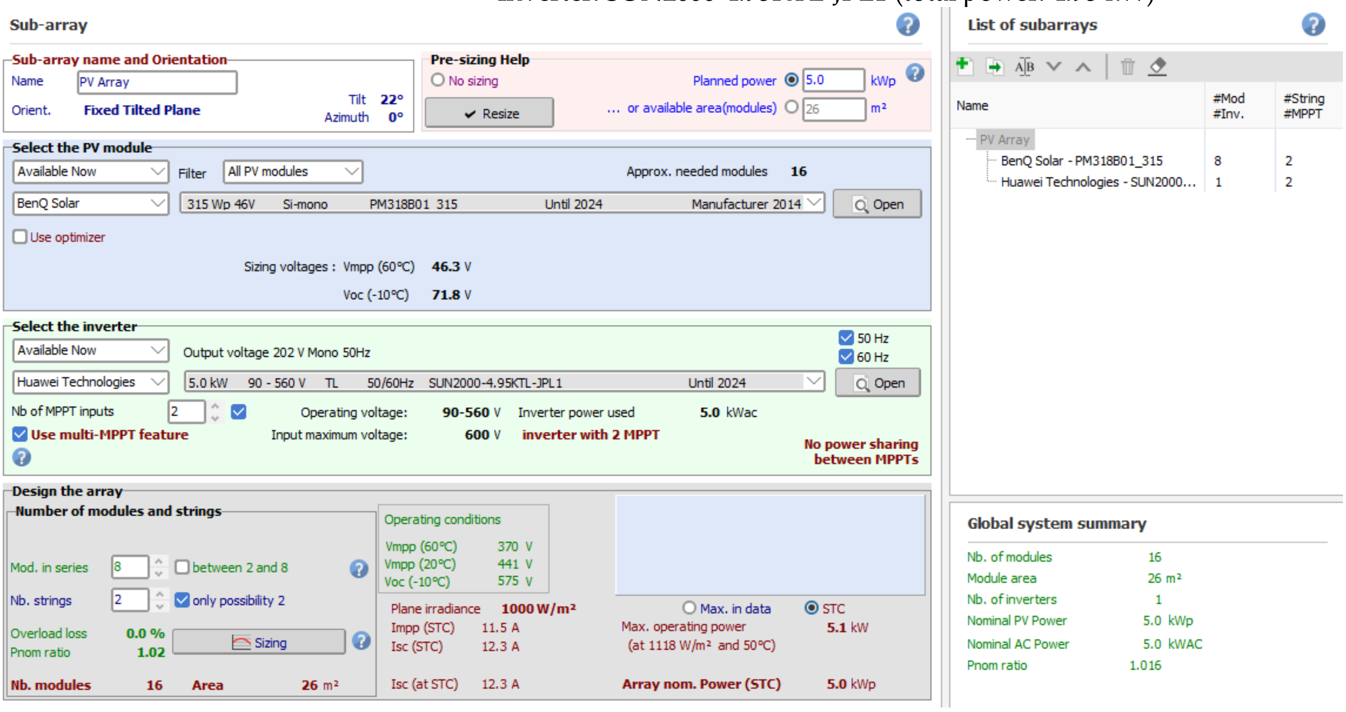


Figure 3. System design overview.

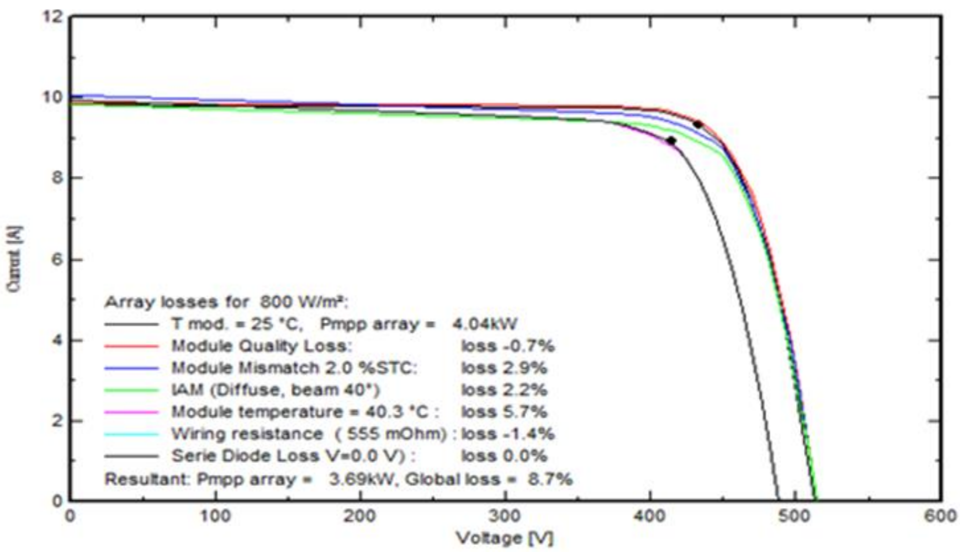


Figure 4. System's detailed losses.

The system is designed to undergo multiple losses, including a -0.7% module quality loss, a -2.9% module mismatch loss, a -2.2% incidence angle loss, a -4.0% temperature loss, and a -1.4% wire resistance loss, resulting in a total global loss of 8.7%. These losses reduce the array's power output from 4.44 kW to 3.69 kW under standard test conditions of 800 W/m² irradiance and 20°C ambient temperature.

2.4 PVsyst Simulation.

The simulation was conducted using PVsyst version 7.4.8. The software was used to model energy production and system efficiency. The following steps were performed:

1. **Weather Data:** Solar radiation and meteorological data for the Borrowdale area in Harare City were collected from Meteonorm 8.1, which gives synthetic data from 1991 to 2005.
2. **System Configuration**: The PV system configuration, including module and inverter details, was entered into the PVsyst software.
3. **Energy Simulation**: The energy yield, system losses, and efficiency under typical operating conditions were computed using PVsyst.
4. **Economic Evaluation.** The system's energy output data was used to assess the overall installation costs, yearly operating costs, and anticipated financial returns.
5. **Environmental Impact:** The reduction in CO_2 emissions was determined using the PV system's electricity generated and the grid's carbon emission factor (660 gCO_2/kWh).

2.5 Economic Data.

The total installation cost was estimated at USD 6,770, which includes PV modules, inverters, installation labor, and other components. The annual operational expenditures, largely for maintenance, were estimated at USD 880.76. These figures were used to compute the system's payback period and cost of produced energy (LCOE).

3. Results.

Energy production, system efficiency, economic performance (financial analysis), and environmental effects are among the outcomes of the simulation that are shown in the results section.

3.1 Energy Production and System Efficiency.

The solar PV system demonstrates strong energy production and efficiency metrics, producing an estimated 8,003.02 kWh annually, which covers a significant portion of the household's energy requirements. Its specific production stands at 1,588 kWh per kWp per year, indicating that the system is highly effective in converting solar energy into electricity relative to its installed capacity. Furthermore, the system's Performance Ratio (PR) of 78.51% demonstrates its capacity to perform well under local environmental conditions by efficiently converting available solar irradiation into usable electricity. This PR value suggests that the system minimizes energy losses and maximizing output, which are key factors in its financial and operational viability.

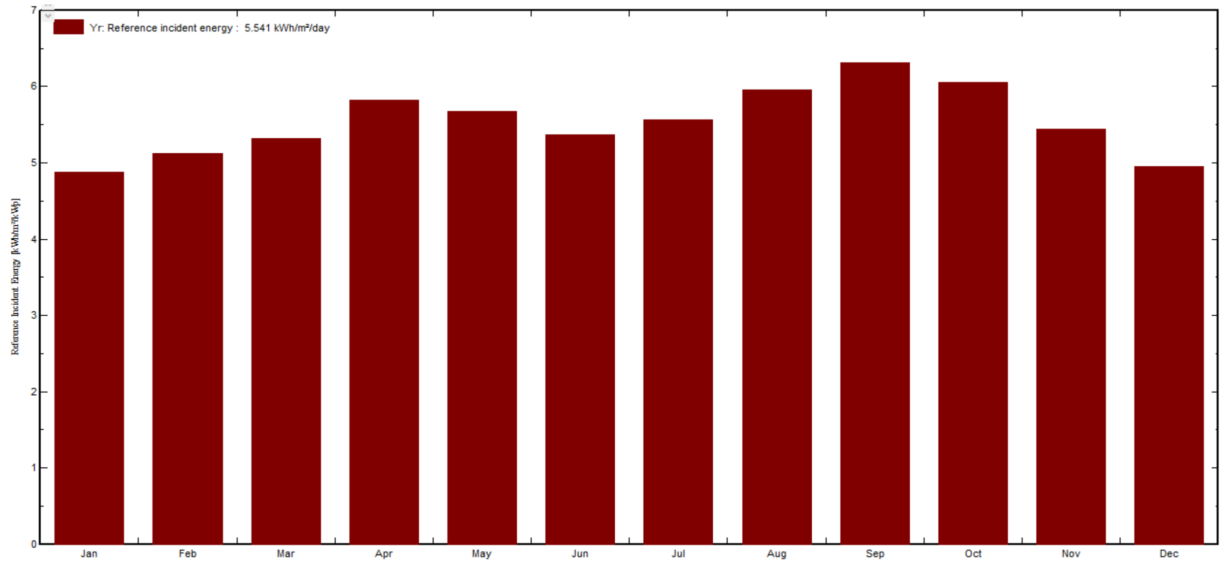


Figure 5. Reference incident energy in collector plane.

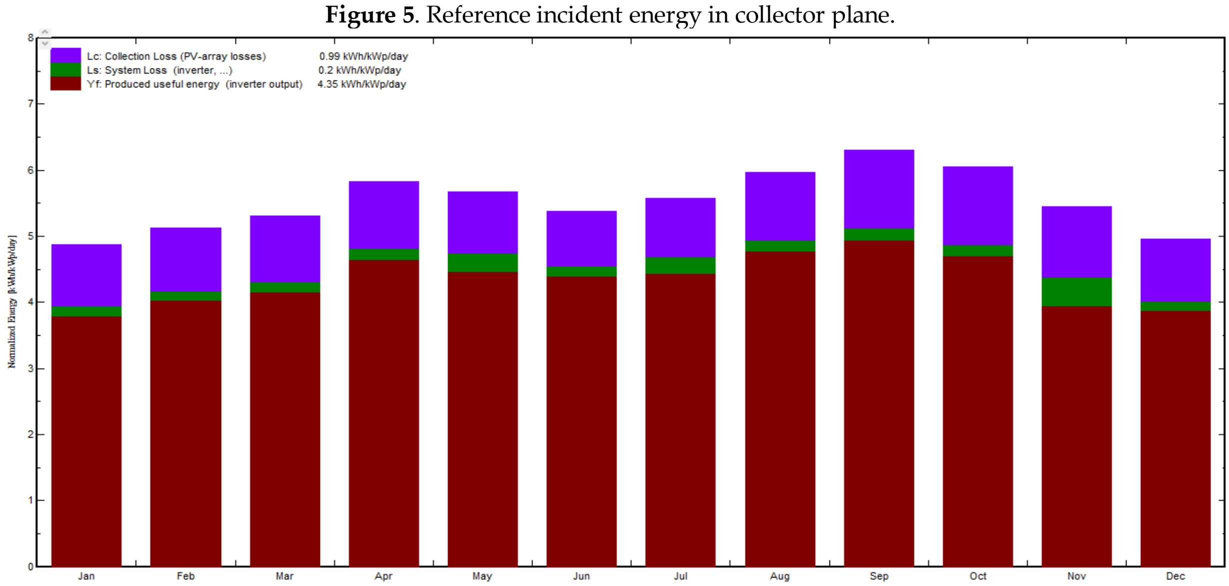


Figure 6. Normalized productions (per installed kWp)- nominal power 5.04 kWp.

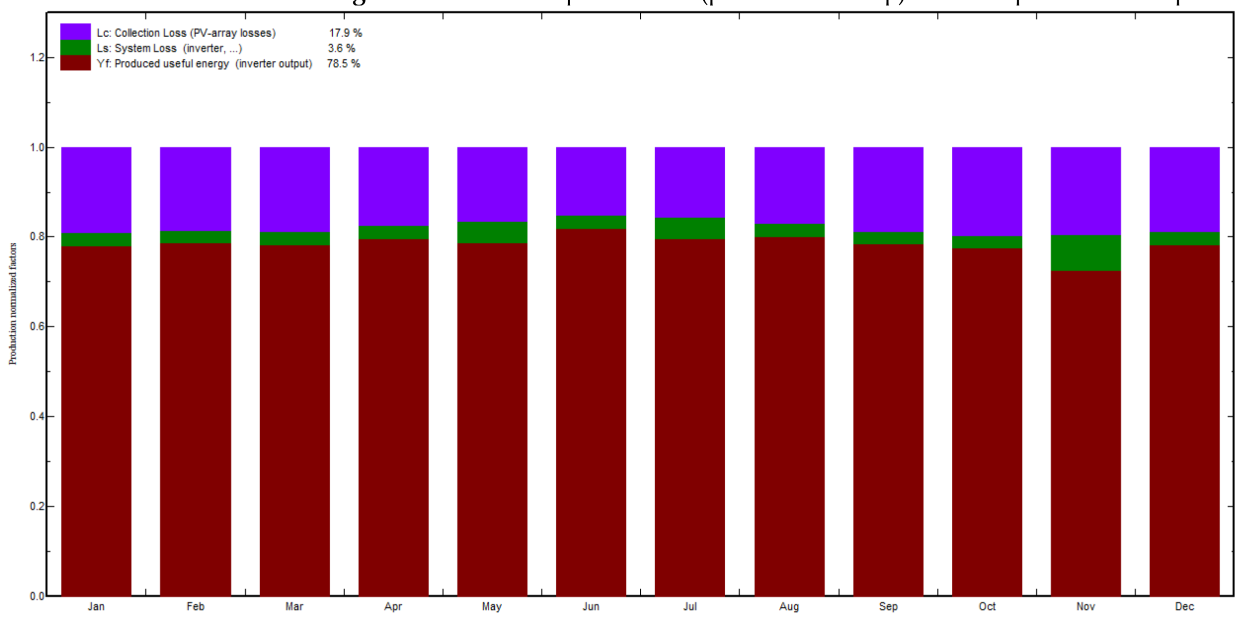


Figure 7. Normalized production and loss factors (Nominal Power 5.04 kWp).

