

A Work Project, presented as part of the requirements for the Award of a Master's degree in  
Management from the Nova School of Business and Economics.

**Field Lab: Economic analysis of rooftop solar panels in Curitiba, Brazil**

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**Table of contents**

Executive Summary.....4

Introduction.....4

Data and assumptions..... 5

Calculations..... 6

Final recommendations.....7

References.....8

Appendix.....9

**Keywords:** Energy Finance, Electricity, Renewable Energy

## Executive Summary - Rooftop Solar Economic Analysis

**Location:** Curitiba, Brazil

**Date of analysis:** Jan/2022

**Recommendation:** install 10 solar panels (12.00 m<sup>2</sup>), for a net present value (NPV) of 11.003 BRL (1.739 EUR), with a payback of 8 years.

### Main economic results:

Financing	NPV (BRL)	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (BRL/kWh)	LCOE (EUR/kWh)
75% debt, 25% equity	11.003	1739	8	8.61%	0.095	0.016
100% equity	13.424	2.121	6	8.59%	0.076	0.012

### Main inputs and assumptions:

#### *Household and Economics*

Electricity Consumption	2.603	kWh/year	Inflation	3.06%	per year
Electricity price – buy	0.51277	BRL/kWh	Bank loan interest rate	8.56%	per year
Electricity price – sell	0.2534	BRL/kWh	Bank loan maturity	8	years
			Equity cost of capital	0.25%	per year

#### *PV panels chosen*

Peak power	330	W/panel	System losses	14%	of output
Panel area	1.94	m <sup>2</sup> /panel	Degradation with age	0.5%	Per year
Useful life	25	Years	Maintenance costs	50	BRL/year per panel
Total cost of optimal installation size (without subsidies)				7.950	BRL (1256 EUR)

**Keywords:** Solar Energy, Photovoltaic, Solar PV, Renewables, Utilities, Project Finance

## **Introduction**

The total supply of energy in Brazil from renewable sources settled at 46% in 2019 (IEA, 2019). Of this, more than half was a mix of biomass and hydro. Following EPE's forecasts, an additional 55 GW of renewable capacity could be installed up to 2030, with strong solar and wind technology rapidity. All this, following further investments in modernization and digitization of the grids (EPE, 2021). Although the Brazilian government has incentivized new investments in the biofuel market with public policies, further agreements are expected to generate electricity from solar photovoltaic and wind energy. Specifically, the installed solar capacity in Brazil went from 7.7GW in 2020 to 14GW in 2021 (Absolar, 2021). For the national energy strategy, by 2030 the government predicts a potential investment of R\$ 100 billion in these technologies and that 2.7 million consumer units will be able to join the program. In addition, the Federal Government decided to zero import taxes on solar energy equipment by the end of 2021 (Absolar, 2021), as a form of incentive to make the country more sustainable.

In Brazil there is no real incentive system for the development of solar systems on residential buildings. ANEEL's national regulatory law 482/12 establishes the rules for this "energy compensation" system (what we are calling "energy credits" or "solar energy incentive law"). This resolution allows you to make this "exchange" of energy with the electrical grid.

Therefore, according to ANEEL regulatory resolution N ° 687, residential solar systems must be designed exclusively for the reduction of invoice costs, and not for the direct marketing of their own self-produced energy. In this case, if the solar system produces more energy than is consumed by the housing unit, it will be converted into credits, available for 60 months, used as a "discount" for your bill. The commercialization of energy takes place only if you operate in the free energy market, by associating with the CCEE (Câmara de Comercialização de Energia Elétrica)

## **Assumptions**

This rooftop solar PV economic feasibility analysis refers to a project located in the city of Curitiba, Brazil, at an altitude of about 900 meters. The property taken into consideration is a 90 square meter apartment, and there are 4 people who live in the house every day, with two working parents and two young people studying from home. Annual consumption is 2.603 kWh/year, with an electricity cost of 0.51 BRL/kWh and a sales price to the grid of 0.25 BRL/kWh. The average selling price of energy is justified by a specific government incentive system for owners of solar plants who register with CCEE, the competent governmental body that certifies solar plants that can commercialize electrical renewable energy into the grid without having to receive credit for discounts in monthly bills. Therefore, this selling price usually refers to utility-scale users, as they manage solar plants of tens of MW and manage to maintain the management costs for registering with the institution.

Regarding the economic variables taken into consideration, the inflation rate is evaluated at 3.06% (Statista, 2022), conserving a temporal horizon of 25 years of the project. After the year 2026, the inflation value will tend to stabilize over time for the entire course of the project. Two scenarios are considered during a basic investment analysis:

1. Simulation of a bank loan with a local financial institution to finance the solar photovoltaic project. In this case, the interest rate on the loan is 8.56% per annum, with a loan length of approximately 8 years. The amount of debt corresponds to 75%, with equity at 25%.
2. Simulation of financing of the solar photovoltaic project with 100% equity by the homeowners.

