Photovoltaic Distributed Generation in Brazil: Investment Valuation for the 27 Capital Cities

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Abstract

This paper presents investment valuations on Photovoltaic (PV) Distributed Generation (DG), on systems simulated for the 27 Brazilian capital cities (for all the 26 states and the Federal District), considering systems start-up in July 2019. The article also presents analyses of Brazilian: PV-DG prices and market evolution, average annual increase for residential energy tariff prices and a survey on tax rates levied on electricity tariffs, for the 27 Brazilian capital cities. The NPV for investment in micro PV-DG systems in the Brazilian capitals had an increase ranging from 326% (Macapá-AP) to 11553% (Porto Velho - RO) in a bit more than six years! The average NPV increase between the capitals was 1504% from May/2013 to Jul/2019. The economic figures and the resulting discounted payback periods demonstrate that rooftop PV is an excellent investment for the residential consumer in Brazil.

Keywords: distributed generation, investment valuation, Brazil, photovoltaics, NPV, payback time, IRR

1. Introduction

According to ANEEL (2019a), the cumulative installed capacity of Brazilian grid-connected Photovoltaic (PV) Distributed Generation (DG) (max. 5 MWp/system) has almost tripled each year, from 2016 to 2018: 68 MWp in December 2016, 195 MWp in December 2017 and 588 MWp in December 2018. Evaluating the cumulative total number of installed PV-DG systems in Brazil, as of July 28, 2019, 74% of the systems were installed in the residential sector. Considering only the first half of 2019 or even the second quarter of 2019, the number of PV-DG systems installed in the residential sector represents 73% of total PV-DG installed systems in Brazil (and 38% of total installed power).

Considering the growth of the PV-DG in residential sector in Brazil, the main purpose of this paper is to present investment valuations on simulated PV-DG systems installed in residential consumer units, for the 27 Brazilian capital cities (from all the 26 states and the Federal District), considering system start-up in July 2019.

The following topics are also addressed in this paper

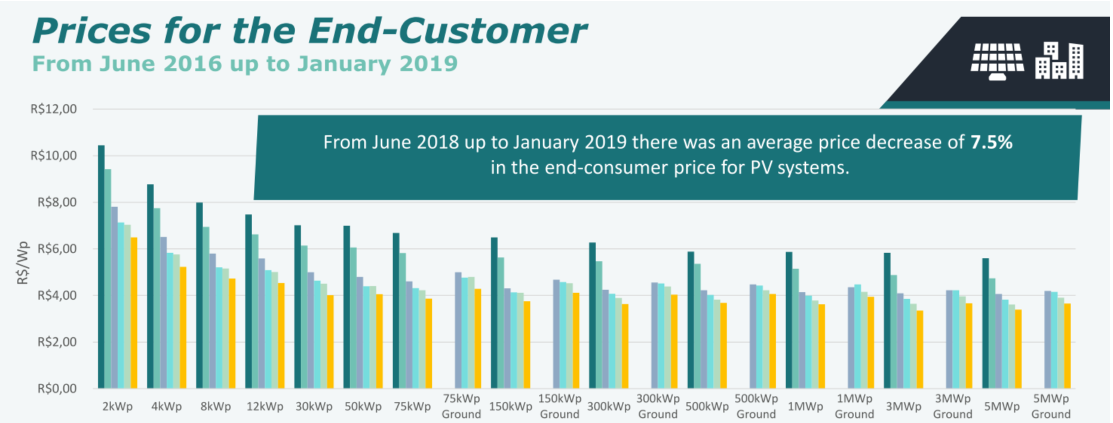
- Evolution in PV-DG prices and market in Brazil,
- Residential energy tariff prices average annual increase;
- Survey on tax rates levied on electricity tariffs, for the 27 Brazilian capital cities.

2. PV-DG in Brazil: evolution in systems prices and market

The market study developed by Greener (2019) interviewed 760 PV integrators companies from all regions of Brazil, in the period between 3 December 2018 and 9 January 2019, using responses from 690 of the interviewed companies (91% validation rate). This study showed that in the last two years (Jan/2017 to Jan/2019) the reduction in average prices for end consumer of 4 kWp PV-DG residential systems (installation costs included) was 32.4% (from 7.74 R$/Wp to 5.23 R$/Wp), as shown in Figure 1. In the same period, the US$ exchange rate increased 16.3% (from 3.210 R$/US$ in Jan/2017 to 3.734 R$/US$ in Jan/2019). This reduction of prices occurred due to the expansion in the PV-DG market in Brazil in the period (as shown in Figures 2 and 3), which brought considerable reductions in the nationalized expenses (e.g. projects, installation labor and metallic structures) referring to PV-DG (Greener, 2019), and also due to the reduction in PV module prices in the international market in the same period (BloombergNEF, 2018). It