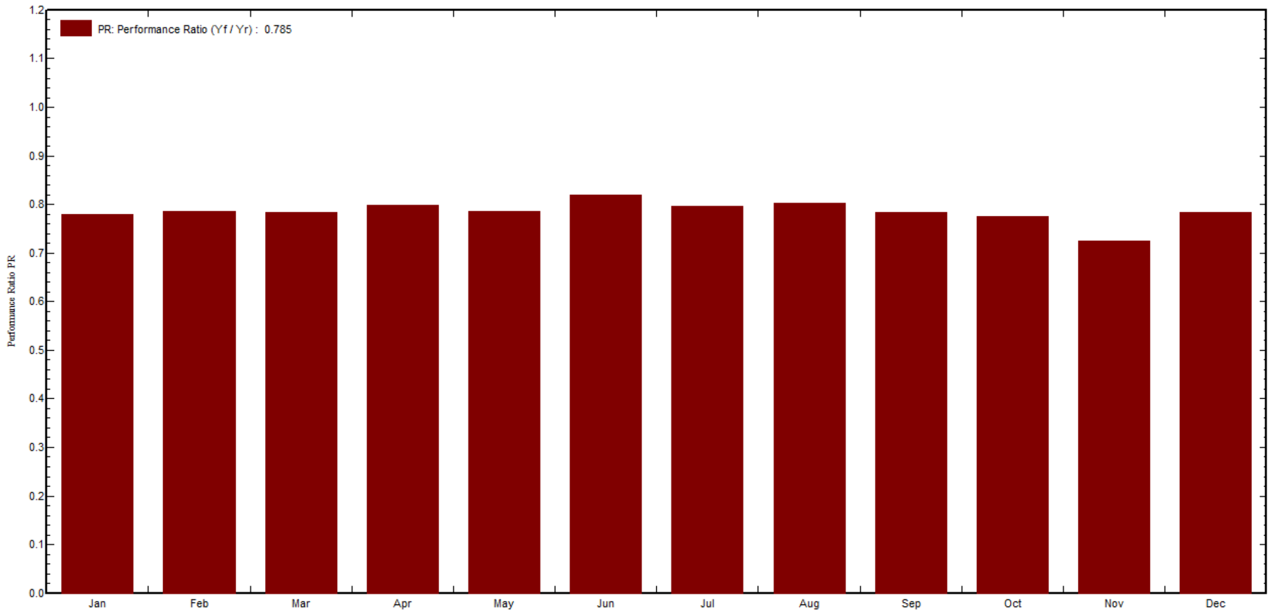


Figure 8. Performance Ratio (PR)

Table 2. Balances and performances of the proposed grid-connected PV system in Borrowdale, Harare, Zimbabwe.

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	168.5	75.43	21.36	151.0	142.6	616.1	593.7	0.780
February	150.7	80.06	21.10	143.5	135.9	589.5	568.6	0.786
March	160.5	63.19	20.71	164.7	157.2	674.6	650.4	0.783
April	156.1	62.42	18.65	174.8	167.4	727.4	702.3	0.797
May	145.2	52.02	16.90	176.0	168.6	741.9	697.9	0.787
June	128.5	46.18	14.62	161.2	154.3	688.9	665.3	0.819
July	138.2	40.94	14.50	172.6	165.4	733.7	692.9	0.796
Auguust	159.2	57.14	17.03	184.7	177.2	772.5	746.2	0.801
September	176.7	57.57	20.00	189.2	181.2	774.4	748.2	0.785
October	191.1	69.05	22.26	187.8	179.1	760.3	734.3	0.776
November	178.3	78.22	21.90	163.3	154.8	663.6	597.1	0.726
December	173.2	88.15	21.46	153.7	144.9	628.8	606.1	0.783
Year	1926.3	770.37	19.20	2022.4	1928.8	8371.6	8003.0	0.785

The **Figure 5** shows that reference incident energy on the collector plane peaks in summer (August-September) and dips in winter, with an annual average of 5.541 kWh/m²/day. **Figure 6** shows monthly energy output normalized per kWp, with seasonal variation where summer months yield higher output. **Figure 7** breaks down losses: PV-array (purple) at 17.9%, inverter/system (green) at 3.6%, and the usable energy output (red) contributing 78.5% on average. **Figure 5** indicates a steady performance ratio (PR) of around 0.785, suggesting the system consistently converts about 78.5% of potential energy into usable output year-round. **Table 2** shows monthly solar energy and performance metrics for a photovoltaic (PV) system, including global horizontal and diffuse irradiance (GlobHor and DiffHor), ambient temperature (T_Amb), global incident irradiance on the inclined plane (GlobInc), and effective irradiance (GlobEff). The key outputs are the energy produced by the array (EArray) and the energy sent to the grid (E_Grid), as well as the performance ratio (PR). With an annual PR of 0.785 and a total grid energy output of 8003 kWh, annual totals show overall system performance.

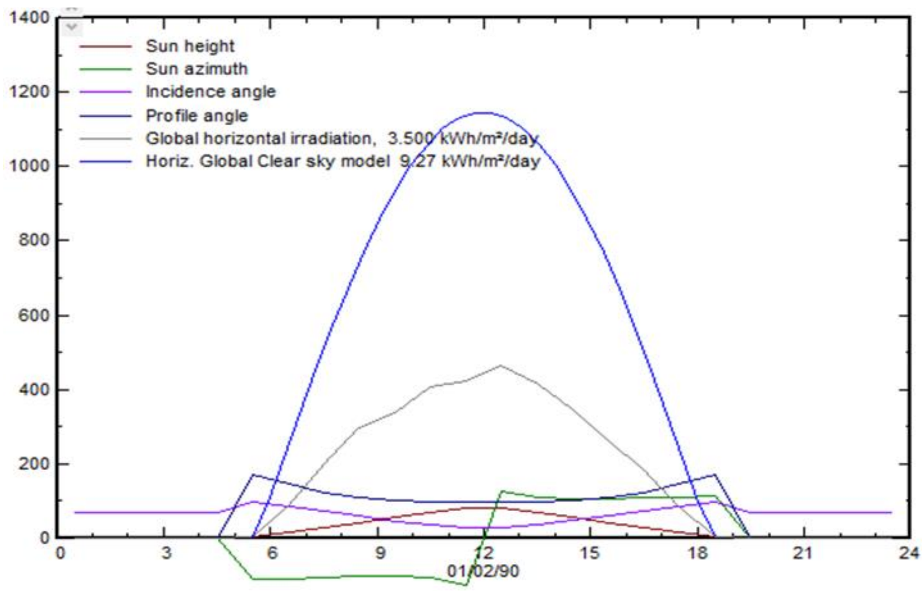
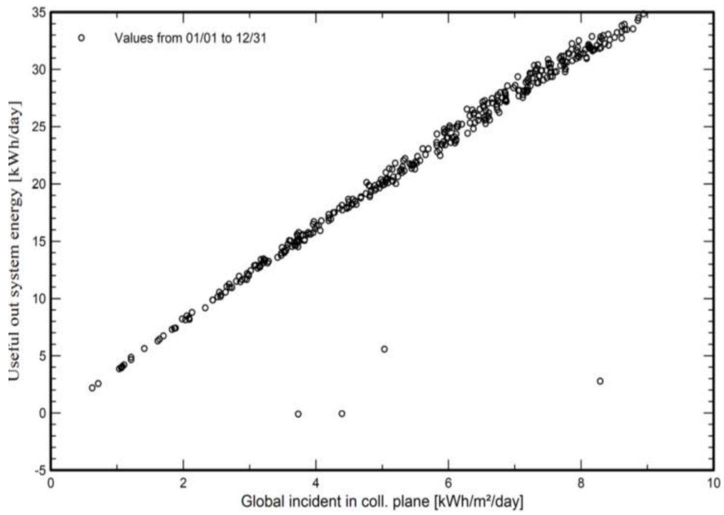
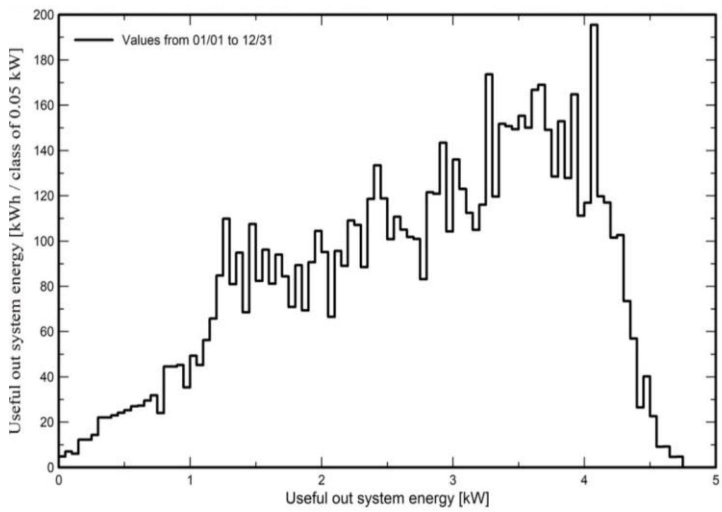


Figure 9. Simulation Variant (Hourly graphs).

The graph in **Figure 9** shows the hourly variation of several solar-related parameters over a single day. Sun height, azimuth, incidence angle, profile angle, global horizontal irradiation, and the horizontal clear sky model are among the key factors shown. The sun height (blue line) peaks around midday, reflecting the highest position of the sun, which corresponds to a rise in global horizontal irradiation (black line) indicating maximum solar exposure. Other variables like incidence and profile angles vary with the sun's movement, peaking at different times. The clear sky model suggests theoretical solar irradiance levels, providing a comparison with actual irradiance levels throughout the day. **Figure A5** shows the graphs related to the array.



(a)



(b)

Figure 10. Daily input/output and system output power distribution: (**a**) Shows a strong linear correlation between global incident irradiance on the collector plane and daily useful output energy for a PV system; (**b**) Displays a histogram of useful output energy, with most values clustered between 2 and 4 kW, indicating common operating output levels throughout the year.

3.2 Losses and Degradation.

Figure 11 presents the simulation results, highlighting various losses that affect the system's overall energy production. Key factors include soiling losses at 2.0%, thermal losses at 5.86%, and a module degradation of 3.86% after 10 years. Inverter efficiency losses are calculated at 3.10%, contributing to the overall reduction in available energy. Despite these losses, the system successfully delivers 8003 kWh of energy to the grid, showcasing the PV system's effectiveness even after factoring in operational inefficiencies. **Figure 12** shows a single-line diagram from a PVsyst simulation for a solar photovoltaic system, indicating a configuration where 8 PV modules (PM318B01_315) are connected to an inverter (5 kVA, SUN2000-4.95KTL-JPL1) with two maximum power point trackers (MPPT).

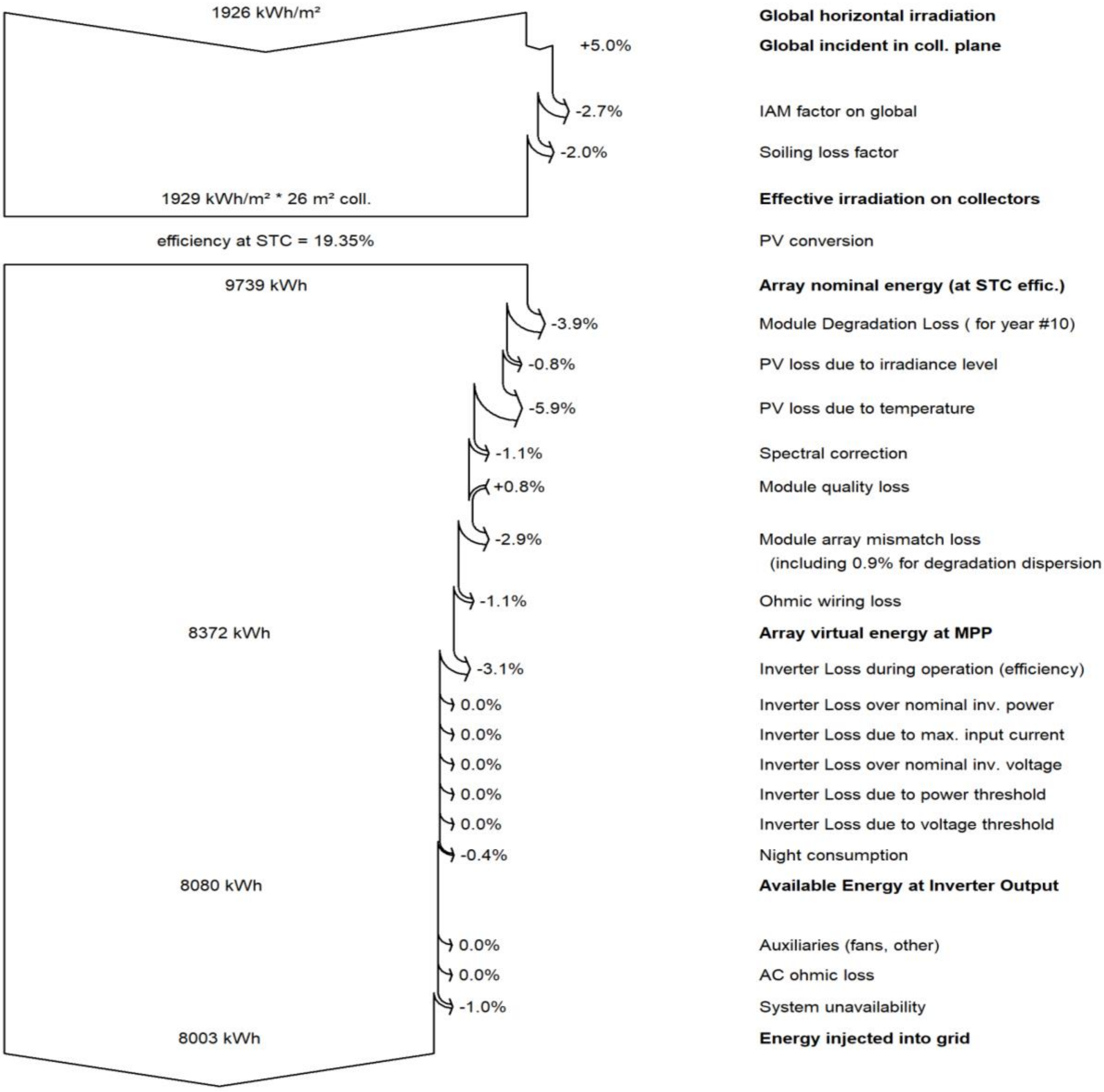


Figure 11. Loss diagram.

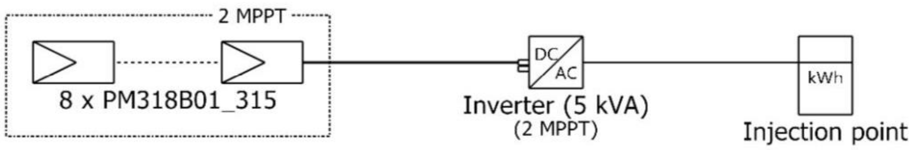


Figure 12. Single-line diagram.