In both cases the equity cost of capital is 0.25%, based on the 10-year swap rate of Brazil.

At the time of the analysis, no significant government subsidies were found to increase NPV and reduce project payback. However, the federal government is studying a new incentive scheme that reduces the issuance of credits used to pay for their own consumption (Cunha, 2021), allowing the creation of a regulated market (energy communities) where every single housing unit will contribute to grid stability and monetization directly based on how much energy is put into the grid during peak demand (Doci, 2015).

Regarding the solar panels, the Canadian Solar MAXPOWER CS6U 330-P panel was taken into consideration, with peak power of 330W, gross area of 1.94 square meters, energy efficiency around 17.00% and with system losses of 14.00%. The useful life of the panel is 25 years. The maintenance costs for each panel are approximately 50 BRL per year (approx. 10 euros).

Installation costs for each solar PV plant is reported below, according to the number of panels considered for the project. These values represented in the table below evidence a real quote of the costs of panels from the supplier and include an estimation for the installation costs.

*Total installation cost for rooftop solar PV plant*

<i>Number of panels installed</i>	<i>Installation cost (BRL)</i>	<i>Exchange rate EUR-BRL</i>	<i>Installation cost (EUR)</i>
1	795	6.30	126
2	1.590		252
3	2.385		379
4	3.180		505
5	3.975		631
6	4.770		757
7	5.565		883
8	6.360		1.010
9	7.155		1.136
10	7.950		1.262
11	8.745		1.388
100	79.500		12.619

## Calculations

Several steps have been carried out to calculate the financial KPIs and evaluate the feasibility of the project. MS Excel is the main tool used for calculations.

*Consumption Profile:* As it was not possible to retrieve a standard consumption profile in Brazil relating to the hourly load levels for segment B (residential), it was decided to use a standard database obtained from the Portuguese E-Redes, which has a similar consumption profile in Curitiba, Brazil.

*Solar Radiation:* Through the PVGIS global database, and by placing the latitude, longitude, slope, and azimuth values, it was possible to extract (with system losses of about 14%) the hourly solar radiation of the building under consideration in Curitiba. In conclusion, there are a total of 8760 lines, with values from 2015 and 2016. The average of the power P per 1 kWp of both years is used for the calculation of hourly consumption.

*Energy Generation from PV:* The “Peak Power Installed capacity” is calculated as the multiplication of the total kWp for each panel with the number of panels installed. After that, some annual energy values are calculated starting from the radiation values, such as “Generation”, “Load”, “Self-consumption”, “Sold to grid” and Residual load”, all expressed in kWh. Then, some economic values are calculated as follow:

1. Cost w/o panels = Electricity costs \* Load =  $0.51277 * 2.603 = 1.335$  BRL
2. Revenue = Electricity selling price \* Amount of kWh sold to grid =  $0.2532 * 2.603 = 296.20$  BRL
3. Residual cost = Electricity costs \* Self consumption =  $0.51277 * 1.498 = 768.17$  BRL

$$4. \text{ Savings due to project: Cost w/o panels + Revenue} - \text{Residual} = 1335 + 296.29 - 768.17$$

$$= 862.76 \text{ BRL}$$

*Project Finance & KPIs:*

The following segments and respective calculations are considered to arrive at a final value of NPV, IRR and basis for the final main results.

Investment in panels:

1. Gross investment = 7.950 BRL (calculated with Excel formula)
2. Government subsidies: not applicable
3. Bank Load = Gross Investment \* Loan Amount (75% debt) = 7.950 BRL \* 0.75 = 5.963 BRL
4. Net Investment: Gross – Bank Loan = 7.950 – 5.963 = 1.987.50 BRL

Household:

1. *Annuity PV Factor* =  $\frac{(1-(1+r)^{-n})}{r} = 5.63$ , where:
  - a. Interest rate (r) = 8.56%.
  - b. Maturity period (n) = 8 years.
2. Annual Payment: 1.060 BRL (calculated with Excel formula)

Cash Flow Analysis:

1. Equity Investment = - Net Investment = -1.987.50 BRL
2. Electricity savings = Energy Generation from PV \* (1 + Inflation Rate)
3. Maintenance costs = Yearly Maintenance Costs \* (1 + Inflation Rate)
3. “Loan repayment” ” = (calculated with Excel formula)
4. “Cash Flow” = (calculated with Excel formula)