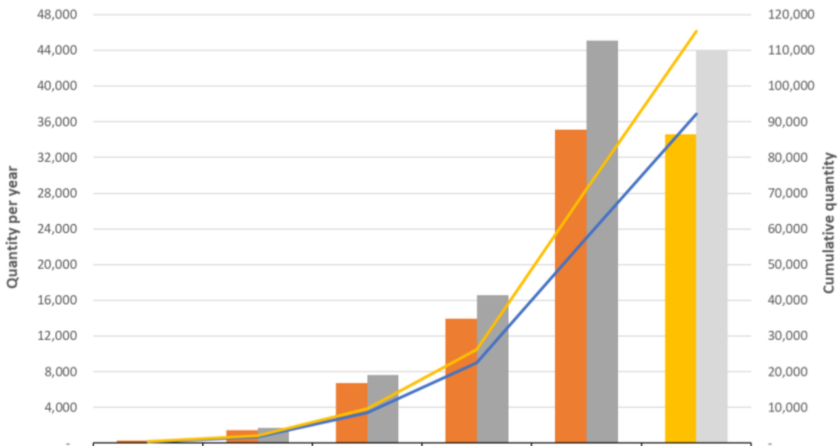
doi:10.18086/swc.2019.25.02 Available at http://proceedings.ises.org

should be noted that, as shown by Greener (2019), from Jun/2017 to Jan/2018, there is a 33.3% reduction in the average prices of PV-DG integration in Brazil, but a 13.2% increase in average prices of PV kits with 4 kWp. As highlighted by Greener (2019), the increase in prices of PV kits in this period occurred mainly due to the increase in the US$ exchange rate.



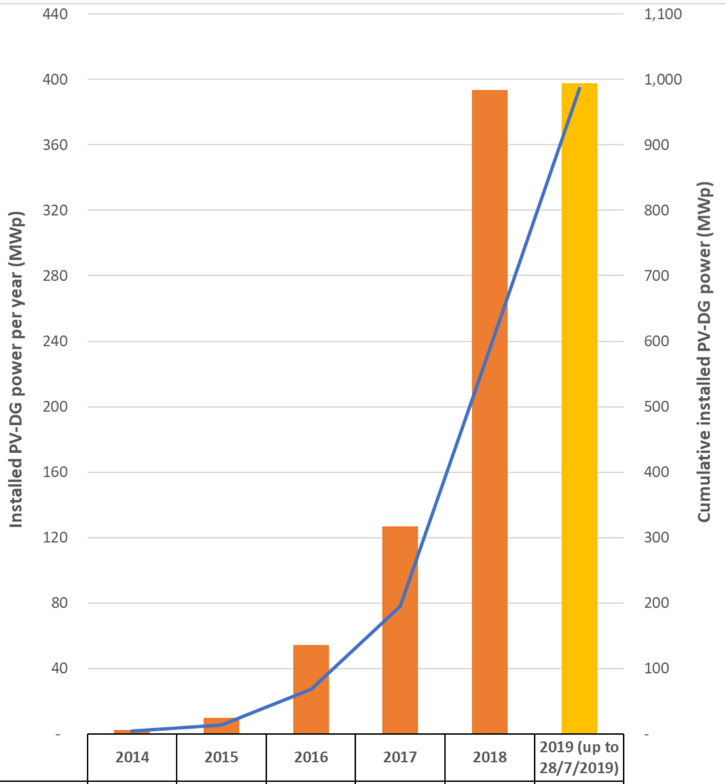
	2kWp	4kWp	8kWp	12kWp	30kWp	50kWp	75kWp	75kWp Ground	150kWp	150kWp Ground	300kWp	300kWp Ground	500kWp	500kWp Ground	1MWp	1MWp Ground	3MWp	3MWp Ground	5MWp	5MWp Ground
jun/16	R$10,45	R$8,77	R$7,99	R$7,47	R$7,01	R$7,00	R$6,69		R$6,49		R$6,28		R$5,88		R$5,88		R$5,83		R$5,60	
jan/17	R$9,43	R$7,74	R$6,94	R$6,63	R$6,14	R$6,06	R$5,82		R$5,63		R$5,47		R$5,36		R$5,15		R$4,88		R$4,74	
jun/17	R$7,81	R$6,52	R$5,80	R$5,59	R$4,99	R$4,80	R$4,60	R$5,00	R$4,31	R$4,67	R$4,24	R$4,55	R$4,22	R$4,47	R$4,14	R$4,35	R$4,10	R$4,23	R$4,06	R$4,19
jan/18	R$7,13	R$5,83	R$5,21	R$5,09	R$4,64	R$4,39	R$4,31	R$4,77	R$4,13	R$4,57	R$4,08	R$4,52	R$4,02	R$4,43	R$4,00	R$4,48	R$3,85	R$4,22	R$3,83	R$4,15
jun/18	R$7,04	R$5,76	R$5,15	R$5,01	R$4,51	R$4,41	R$4,23	R$4,80	R$4,11	R$4,53	R$3,89	R$4,38	R$3,82	R$4,23	R$3,78	R$4,15	R$3,64	R$3,97	R$3,61	R$3,90
jan/19	R$ 6,49	R$ 5,23	R$ 4,72	R$ 4,54	R$ 4,02	R$ 4,05	R$ 3,86	R$ 4,28	R$ 3,76	R$ 4,12	R$ 3,63	R$ 4,04	R$ 3,69	R$ 4,06	R$ 3,62	R$ 3,95	R$ 3,36	R$ 3,66	R$ 3,39	R$ 3,66