3.3 Financial Analysis.

The goal of the financial analysis is to determine the project's financial feasibility from the project developer's perspective, aiding in making a sound investment decision. **Table 3** presents a detailed breakdown, with all costs listed in U.S. dollars (USD). The system cost includes the costs of PV modules, inverters, mounting hardware, and other components such as cables, mounting systems, charge controllers, and utility meters, as well as the balance of system and connectivity costs.

Table 3. Cost details of the PV system components.

Description		**Quantity**	**Unit price (USD)**	**Total**
PV modules	PM318B01_315	16	200	3,200
	Support for modules	16	100	1,600
Inverter		1		1,000
Other components		6	220	220
Studies and analysis		4	250	250
Installation		3	500	500
Total				**6,770**

Table 3 shows that the total installation cost is USD 6,770, with an annual operating cost of USD 880.76. The cost of energy produced (LCOE) is $0.16 per kWh. After a rigorous analysis, it was established that the project is financially viable, with a project lifetime of 30 years (beginning in 2024), financing cost of USD 6,770, and a payback period of 2.8 years. The net present value (NPV) is USD 33 427.08, and the return on investment (ROI) is estimated at 44.08%, as shown in **Figure A4**. The financial parameters in **Figure 13** indicate a 20-year project starting in 2025, with a total investment of $6,770 USD. The project is funded by 73.41% own cash, 7.39% subsidies, and the remainder through loans, including 8.86% Loan 1 (fixed annuity), 7.39% Loan 2 (fixed amortization), and an interest-only bullet loan. The loans have a 1% interest rate plus inflation and a discount rate. Depreciation is spread out over 20 years using a straight-line method, especially for PV modules and inverters. Income tax and dividends are levied at 1% every year.

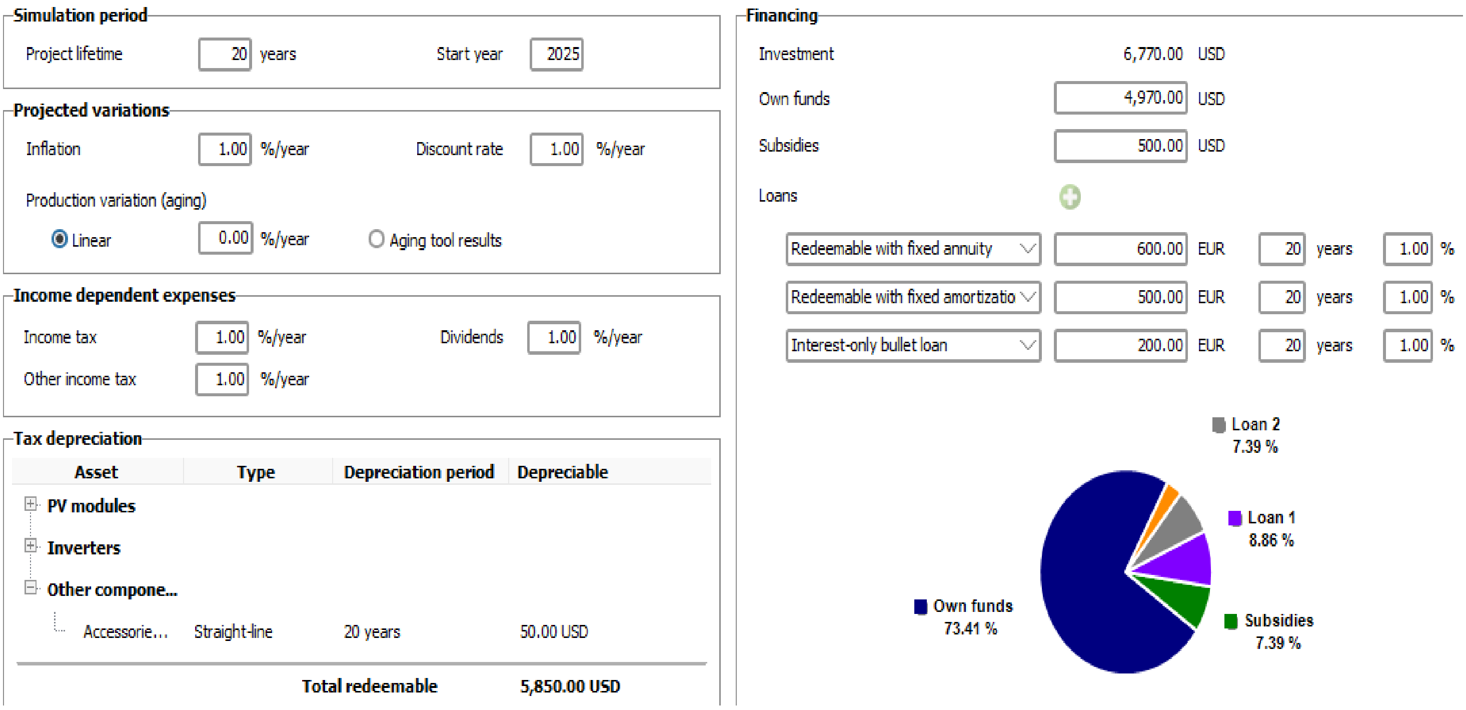


Figure 13. Financial Parameters.

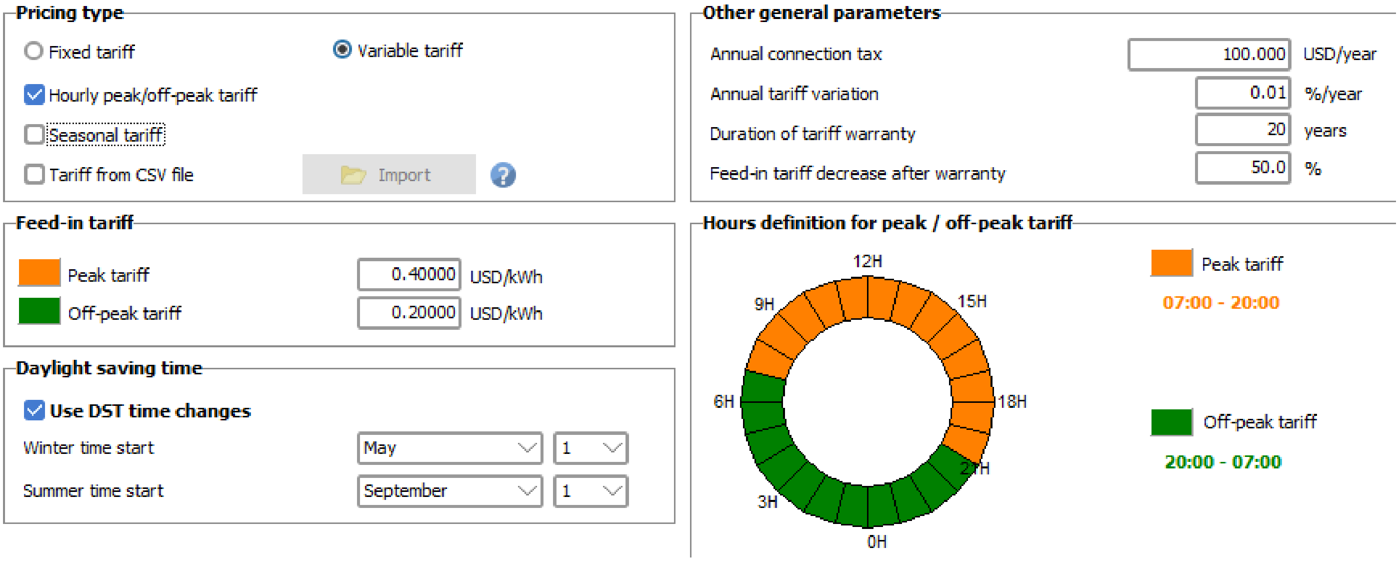


Figure 14. Electricity sales.

Figure 14 shows that electricity sales follow a variable tariff, with peak hours (07:00 to 20:00) charged at 0.40000 USD/kWh and off-peak hours (20:00 to 07:00) charged at 0.20000 USD/kWh. The annual connection tax is $100 USD, and the annual tariff variation is 0.01% throughout a 20-year tariff warranty period. Following the warranty, the feed-in tariff is reduced by 50%. Daylight saving time adjustments are implemented, with changes occurring in May and September. **Figure 15** shows a 20-year financial analysis. After an initial investment of $4,970, steady electricity sales begin in *year 1*. After an initial expenditure of $4,970, consistent electricity sales begin in year one. Operating expenditure and loan payments fall over time, while after-tax profit rises annually. By *year 3*, cumulative profit is positive, reaching $33,427 by year 20, when the debt is entirely amortized. The project demonstrates great profitability and financial sustainability in the long term.

Year	Electricity sale	Own funds	Loan principal	Loan interest	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Divid. 1.00%	Cumul. profit	% amorti.
0	0	4,970	0	0	0	0	0	0	0	0	-4,970	0.0%
1	3,114	0	52	13	800	293	2,008	40	2,208	22	-2,784	35.7%
2	3,114	0	53	12	808	293	2,001	40	2,201	22	-626	70.9%
3	3,114	0	53	12	816	293	1,994	40	2,193	22	1,503	105.7%
4	3,114	0	53	11	824	293	1,986	40	2,186	22	3,603	140.1%
5	3,115	0	53	11	832	293	1,979	40	2,178	22	5,676	174.0%
6	3,115	0	54	10	841	293	1,971	39	2,171	22	7,721	207.5%
7	3,115	0	54	10	849	293	1,964	39	2,163	22	9,739	240.5%
8	3,116	0	54	9	858	293	1,956	39	2,155	22	11,729	273.1%
9	3,116	0	55	9	866	293	1,949	39	2,148	21	13,693	305.3%
10	3,116	0	55	8	875	293	1,941	39	2,140	21	15,630	337.1%
11	3,117	0	55	8	884	293	1,933	39	2,132	21	17,540	368.4%
12	3,117	0	55	7	893	293	1,925	38	2,124	21	19,425	399.4%
13	3,117	0	56	7	901	293	1,917	38	2,115	21	21,284	429.9%
14	3,118	0	56	6	910	293	1,909	38	2,107	21	23,117	460.0%
15	3,118	0	56	5	920	293	1,901	38	2,099	21	24,924	489.8%
16	3,118	0	57	5	929	293	1,892	38	2,090	21	26,707	519.1%
17	3,119	0	57	4	938	293	1,884	38	2,082	21	28,465	548.0%
18	3,119	0	57	4	947	293	1,875	38	2,073	21	30,198	576.6%
19	3,119	0	58	3	957	293	1,867	37	2,064	21	31,906	604.8%
20	3,120	0	258	3	966	293	1,858	37	1,855	19	33,427	633.1%

Figure 15. Detailed economic results (USD).

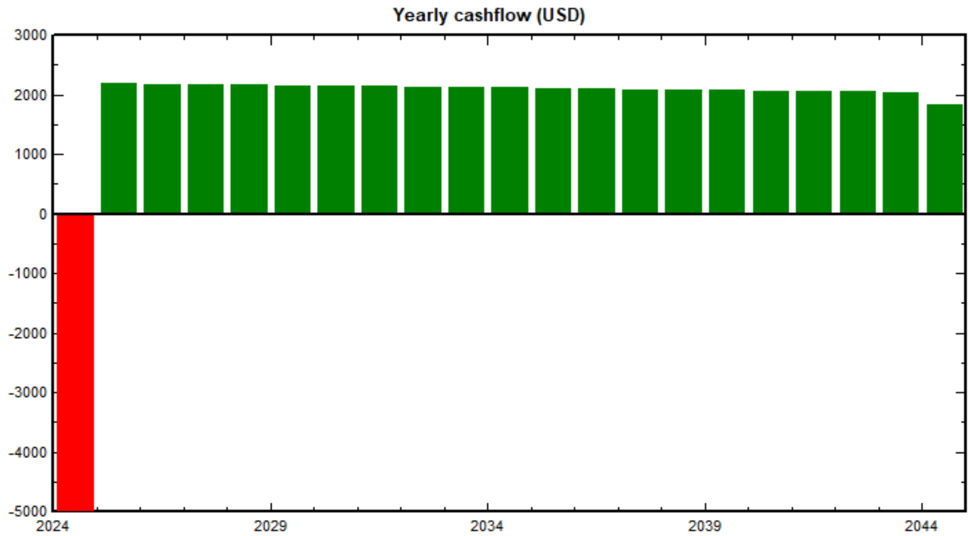


Figure 16. Yearly net profit in USD during the lifetime of a 5.04 kWp PV system.

Figure 17 shows that the project begins generating profit after the third year, as the cumulative cash flow turns positive. The cash flow was calculated by comparing (1) the energy tariff rate (USD/kWh) generated by the solar PV system to (2) the initial installation expenses and (3) the annual operating costs. The difference between revenue from energy production and total costs was computed as (1) - (2 + 3), yielding the cash flow values shown in the graph. The analysis includes a 30-year project lifecycle. In the first 2.8 years, the cumulative cash flow remains negative because of the high initial installation costs. However, once the breakeven point is reached, the cash flow turns positive, and the system starts generating growing profits each year. By the end of the project's lifespan in 2044, the accumulated profits are significant, highlighting the long-term financial sustainability of the solar PV system.

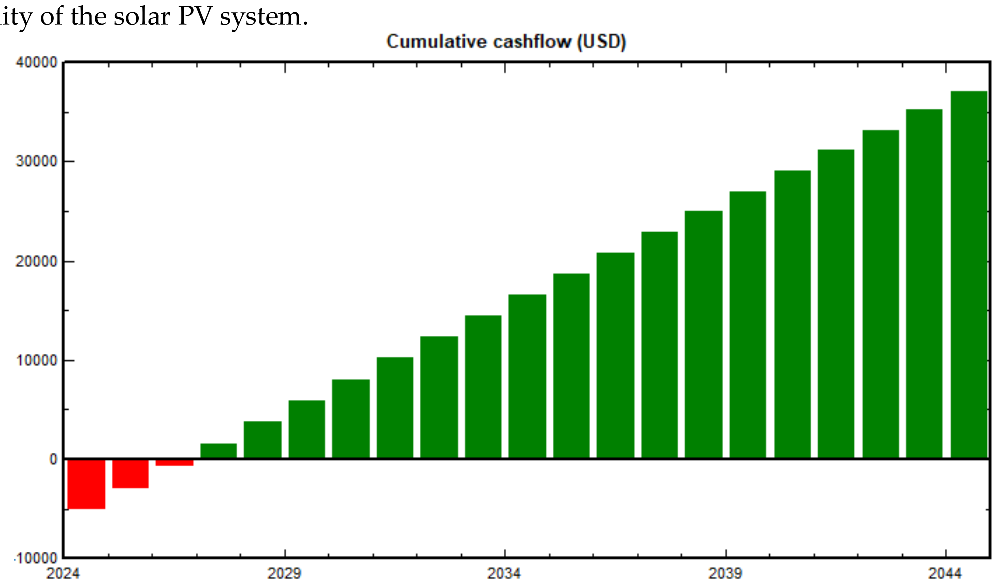


Figure 17. Cumulative cashflow in USD during the lifetime of a 5.04 kWp PV system.