5.  $Present\ Value = \frac{Cash\ Flow}{(1 + Inflation\ Rate)^n}$ , considering the CF value of the considered period, discounting the inflation rate and the number of years for the project.
4. **NPV**: Sum of all Present Values (Cash Flow) = 11.003.48 BRL (1.738 EUR)
5. **IRR**: (Calculated with Excel) = 8.61%
6. **Payback** =  $Year\ n - Accumulated\ CF * \frac{(Year\ n) - (Year\ n-1)}{(Accumulated\ CF\ n) - (Accumulated\ CF\ n-1)}$ , corresponding to 8 years (first positive value).
7. **LCOE**: calculated with the “goal seek formula” on Excel, with a result of 0.095 BRL (0.016 EUR). The Levelized Cost of Energy (LCOE) is average revenue per unit of generated electricity, necessary to recover the construction and management costs of a PV generation plant during a financial and operating life cycle. The main inputs for the calculation of LCOE include costs of capital, energy produced from the solar PV plant and many different operation and maintenance (O&M) costs for the properly operation of the energy system.

## Final recommendations

As main results of this basic analysis, with 10 panels installed, having got the highest IRR and NPV, is a great investment with a payback of 8 years, considering also the electricity sell price at the LCOE value showed above. It should also be noted that installing half of the panels results in a very low NPV value, demonstrating in this case study that it is highly recommended to install as many panels as possible in Curitiba.

Furthermore, if the family might have significant liquidity, it continues to be cheaper to don't consider a bank loan (particularly with the high yearly interests) and finance the project 100% equity, having a reduced payback to just 6 years and a greater LCOE value.

*Panoramic table with key financial metrics for the solar PV project.*

Number of panels installed	NPV (BRL)	NPV (EUR)	IRR (%)	Payback (years)	LCOE (BRL/kWh)
1	Didn't consider lower number of panels because of negative NPV				
2					
3					
4					
5	577.65	91.69	1.26	9	0.108
6	2.503.38	397.36	3.68	9	0.104
7	4.540.09	720.65	5.40	9	0.102
8	6.651.15	1.055.74	6.72	8	0.100
9	8.810.48	1.398.49	7.76	8	0.097

10	11.003.48	1.746.58	8.61	8	0.095
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## References

- ABSOLAR - Associação Brasileira de Energia Solar Fotovoltaica. Available at:  
<https://www.absolar.org.br>
- ANEEL - Agência Nacional de Energia Elétrica. Available at: <https://www.gov.br/aneel/pt-br>
- ANEEL, Regulatory Framework n°682. Available at: <https://solisenergia.com.br/resolucao-aneel-687-2015/>
- COZZI, Laura, et al. World Energy Outlook 2020. *vol*, 2020, 2050: 1-461.
- CUNHA, Felipe Barroco Fontes, et al. Transitioning to a low carbon society through energy communities: Lessons learned from Brazil and Italy. *Energy Research & Social Science*, 2021, 75: 101994.
- DA ROSA, Antonio Robson Oliveira; GASPARIN, Fabiano Perin. Panorama da energia solar fotovoltaica no Brasil. *Revista brasileira de energia solar*, 2016, 7.2: 140-147.
- DÓCI, Gabriella; VASILEIADOU, Eleftheria; PETERSEN, Arthur C. Exploring the transition potential of renewable energy communities. *Futures*, 2015, 66: 85-95.
- EPE - Empresa de Pesquisa Energética. Energy Matrix in Brazil, 2021. Available at:  
<https://www.epe.gov.br/pt/abcdenergia/matriz-energetica-e-eletrica>
- ESPOSITO, Alexandre Siciliano; FUCHS, Paulo Gustavo. Desenvolvimento tecnológico e inserção da energia solar no Brasil. Available  
at: <https://web.bndes.gov.br/bib/jspui/handle/1408/1421>, 2013.
- ROSS, Stephen A.; WESTERFIELD, Randolph; JAFFE, Jeffrey F. *Corporate finance*. Irwin/McGraw-Hill, 1999.

- ROSS, Stephen A. Uses, abuses, and alternatives to the net-present-value rule. *Financial management*, 1995, 24.3: 96-102.
- Statista: Brazil: Inflation rate up to 2026 and forecasts. Available at:  
<https://www.statista.com/statistics/270812/inflation-rate-in-brazil/>
- YESCOMBE, Edward R. *Principles of project finance*. Elsevier, 2002.
- WECKEND, Stephanie; WADE, Andreas; HEATH, Garvin A. *End of life management: solar photovoltaic panels*. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2016.

## Appendix

Appendix 1: Energy matrix in Brazil (left, BEN 2021); Electric matrix in Brazil (right, BEN 2021)