Figure 1: Average prices for end-consumers of PV-DG systems in Brazil (installation costs included), from June 2016 to January 2019 (Greener, 2019).



	2014	2015	2016	2017	2018	2019 (up to 28/7/2019)
Number of new PV-DG systems per year	295	1,447	6,752	13,953	35,145	34,596
Number of new consumer units that start receiving PV-DG credits per year	322	1,673	7,634	16,595	45,066	44,041
Cumulative number of new PV-DG systems per year	358	1,805	8,557	22,510	57,655	92,251
Cumulative number of new consumer units that start receiving PV-DG credits per year	400	2,073	9,707	26,302	71,368	115,409

Figure 2: PV-DG market in Brazil: evolution in the quantities (per year and cumulative) of installed PV-DG systems and of consumer units that receive PV-DG credits, from 2014 to 28/07/2019, based on ANEEL (2019a) data.



	2014	2015	2016	2017	2018	2019 (up to 28/7/2019)
Installed PV-DG power per year (MWp)	3	10	54	127	394	398
Cumulative installed PV-DG power per year (MWp)	4	14	68	195	588	986

Figure 3: PV-DG market in Brazil: evolution in the installed power (per year and cumulative) of PV-DG systems, from 2014 to 28/07/2019, based on ANEEL (2019a) data.

3. Residential energy tariff prices from Dec/2012 to Jul/2019

A survey of the values for residential energy tariffs without taxes – named B1 tariff, that in fact includes the energy tariff per se, the power transmission and distribution systems use tariff, and sector charges – for Dec/2012, and for the 27 Brazilian capital cities were presented by Montenegro (2013). The values of the B1 tariffs without taxes practiced in Dec/2012 for the Brazilian capital cities did not change until May/2013, which was the month of the investment return evaluations presented in that study, and that are updated in this paper. The updated values of B1 tariffs without taxes for Jul/2019 were checked (ANEEL, 2019b), and a comparison was made with the values, also without taxes, practiced in Dec/2012, for the 27 Brazilian capital cities.

As shown in Table 1, for the period considered (Dec/2012 to Jul/2019), considering the B1 nominal tariff in R$ for the 27 cities, it was noted: a mean annual average increase of 10.4%, a minimum annual average increase of 7.5% (Rio Branco - AC) and a maximum annual average increase of 17.4% (Macapá-AP). The capital city with highest B1 tariff in Jul/2019 (not including taxes) is Manaus - AM (0.70606 R$/kWh, which is equivalent to 0.18659 US$/kWh). If the B1 tariff prices from Dec/2019 are corrected by inflation index IGP-M (FGV, 2019), it was noted: a mean annual average increase of 4.3%, a minimum annual average increase of 1.6% (Rio Branco - AC) and a maximum annual average increase of 10.9% (Macapá-AP).

Despite the high annual average values of nominal residential electricity tariff increases observed in Table 1, as shown in Table 2, these values are being greatly influenced by the average 40% nominal increase between 2014 and 2015 in these tariffs. In addition, Table 2 shows that from 2016 to 2017, the national average nominal residential tariff showed a price reduction of 0.2%. The other annual nominal increases for the period analyzed in Table 2 were 7.1% (2013-2014) and 6.2% (2015-2016).