Figure 18 illustrates the income allocation, showing that the project is highly profitable, with 67.48% of the revenue retained as net profit. Maintenance expenses make up a significant 28.26%, while smaller portions are dedicated to loan repayments (2.34%), income tax (1.24%), and dividends (0.68%). This breakdown reflects a financially successful project focused on operational sustainability, minimal debt, and limited investor payouts, demonstrating strong profitability and efficient cost control throughout its lifespan.

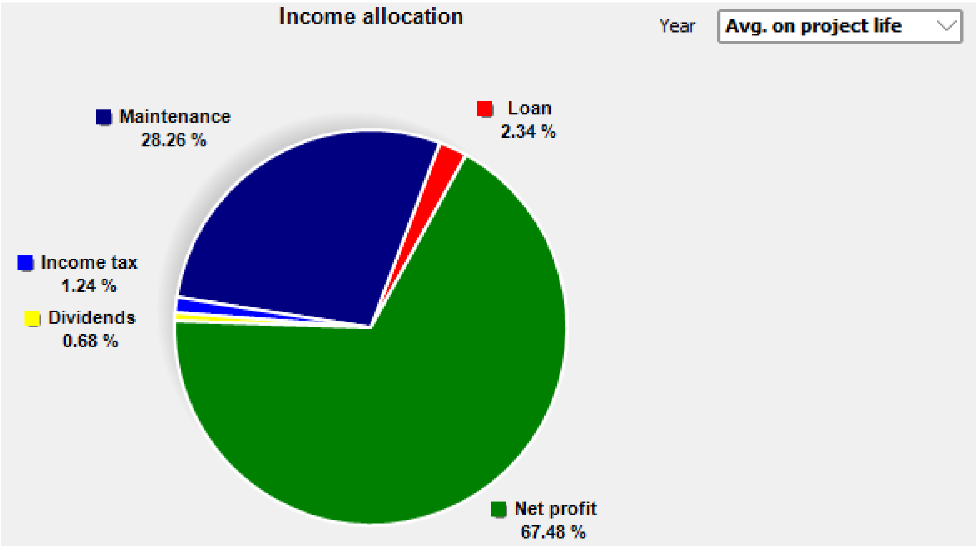


Figure 18. Income allocation (Average on project life).

3.4 Environmental Impact.

Over its 30-year lifespan, the system is projected to cut CO_2 emissions by 158.5 tons, with an average annual energy production of 8003 kWh and a grid emission factor of 660 gCO_2/kWh. This significant reduction contributes directly to mitigating climate change by displacing fossil-fuel-based electricity generation. **Figure 19** illustrates the cumulative CO_2 emissions savings over time, demonstrating the increasing environmental benefit as the system operates throughout its lifetime.

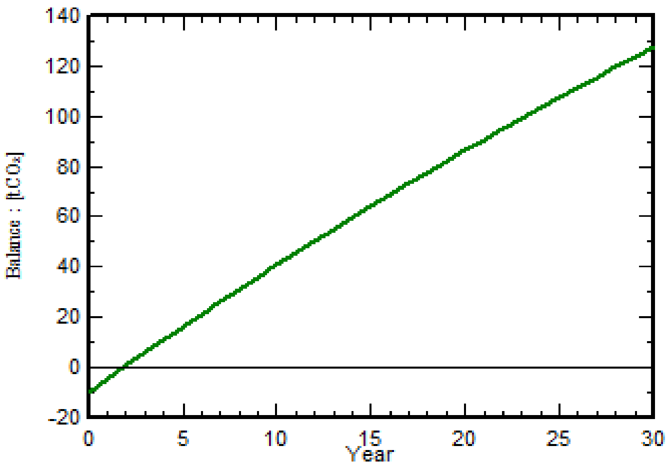


Figure 19. Saved CO_2 Emissions vs Time.

Table 4: Summary of Simulation Results.

Parameter	**Value**
Total Energy Production	8003 kWh/year
Performance Ratio (PR)	78.51%
Installation Cost	USD 6,770
Payback Period	2.8 years
LCOE	USD 0.16/kWh

4. Discussion.

The simulation results indicate that the proposed solar PV system for a single-family house in Borrowdale, Harare, is technically viable and economically attractive. **Figure A4** shows the system overview generated by PVsyst software. The system's performance ratio of 78.51% aligns well with industry standards for similar grid-connected systems, confirming the adequacy of the local solar irradiance for efficient energy generation. With a payback period of 2.8 years, the system can quickly offset installation costs through energy savings. This payback period is notably shorter than the timeframes observed in recent studies, such as the 8.6 years for a household PV system in Kathmandu (Poudyal et al., 2021) [16] or the 17.4 years for a commercial setup in Turkey (Aktas and Ozenc, 2024 [3]), underscoring the system's economic viability in Harare.

The environmental impact is another key advantage, with the system projected to save 158.5 tons of CO_2 over its 30-year lifetime, aligning with global efforts to mitigate climate change. Comparable studies show similar benefits, such as the CO_2 savings reported by Ijeoma et al. (2023) [9] for Nigerian supermarkets and Yusri et al. (2023) [14] at Universiti Teknologi MARA. These findings highlight the PV system's potential to reduce the household's carbon footprint effectively. Future research could further explore the integration of battery storage to enhance energy reliability and reduce grid dependence. Furthermore, examining the impacts of shading and module orientation may help improve system performance, potentially leading to even better efficiency and cost-effectiveness.

4.1 Recommendations.

To optimize the performance and benefits of the solar PV system and maximize its economic savings, environmental impact, and overall performance for residential users, the following recommendations are made:

1. **Regular Maintenance**: Implementing a routine maintenance schedule to keep the PV modules clean and ensure the inverter operates efficiently is highly recommended.
2. **Real-Time Monitoring**: Establishing a monitoring system to track energy production and system performance will allow for quick identification and resolution of any issues that may arise.
3. **Battery Storage**: Adding battery storage solutions is suggested to enhance energy availability during peak usage times and further reduce dependence on the grid.
4. **Shading and Orientation Analysis**: Conducting a comprehensive shading analysis during the design phase will help ensure maximum solar exposure and optimize energy production.
5. **Community Engagement**: Promoting awareness about the benefits of solar PV systems within the local community is recommended to encourage broader adoption of renewable energy technologies.

5. Conclusions.

The key conclusions from this study show that the solar PV system is expected to generate *8,003 kWh* of energy annually, achieving a performance ratio (PR) of *78.51%*, which indicates efficient operation under local solar conditions. With a total installation cost of *USD 6,770,* the system is projected to offset costs through electricity bill savings within a payback period of just *2.8 years*. Additionally, the levelized cost of energy (LCOE) at *USD 0.16* per kWh makes it a competitive option compared to conventional grid electricity. Over a *30-year* lifespan, the system also contributes to environmental sustainability by reducing carbon dioxide (CO_2) emissions by *158.5* tons. These key conclusions emphasize the ability of solar energy to offer a sustainable and affordable solution for residential energy requirements, fostering energy independence and contributing to climate change mitigation efforts.

Supplementary Materials: Not applicable.

Author Contributions: The article was solely written, read, revised, and published by Wiseman Siriro.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: I would like to express my sincere gratitude to Professor A. Gebremedhin and Norwegian University of Science and Technology (NTNU), Gjøvik, for providing guidance and support.

Conflicts of Interest: The author declares no conflict of interest.

Appendix A.

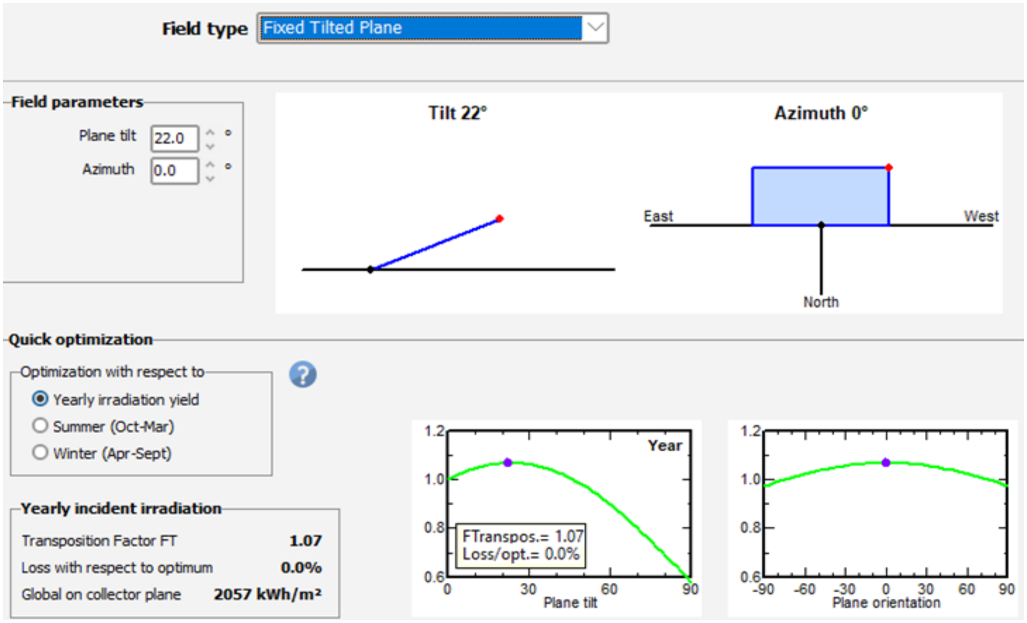
Site **Borrowdale, Harare (Zimbabwe)**

Data source Borrowdale, Harare_MN81.SIT -- Meteonorm 8.1 (1991-2005)

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/mth	kWh/m²/mth	°C	m/s	[-]	%
January	168.5	75.4	21.4	3.00	2.801	73.0
February	150.7	80.1	21.1	3.01	2.796	73.3
March	160.5	63.2	20.7	2.89	2.700	72.7
April	156.1	62.4	18.7	2.90	2.446	67.7
May	145.2	52.0	16.9	2.70	2.319	58.9
June	128.5	46.2	14.6	2.90	2.297	57.4
July	138.2	40.9	14.5	3.10	2.390	53.3
August	159.2	57.1	17.0	3.39	2.651	45.8
September	176.7	57.6	20.0	4.00	3.204	41.6
October	191.1	69.0	22.3	4.00	3.149	44.8
November	178.3	78.2	21.9	3.70	3.035	57.7
December	173.2	88.2	21.5	3.20	2.902	70.6
Year	**1926.2**	**770.3**	**19.2**	**3.2**	**2.724**	**59.7**

Global horizontal irradiation year-to-year variability 5.7%

Appendix B.



Appendix C.

Compatibility between System defintions

Full system orientation — **tilt/azim = 22° / 0°**

1 sub-array — PNom = 5.0 kWp, modules area = 26 m²

No shading field defined in the 3D scene !

System parameters

Sub-array #1 — **PV Array**

PV modules: — 2 strings of 8 modules in series, 16 total

Pnom = 315 Wp — PNom array = 5.0 kWp, area = 26 m²

Inverters (4.95 kWac) — 2 MPPT inputs, Total 5 kWac, Pnom ratio = 1.02

3D shadings parameter

No shading scene defined

Appendix D.

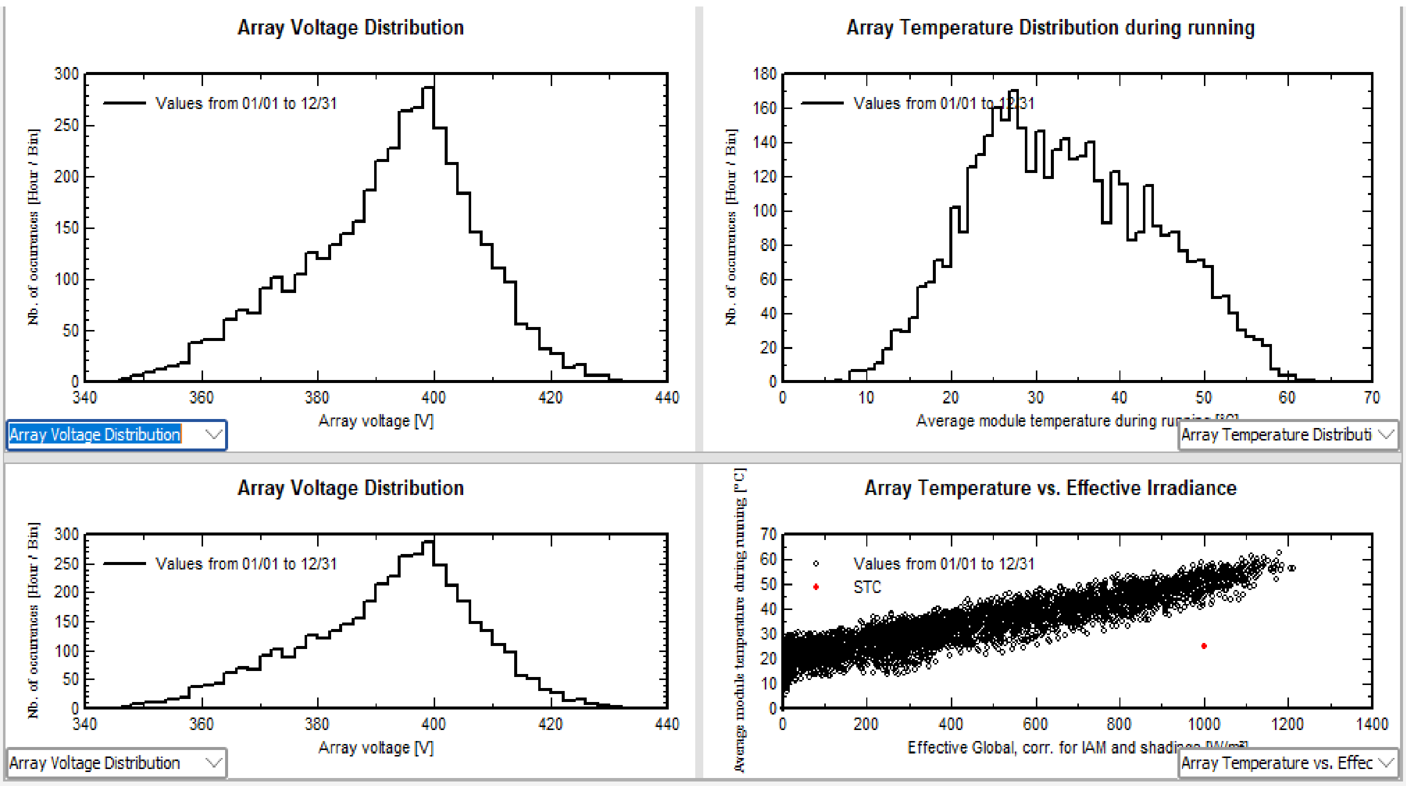
Installation costs (CAPEX)	
Total installation cost	6,770.00 USD
Depreciable asset	5,850.00 USD

Financing	
Own funds	4,970.00 USD
Subsidies	500.00 USD
Loans	1,300.00 USD
Total	**6,770.00 USD**

Expenses	
Operating costs(OPEX)	880.76 USD/year
Loan annuities	65.25 USD/year
Total	**953.63 USD/year**
LCOE	**0.1649 USD/kWh**

Return on investment	
Net present value (NPV)	**33,427.08 USD**
Internal rate of return (IRR)	**44.06 %**
Payback period	**2.8 years**
Return on investment (ROI)	**533.1 %**

Appendix E.



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Version 7.4.8

PVsyst - Simulation report

Grid-Connected System

Project: Techno-Economic Assessment - Solar Photovoltaic Project

Variant: New Simulation Variant

No 3D scene defined, No shadings

System power: 5.04 kWp

Borrowdale, Harare - Zimbabwe

Client

SR Family Holdings

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Harare

Zimbabwe

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Project summary

Geographical Site
Borrowdale, Harare
Zimbabwe

Situation

Latitude	-17.76 °S
Longitude	31.11 °E
Altitude	1524 m
Time zone	UTC+2

Project settings

Albedo	0.20

Weather data
Borrowdale, Harare
Meteonorm 8.1 (1991-2005) - Synthetic

System summary

Grid-Connected System
Simulation for year no 10

No 3D scene defined, No shadings

PV Field Orientation
Fixed plane

Tilt/Azimuth	22 / 0 °

Near Shadings
No Shadings

User's needs
Unlimited load (grid)

System information

PV Array		**Inverters**	
Nb. of modules	16 units	Nb. of units	1 unit
Pnom total	5.04 kWp	Pnom total	4960 W
		Pnom ratio	1.016

Results summary

Produced Energy	8003.05 kWh/year	Specific production	1588 kWh/kWp/year	Perf. Ratio PR	78.52 %

Table of contents

General parameters

Grid-Connected System | **No 3D scene defined, No shadings**

PV Field Orientation

Orientation
Fixed plane
Tilt/Azimuth 22 / 0 °

Sheds configuration
No 3D scene defined

Models used
Transposition Perez
Diffuse Perez, Meteonorm
Circumsolar separate

Horizon
Free Horizon

Near Shadings
No Shadings

User's needs
Unlimited load (grid)

PV Array Characteristics

PV module

Manufacturer	Generic
Model	PM318B01_315
(Custom parameters definition)	
Unit Nom. Power	315 Wp
Number of PV modules	16 units
Nominal (STC)	5.04 kWp
Modules	2 string x 8 In series
At operating cond. (50°C)	
Pmpp	4567 Wp
U mpp	388 V
I mpp	12 A

Inverter

Manufacturer	Generic
Model	SUN2000-4.95KTL-JPL1
(Custom parameters definition)	
Unit Nom. Power	4.95 kWac
Number of inverters	2 * MPPT 50% 1 unit
Total power	5.0 kWac
Operating voltage	90-560 V
Max. power (=>40°C)	5.21 kWac
Pnom ratio (DC:AC)	1.02
No power sharing between MPPTs	

Total PV power

Nominal (STC)	5 kWp
Total	16 modules
Module area	26.1 m²

Total inverter power

Total power	5 kWac
Number of inverters	1 unit
Pnom ratio	1.02

Array losses

Array Soiling Losses
Loss Fraction 2.0 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 555 mΩ
Loss Fraction 1.5 % at STC

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Module average degradation
Year no 10
Loss factor 0.4 %/year
Mismatch due to degradation
Imp RMS dispersion 0.4 %/year
Vmp RMS dispersion 0.4 %/year

IAM loss factor
ASHRAE Param.: IAM = 1 - bo (1/cosi -1)
bo Param. 0.05

Spectral correction
FirstSolar model
Precipitable water estimated from relative humidity

Coefficient Set	C0	C1	C2	C3	C4	C5
Monocrystalline Si	0.85914	-0.02088	-0.0058853	0.12029	0.026814	-0.001781

System losses

Unavailability of the system

Time fraction	1.0 %
	3.7 days,
	3 periods

Auxiliaries loss

AC wiring losses

Inv. output line up to injection point

Inverter voltage	202 Vac mono
Loss Fraction	0.00 % at STC

Inverter: SUN2000-4.95KTL-JPL1

Wire section (1 Inv.)	Copper 1 x 2 x 4 mm²
Wires length	0 m

Main results

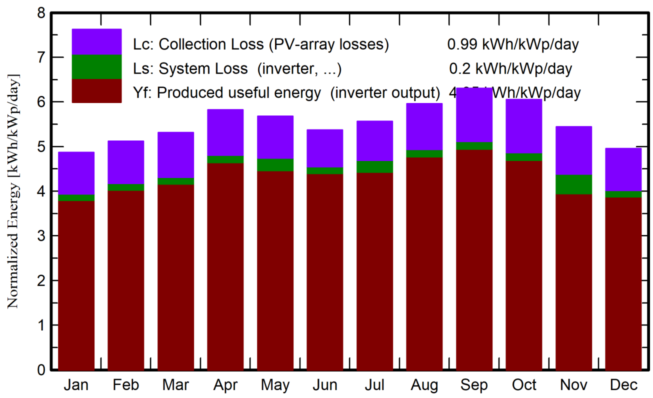
System Production

Produced Energy	8003.05 kWh/year	Specific production	1588 kWh/kWp/year
		Perf. Ratio PR	78.52 %

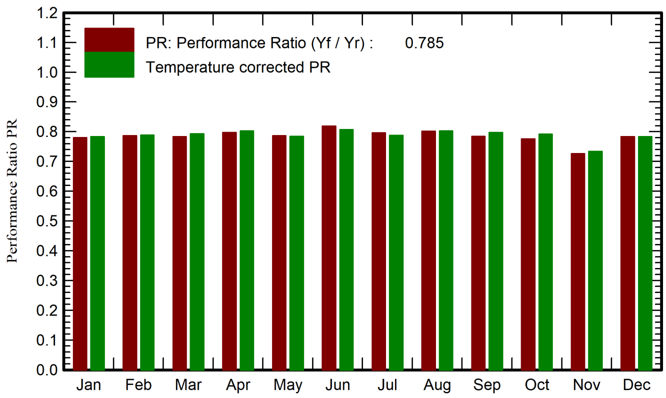
Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	6,770.00 USD	Annuities	65.25 USD/yr	Energy cost	0.16 USD/kWh
Specific	1.34 USD/Wp	Run. costs	880.76 USD/yr		
		Payback period	2.8 years		

Normalized productions (per installed kWp)



Performance Ratio PR



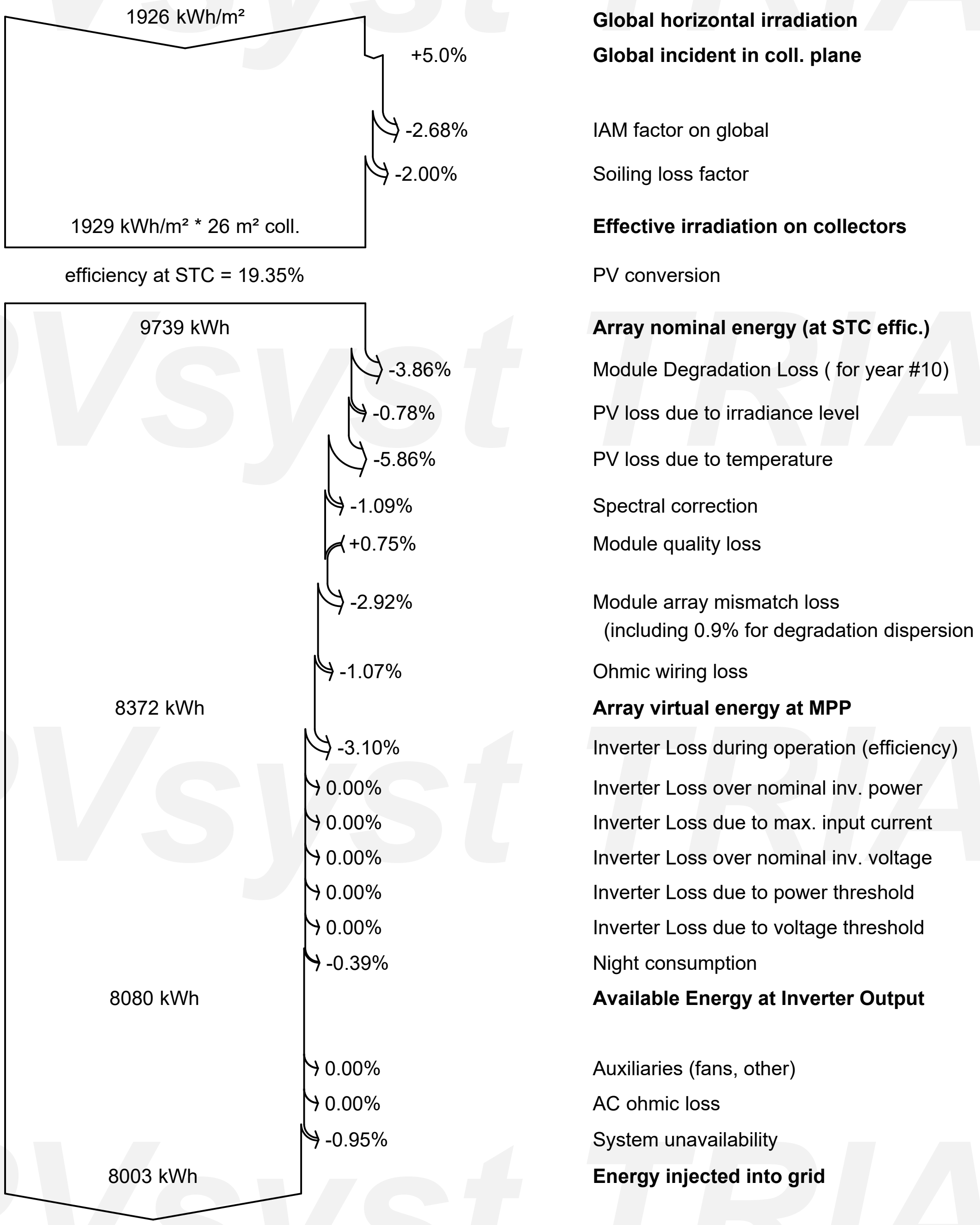
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio	PRTemp ratio
January	168.5	75.43	21.36	151.0	142.6	616.1	593.7	0.780	0.783
February	150.7	80.06	21.10	143.5	135.9	589.5	568.6	0.786	0.788
March	160.5	63.19	20.71	164.7	157.2	674.6	650.4	0.783	0.793
April	156.1	62.42	18.65	174.8	167.4	727.4	702.3	0.797	0.802
May	145.2	52.02	16.90	176.0	168.6	741.9	697.9	0.787	0.784
June	128.5	46.18	14.62	161.2	154.3	688.9	665.3	0.819	0.807
July	138.2	40.94	14.50	172.6	165.4	733.7	692.9	0.796	0.788
August	159.2	57.14	17.03	184.7	177.2	772.4	746.2	0.801	0.802
September	176.7	57.57	20.00	189.2	181.2	774.4	748.2	0.785	0.797
October	191.1	69.05	22.26	187.8	179.1	760.3	734.3	0.776	0.791
November	178.3	78.22	21.90	163.3	154.8	663.6	597.1	0.726	0.734
December	173.2	88.15	21.46	153.7	144.9	628.8	606.1	0.783	0.783
Year	1926.3	770.38	19.20	2022.4	1928.8	8371.6	8003.0	0.785	0.788

Legends

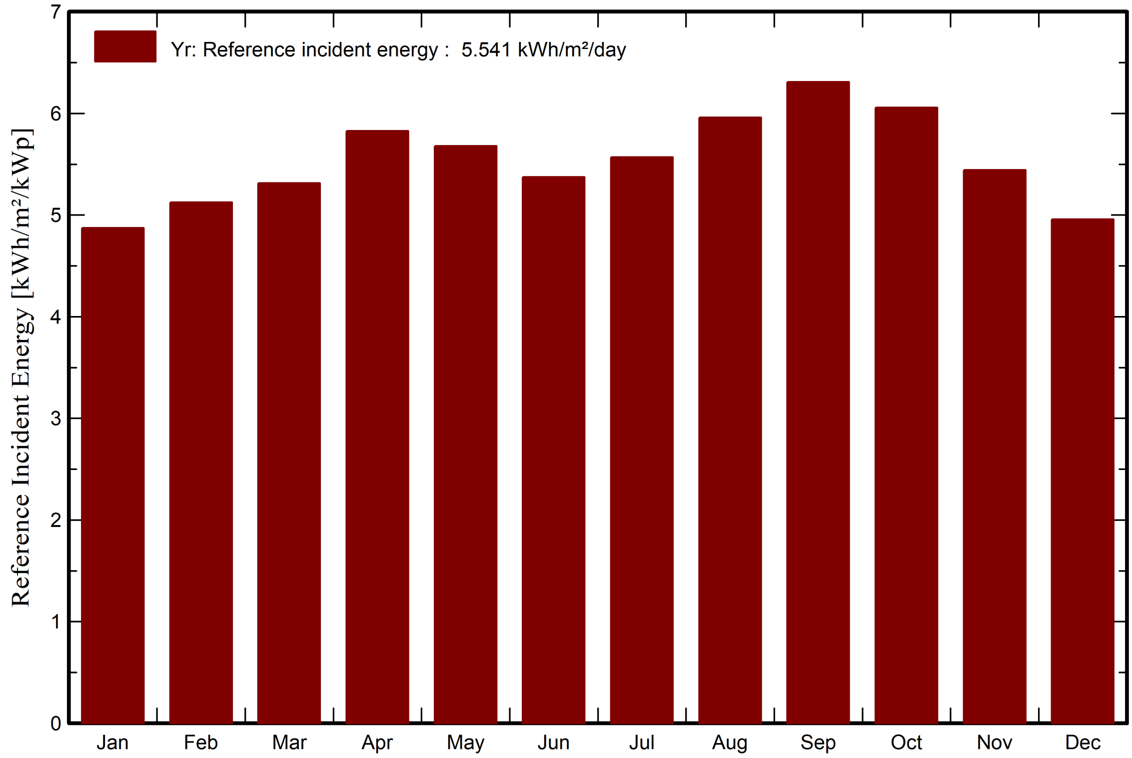
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane	PRTemp	Weather corrected PR
GlobEff	Effective Global, corr. for IAM and shadings		