Table 1: Evolution of residential electricity tariff prices for the 27 Brazilian capital cities, from Dec/2012 to Jul/2019. Nominal Dec/2012 tariff prices data from Montenegro (2013). Nominal Jul/2019 tariff prices data from ANEEL (2019b). R$_2019 means tariff prices corrected by IGP-M (FGV, 2019) inflation index, from Dec/2012 to Jul/2019. R$_2012 means nominal tariff prices in Dec/2012.

Capital city	State	Nominal electricity tariff, residential sector (B1), without taxes, in Dec/2012 [R$_2012/kWh]	Real (corrected by inflation) electricity tariff, residential sector (B1), without taxes, in Dec/2012 [R$_2019/kWh]	Nominal (and real) electricity tariff, residential sector (B1), without taxes, in Jul/2019 [R$]	Percentage increase in nominal electricity tariff Dec/2012 (R$_2012) to Jul/2019 [%]	Percentage increase in real electricity tariff Dec/2012 (R$_2019) to Jul/2019 [%]	Average annual percentage increase in nominal electricity tariff Dec/2012 (R$_2012) to Jul/2019 [% PY]	Average annual percentage increase in real electricity tariff Dec/2012 (R$_2019) to Jul/2019 [% PY]
Aracaju	SE	0.30829	0.44812	0.53072	72.1%	18.4%	8.6%	2.6%
Belém	PA	0.32076	0.46624	0.67098	109.2%	43.9%	11.9%	5.7%
Belo Horizonte	MG	0.34700	0.50439	0.62833	81.1%	24.6%	9.4%	3.4%
Boa Vista	RR	0.26009	0.37806	0.63462	144.0%	67.9%	14.5%	8.2%
Brasília	DF	0.24253	0.35253	0.55722	129.8%	58.1%	13.5%	7.2%
Campo Grande	MS	0.32648	0.47456	0.60865	86.4%	28.3%	9.9%	3.9%
Cuiabá	MT	0.34282	0.49831	0.62684	82.8%	25.8%	9.6%	3.5%
Curitiba	PR	0.24258	0.35260	0.51761	113.4%	46.8%	12.2%	6.0%
Florianópolis	SC	0.25580	0.37182	0.52049	103.5%	40.0%	11.4%	5.2%
Fortaleza	CE	0.30821	0.44800	0.52949	71.8%	18.2%	8.6%	2.6%
Goiânia	GO	0.29662	0.43115	0.56175	89.4%	30.3%	10.2%	4.1%
João Pessoa	PB	0.31782	0.46197	0.57177	79.9%	23.8%	9.3%	3.3%
Macapá	AP	0.19729	0.28677	0.56638	187.1%	97.5%	17.4%	10.9%
Maceió	AL	0.30293	0.44033	0.53525	76.7%	21.6%	9.0%	3.0%
Manaus	AM	0.27139	0.39448	0.70606	160.2%	79.0%	15.6%	9.2%
Natal	RN	0.30853	0.44847	0.50553	63.9%	12.7%	7.8%	1.8%
Palmas	TO	0.34423	0.50036	0.60008	74.3%	19.9%	8.8%	2.8%
Porto Alegre	RS	0.27588	0.40101	0.54760	98.5%	36.6%	11.0%	4.8%
Porto Velho	RO	0.33862	0.49220	0.58137	71.7%	18.1%	8.6%	2.6%
Recife	PE	0.29877	0.43428	0.54933	83.9%	26.5%	9.7%	3.6%
Rio Branco	AC	0.37060	0.53869	0.59777	61.3%	11.0%	7.5%	1.6%
Rio de Janeiro	RJ	0.31416	0.45665	0.62565	99.2%	37.0%	11.0%	4.9%
Salvador	BA	0.29327	0.42629	0.55213	88.3%	29.5%	10.1%	4.0%
São Luís	MA	0.36610	0.53215	0.65602	79.2%	23.3%	9.3%	3.2%
São Paulo	SP	0.23801	0.34596	0.51559	116.6%	49.0%	12.5%	6.2%
Teresina	PI	0.36292	0.52753	0.61531	69.5%	16.6%	8.3%	2.4%
Vitória	ES	0.31509	0.45800	0.56228	78.5%	22.8%	9.2%	3.2%
	Average	**0.30247**	**0.43966**	**0.58055**	**91.9%**	**32.0%**	**10.4%**	**4.3%**

Table 2: Evolution of Brazilian average residential nominal electricity tariff prices, from 2013 to 2017, based on EPE (2018) Figure 2.14 data.