Loss diagram

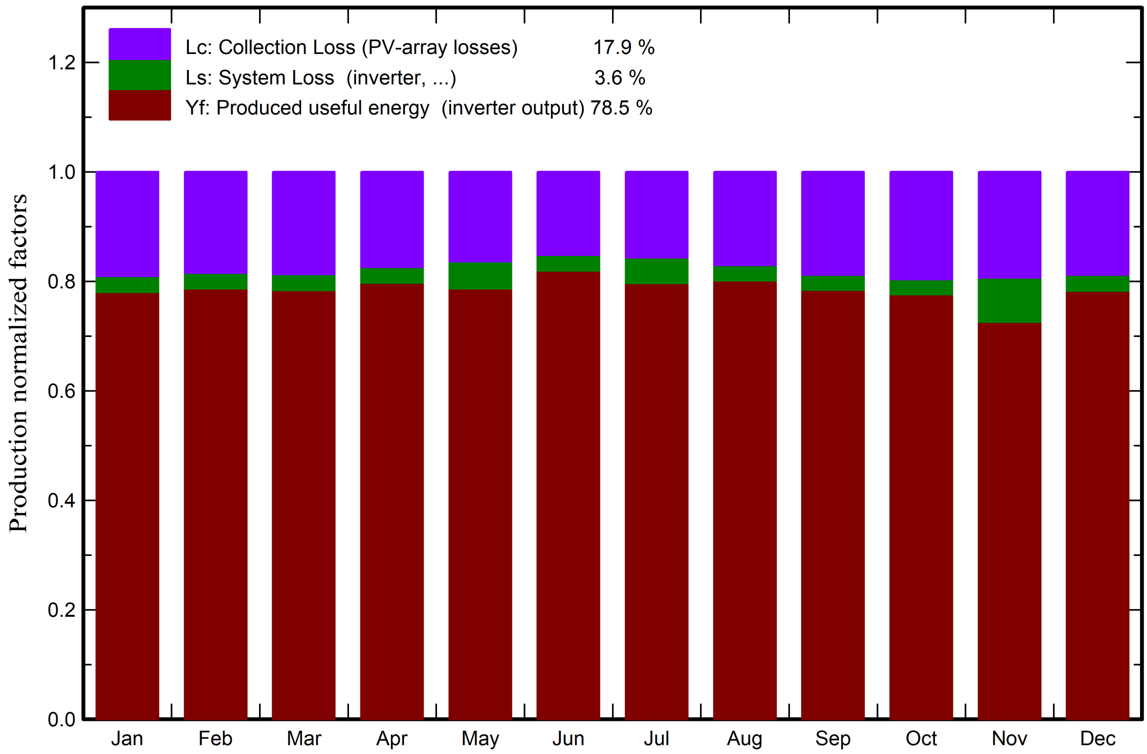


Predef. graphs

Reference Incident Energy in Collector Plane

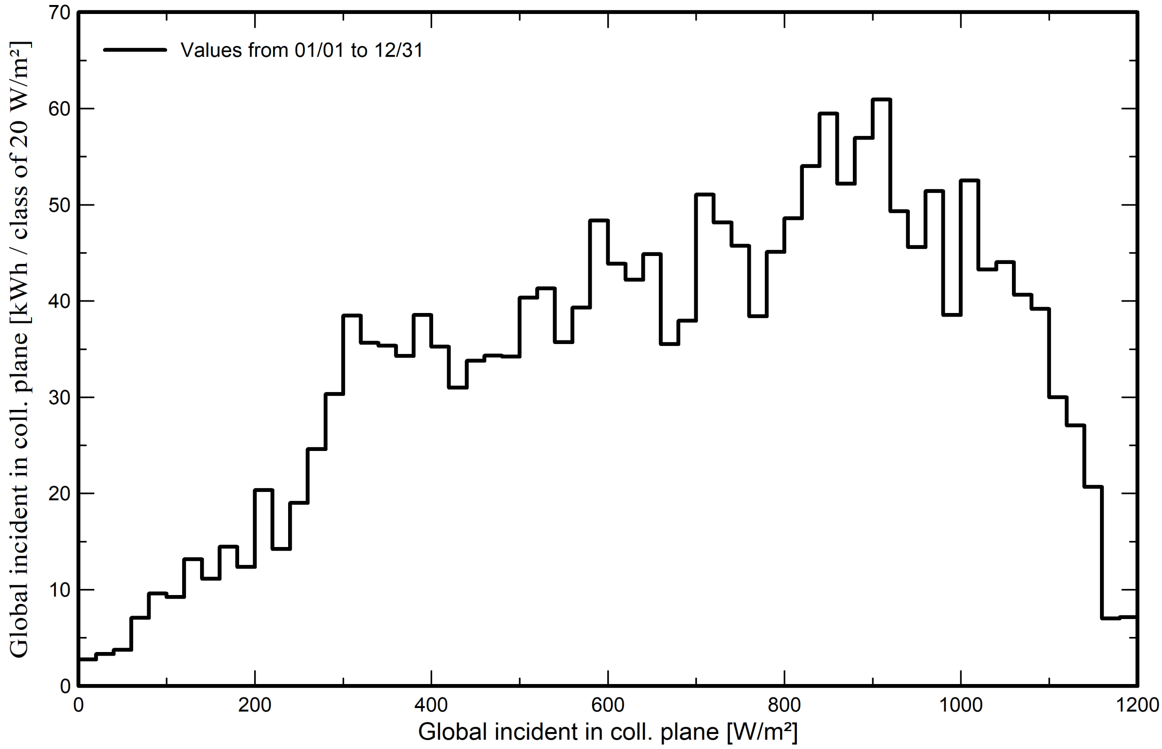


Normalized Production and Loss Factors

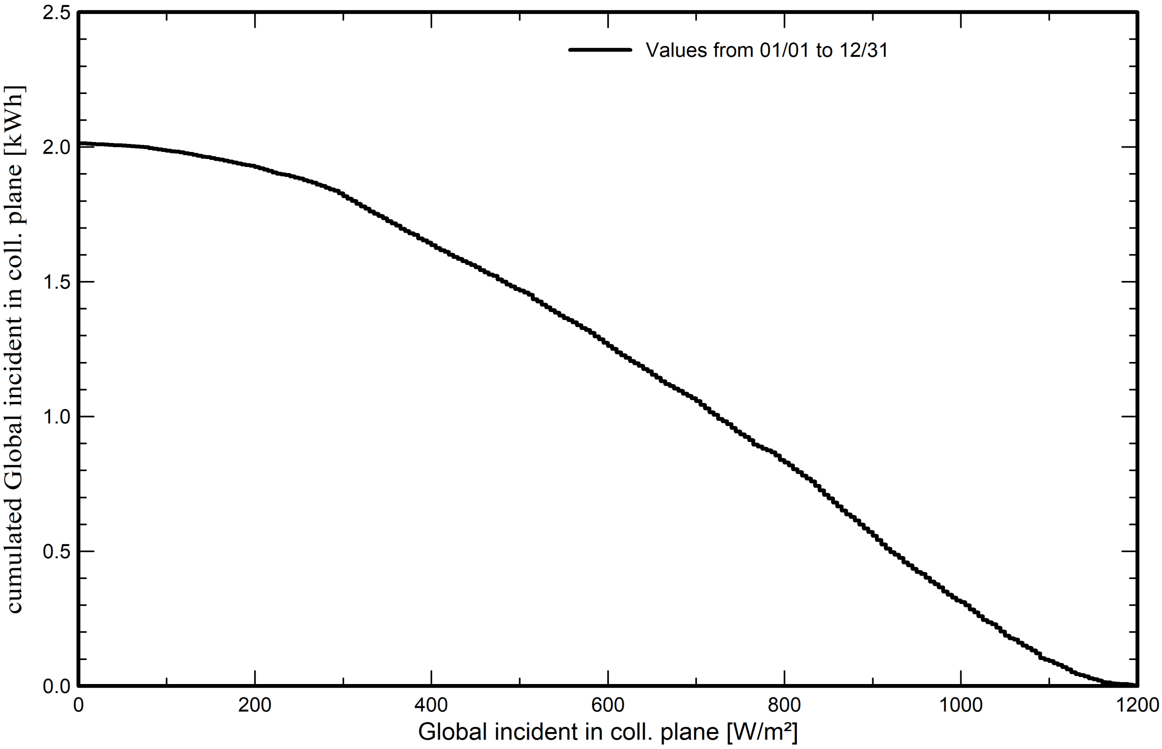


Predef. graphs

Incident Irradiation Distribution

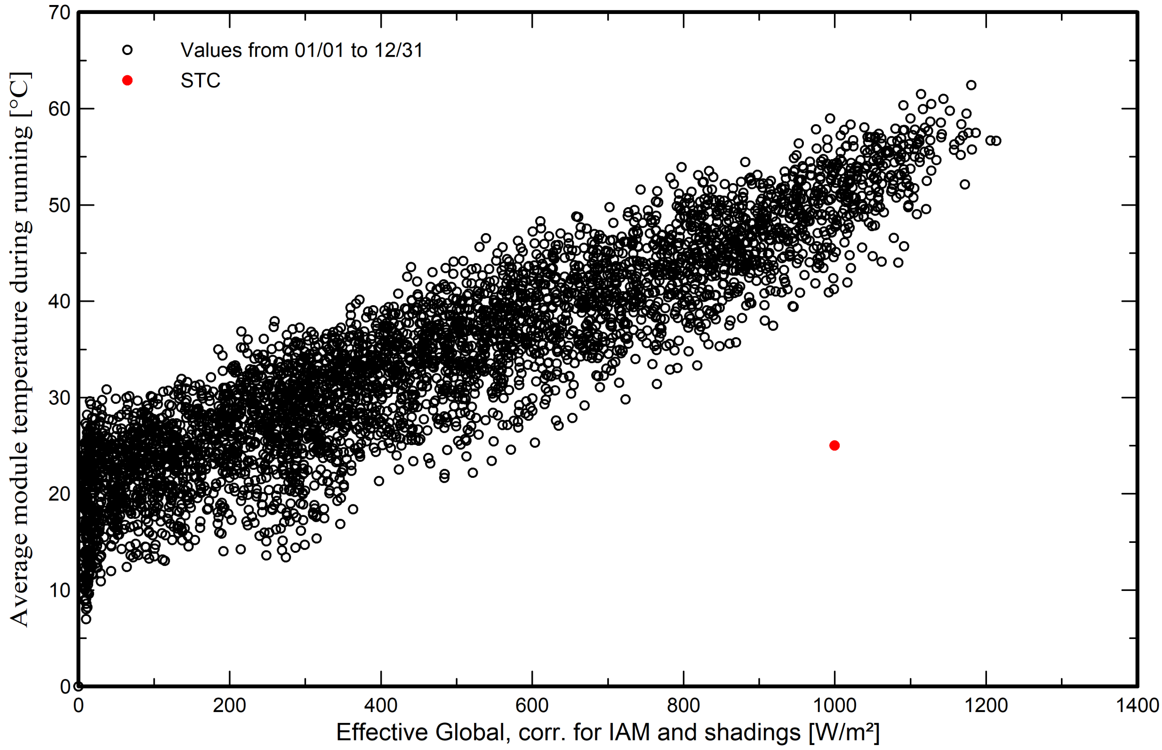


Incident Irradiation cumulative distribution

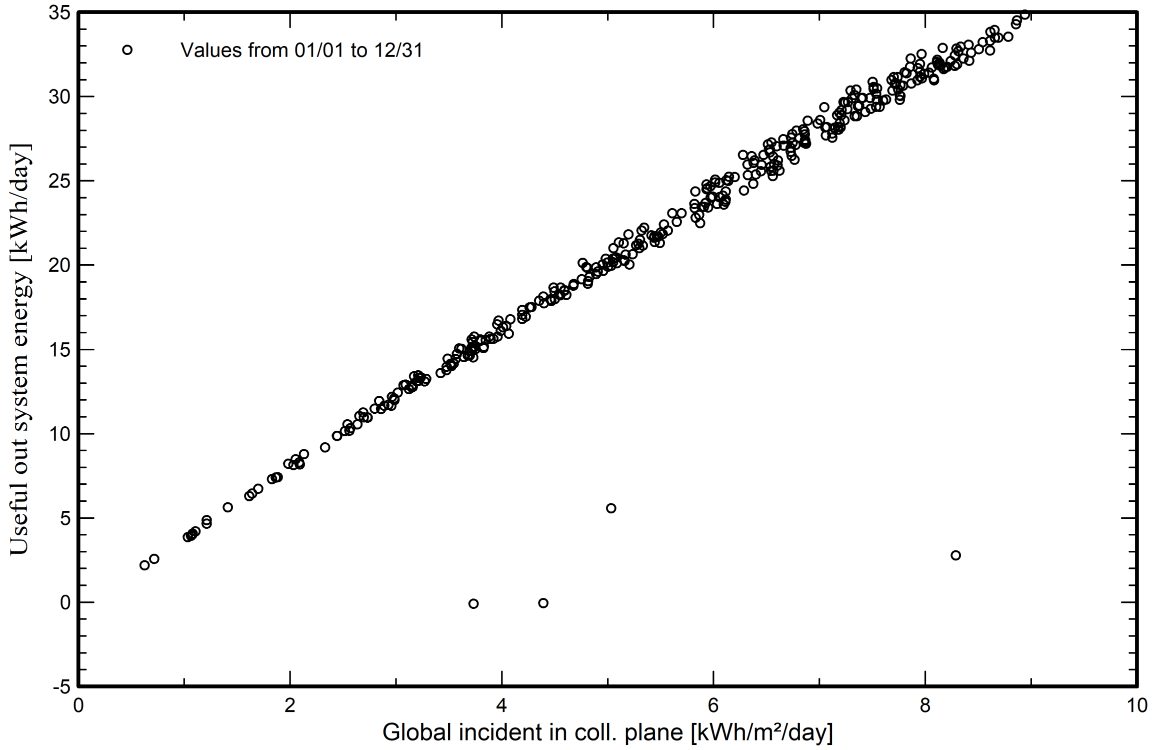


Predef. graphs

Array Temperature vs. Effective Irradiance

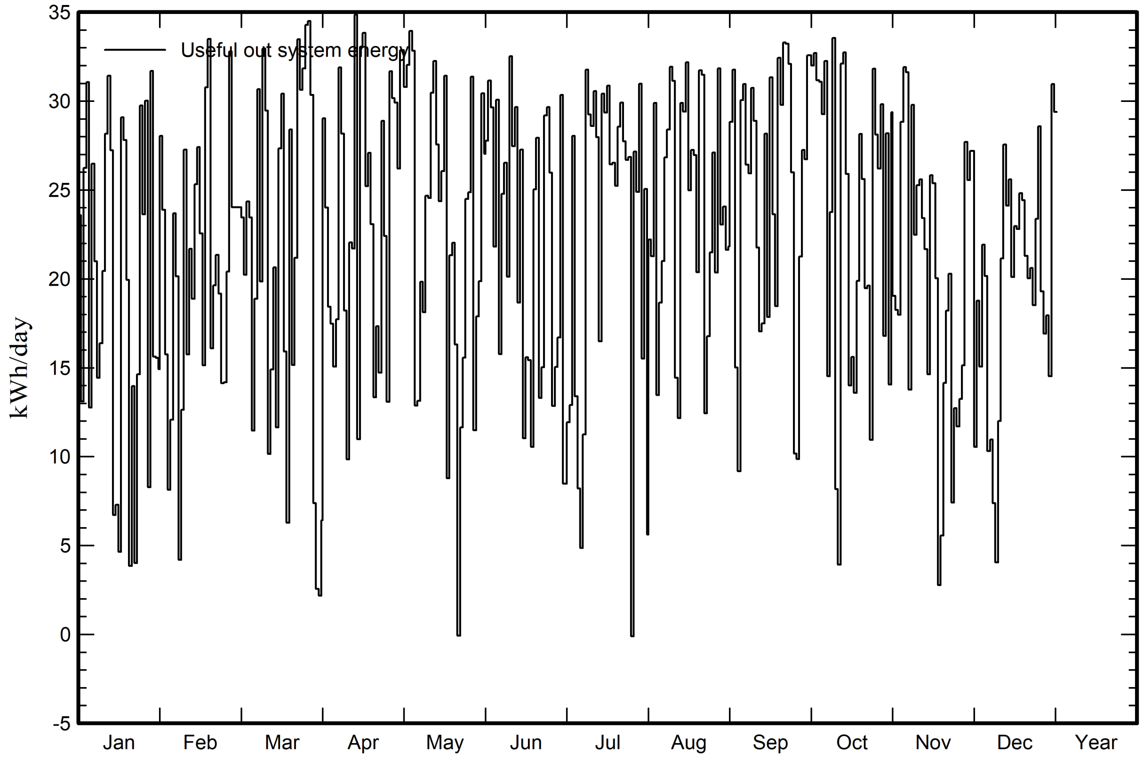


Daily Input/Output diagram

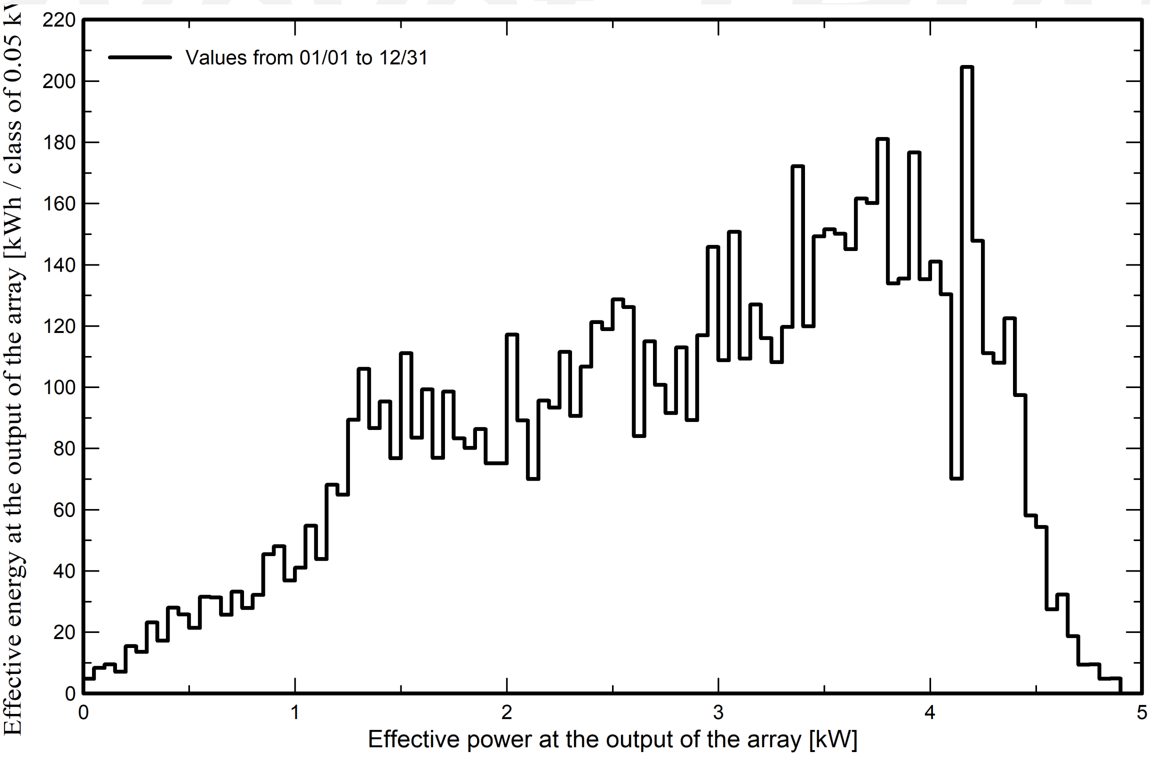


Predef. graphs

Daily System Output Energy

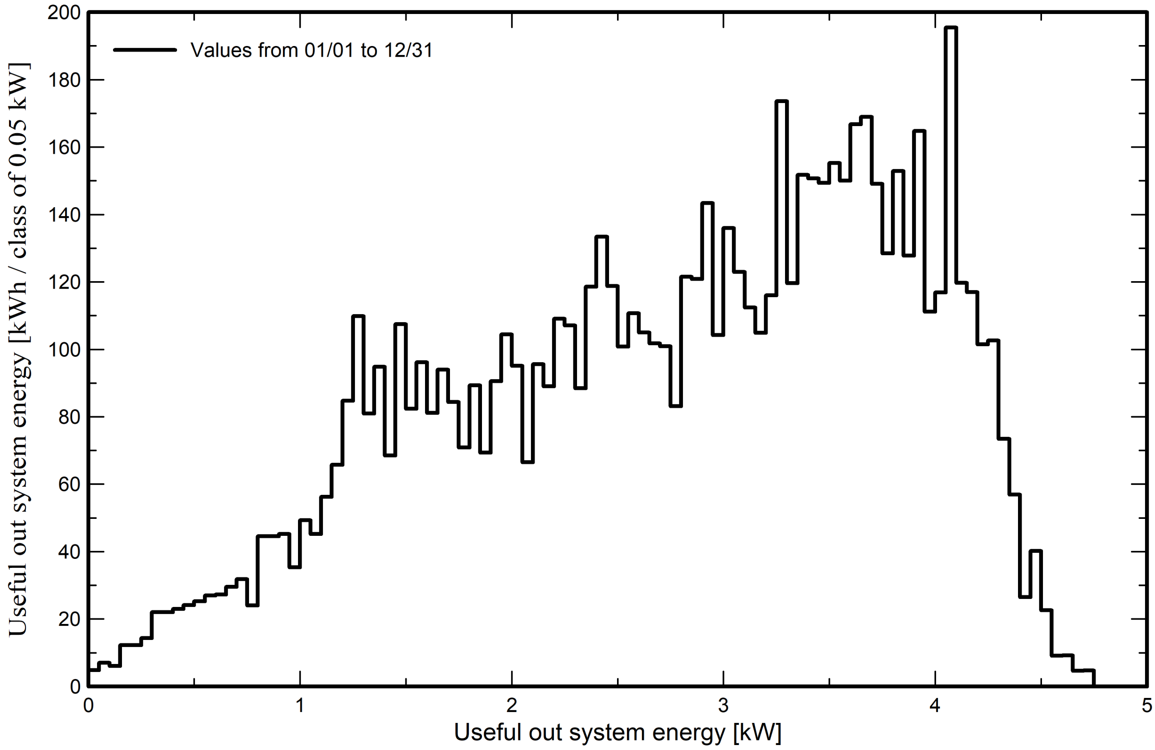


Array Power Distribution

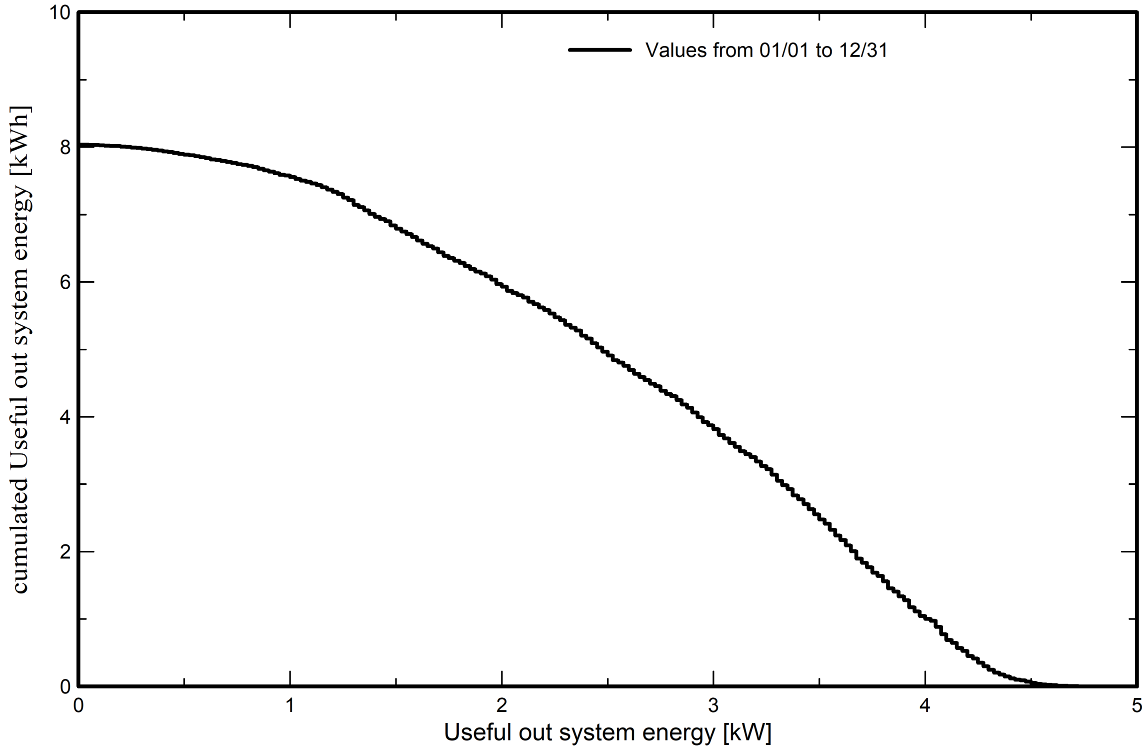


Predef. graphs

System Output Power Distribution

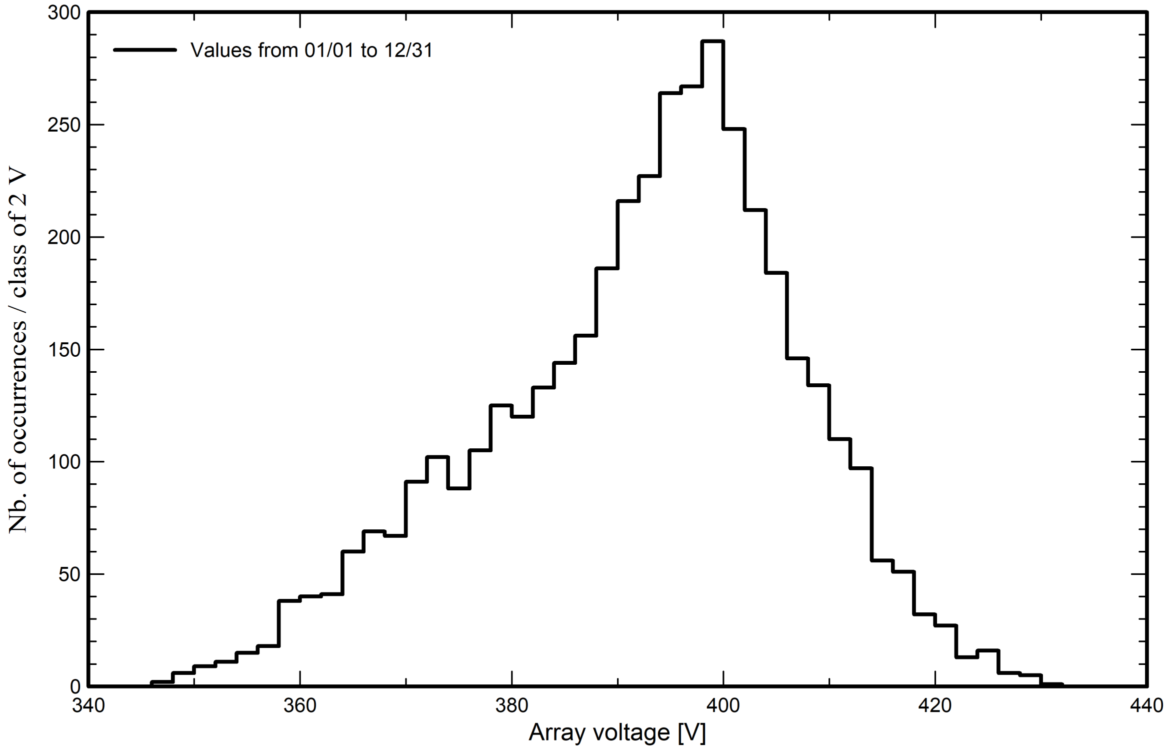


System Output Power cumulative distribution

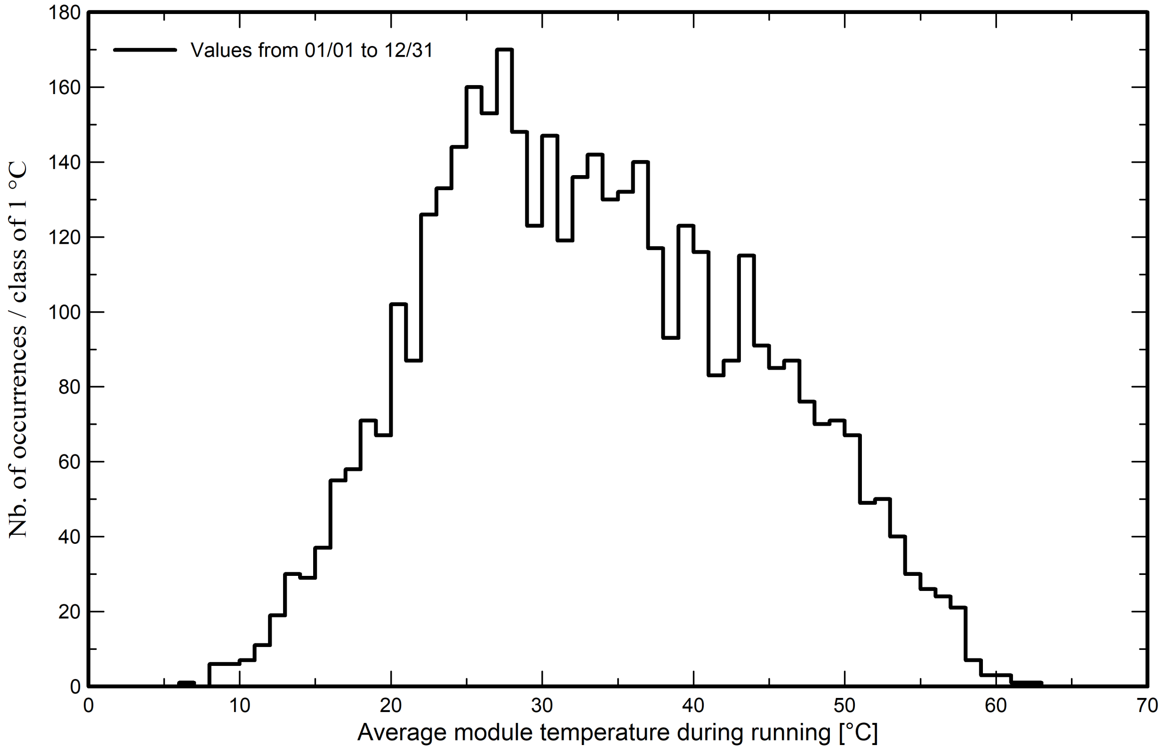


Predef. graphs

Array Voltage Distribution

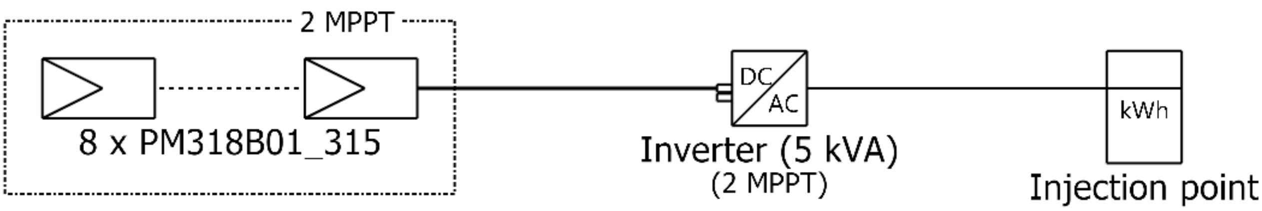


Array Temperature Distribution during running



Single-line diagram

PVsyst V7.4.8
VC0, Simulation date:
10/24/24 01:03
with V7.4.8



PV module	PM318B01_315
Inverter	SUN2000-4.95KTL-JPL1
String	8 x PM318B01_315

Techno-Economic Assessment - Solar Photovoltaic	
VC0 : New simulation variant	10/27/24

Cost of the system

Installation costs

Item	Quantity units	Cost USD	Total USD
PV modules			
PM318B01_315	16	200.00	3,200.00
Supports for modules	16	100.00	1,600.00
Inverters			
SUN2000-4.95KTL-JPL1	1	1,000.00	1,000.00
Other components			
Accessories, fasteners	1	50.00	50.00
Wiring	1	50.00	50.00
Combiner box	1	50.00	50.00
Monitoring system, display screen	1	50.00	50.00
Measurement system, pyranometer	1	10.00	10.00
Surge arrester	1	10.00	10.00
Studies and analysis			
Engineering	1	100.00	100.00
Permitting and other admin. Fees	1	50.00	50.00
Environmental studies	1	50.00	50.00
Economic analysis	1	50.00	50.00
Installation			
Transport	1	50.00	50.00
Settings	1	150.00	150.00
Grid connection	1	300.00	300.00
		Total	6,770.00
		Depreciable asset	5,850.00

Operating costs

Item	Total USD/year
Maintenance	
Provision for inverter replacement	200.00
Repairs	500.00
Cleaning	100.00
Total (OPEX)	800.00
Including inflation (1.00%)	880.76

System summary

Total installation cost	6,770.00 USD
Operating costs (incl. inflation 1.00%/year)	880.76 USD/year
Produced Energy	8035 kWh/year
Cost of produced energy (LCOE)	0.1649 USD/kWh

Financial analysis

Simulation period

Project lifetime	20 years	Start year	2025

Income variation over time

Inflation	1.00 %/year
Production variation (aging)	0.00 %/year
Discount rate	1.00 %/year

Income dependent expenses

Income tax rate	1.00 %/year
Other income tax	1.00 %/year
Dividends	1.00 %/year

Depreciable assets

Asset	Depreciation method	Depreciation period (years)	Salvage value (USD)	Depreciable (USD)
PV modules				
PM318B01_315	Straight-line	20	0.00	3,200.00
Supports for modules	Straight-line	20	0.00	1,600.00
Inverters				
SUN2000-4.95KTL-JPL1	Straight-line	20	0.00	1,000.00
Accessories, fasteners	Straight-line	20	0.00	50.00
		Total	0.00	5,850.00

Financing

Own funds	4,970.00 USD	
Subsidies	500.00 USD	
Loan 1 - Redeemable with fixed annuity - 20 years	600.00 USD	Interest rate: 1.00%/year
Loan 2 - Redeemable with fixed amortization - 20 years	500.00 USD	Interest rate: 1.00%/year
Loan 3 - Interest-only bullet loan - 20 years	200.00 USD	Interest rate: 1.00%/year

Electricity sale

Feed-in tariff	Peak tariff	0.40000 USD/kWh	
	Off-peak tariff	0.20000 USD/kWh	20:00-07:00
Duration of tariff warranty		20 years	
Annual connection tax		100.00 USD/kWh	
Annual tariff variation		+0.0 %/year	
Feed-in tariff decrease after warranty		50.00 %	

Return on investment

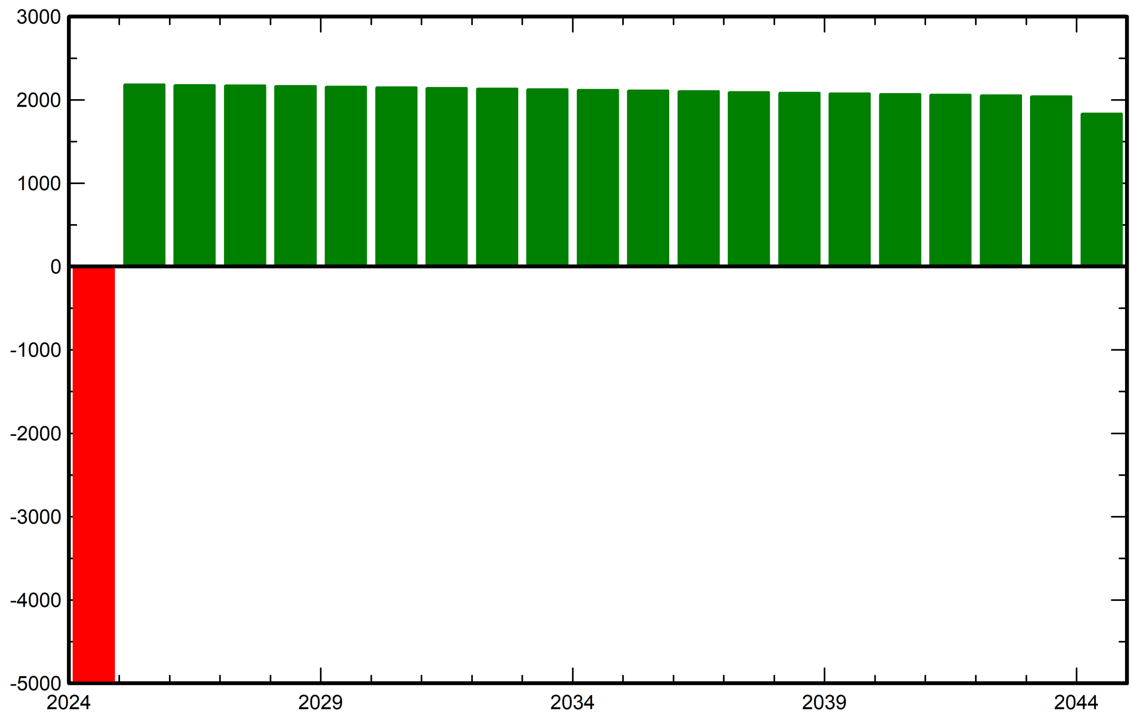
Payback period	2.8 years
Net present value (NPV)	33,427.08 USD
Internal rate of return (IRR)	44.06 %
Return on investment (ROI)	533.1 %
Paid dividends	424.84 USD

Financial analysis

Detailed economic results (USD)

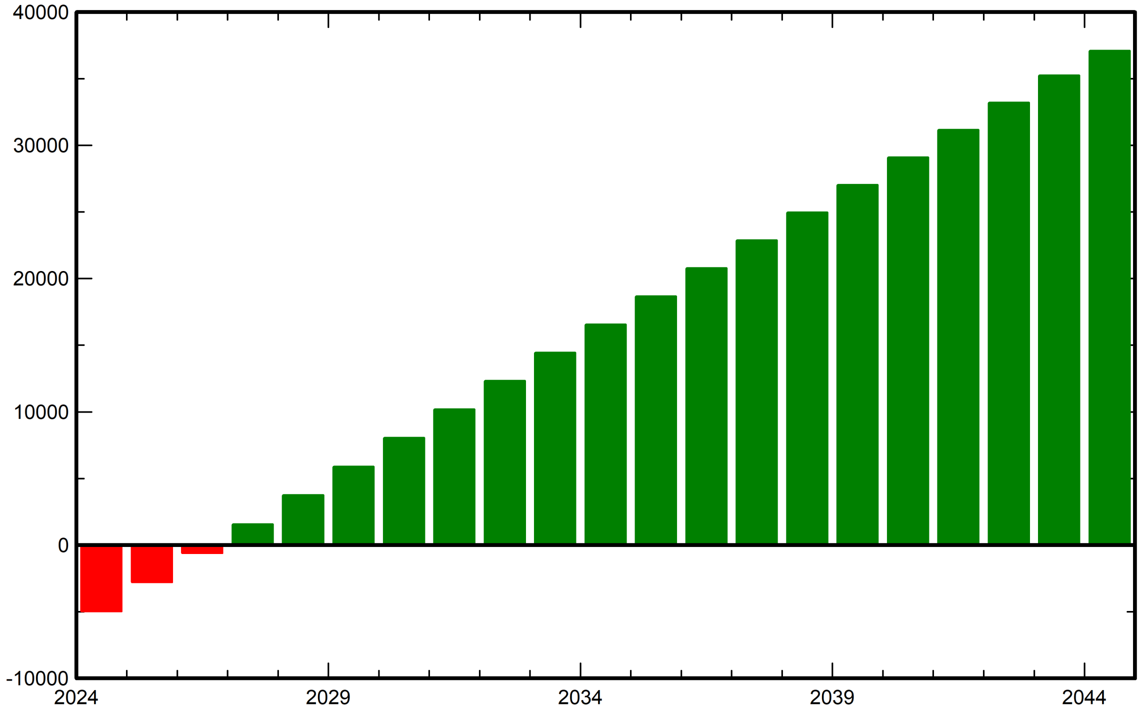
Year	Electricity sale	Own funds	Loan principal	Loan interest	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Divid. 1.00%	Cumul. profit	% amorti.
0	0	4,970	0	0	0	0	0	0	0	0	-4,970	0.0%
1	3,114	0	52	13	800	293	2,008	40	2,208	22	-2,784	35.7%
2	3,114	0	53	12	808	293	2,001	40	2,201	22	-626	70.9%
3	3,114	0	53	12	816	293	1,994	40	2,193	22	1,503	105.7%
4	3,114	0	53	11	824	293	1,986	40	2,186	22	3,603	140.1%
5	3,115	0	53	11	832	293	1,979	40	2,178	22	5,676	174.0%
6	3,115	0	54	10	841	293	1,971	39	2,171	22	7,721	207.5%
7	3,115	0	54	10	849	293	1,964	39	2,163	22	9,739	240.5%
8	3,116	0	54	9	858	293	1,956	39	2,155	22	11,729	273.1%
9	3,116	0	55	9	866	293	1,949	39	2,148	21	13,693	305.3%
10	3,116	0	55	8	875	293	1,941	39	2,140	21	15,630	337.1%
11	3,117	0	55	8	884	293	1,933	39	2,132	21	17,540	368.4%
12	3,117	0	55	7	893	293	1,925	38	2,124	21	19,425	399.4%
13	3,117	0	56	7	901	293	1,917	38	2,115	21	21,284	429.9%
14	3,118	0	56	6	910	293	1,909	38	2,107	21	23,117	460.0%
15	3,118	0	56	5	920	293	1,901	38	2,099	21	24,924	489.8%
16	3,118	0	57	5	929	293	1,892	38	2,090	21	26,707	519.1%
17	3,119	0	57	4	938	293	1,884	38	2,082	21	28,465	548.0%
18	3,119	0	57	4	947	293	1,875	38	2,073	21	30,198	576.6%
19	3,119	0	58	3	957	293	1,867	37	2,064	21	31,906	604.8%
20	3,120	0	258	3	966	293	1,858	37	1,855	19	33,427	633.1%
Total	**62,331**	**4,970**	**1,300**	**157**	**17,615**	**5,850**	**38,709**	**774**	**42,484**	**425**	**33,427**	**633.1%**

Yearly net profit (USD)



Financial analysis

Cumulative cashflow (USD)



CO_2 Emission Balance

Total: 127.7 tCO_2

Generated emissions

Total: 9.77 tCO_2

Source: Detailed calculation from table below

Replaced Emissions

Total: 158.5 tCO_2

System production: 8003.05 kWh/yr

Grid Lifecycle Emissions: 660 gCO_2/kWh

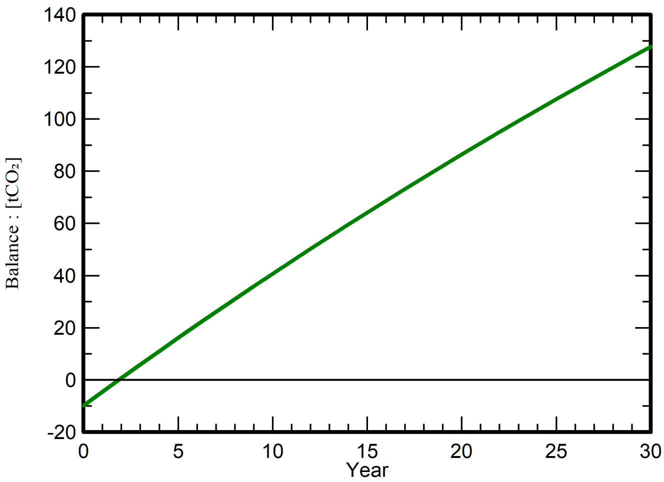
Source: IEA List

Country: Zimbabwe

Lifetime: 30 years

Annual degradation: 1.0 %

Saved CO_2 Emission vs. Time



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	5.04 kWp	8632
Supports	4.40 kgCO2/kg	160 kg	704
Inverters	436 kgCO2/units	1.00 units	436