Year	Brazilian average electricity tariff for residential sector (R$/kWh)	Increase in the average Brazilian electricity tariff over the previous year
2013	0.28524	
2014	0.30535	7.1%
2015	0.42789	40.1%
2016	0.45433	6.2%
2017	0.45356	-0.2%

4. Residential energy tariff taxes

The tax rates levied on Brazilian electricity tariff are named:

- ICMS: state tax, with rates set by each state government (ANEEL, 2019c) and
- PIS/PASEP+COFINS: federal taxes (actually, they are called federal “contributions”), with rates set by each utility (ANEEL, 2005; EDP, 2019).

Table 3 shows the updated ICMS tax rates levied on electricity tariffs, for the 27 Brazilian capital cities, in Jul/2019, for residential consumers, based on data available on each city utility's website. The ICMS tax has a wide range of rates in the various states of the country and depends on the consumption level. All these variations were considered in the investment analyses presented in this article.

Table 3: ICMS tax rates levied on electricity tariffs, for the 27 Brazilian capital cities, in Jul/2019, for residential consumers, based on data available on each city utility's website.

Capital city	State	Consumption range (kWh) for application of ICMS tax rates	ICMS tax rates for each consumption range
Aracaju	SE	0-50, 51-220, >220	0%, 25%, 27%
Belém	PA	0-100, 101-150, >150	0%, 15%, 25%
Belo Horizonte	MG	Invariable Tax Rate	30%
Boa Vista	RR	0-100, >100	0%, 17%
Brasília	DF	0-50, 51-200, 201-300, 301-500, >500	0%, 12%, 18%, 21%, 25%
Campo Grande	MS	0-50, 51-200, 201-500, >500	0%, 17%, 20%, 25%
Cuiabá	MT	0-100, 101-150, 151-250, 251-500, >500	0%, 10%, 17%, 25%, 27%
Curitiba	PR	0-30, >30	0%, 29%
Florianópolis	SC	0-150, >150	12%, 25%
Fortaleza	CE	0-50, >50	0%, 27%
Goiânia	GO	0-50, >50	0%, 29%
João Pessoa	PB	0-50, 51-100, >100	0%, 25%, 27%
Macapá	AP	0-100, >100	0%, 17%
Maceió	AL	0-100, 101-150, >150	0%, 17%, 27%
Manaus	AM	Invariable Tax Rate	25%
Natal	RN	0-60, 61-300, >300	0%, 18%, 27%
Palmas	TO	Invariable Tax Rate	25%
Porto Alegre	RS	0-50, >50	12%, 30%
Porto Velho	RO	0-220, >220	17%, 20%
Recife	PE	0-30, >30	0%, 25%
Rio Branco	AC	0-100, 101-140, >140	0%, 16%, 25%
Rio de Janeiro	RJ	0-50, 51-300, 301-450, >450	0%, 18%, 31%, 32%
Salvador	BA	Invariable Tax Rate	27%
São Luís	MA	0-50, 51-100, 101-500, >500	0%, 12%, 14%, 27%
São Paulo	SP	0-90, 91-200, >200	0%, 12%, 25%
Teresina	PI	0-50, 51-200, >200	0%, 20%, 25%
Vitória	ES	0-50, >50	0%, 25%

Table 4 shows the PIS/PASEP+COFINS tax rates levied on electricity tariffs, for the 27 Brazilian capital cities, in Dec/2012, as shown in the electricity bills obtained by Montenegro (2013) from one residential consumer for each capital city. The PIS+COFINS tax has a wide monthly variation of rates for each utility in the various states of the country (EDP, 2019; Montenegro, 2013). Also, several utilities do not disclose official and reliable information about the monthly PIS/PASEP+COFINS applied rates. For these reasons, and in order to include this tax in the financial analysis of the investment, the rates effectively verified in electricity bills made available by Montenegro (2013) were used, and such rates were considered constant throughout the investment period analyzed.

Table 4: PIS/PASEP+COFINS tax rates levied on electricity tariffs, for the 27 Brazilian capital cities, for residential consumers (Montenegro, 2013).

Capital city	State	PIS/PASEP+COFINS tax rate
Aracaju	SE	5.3157%
Belém	PA	7.7319%
Belo Horizonte	MG	4.4831%
Boa Vista	RR	5.5923%
Brasília	DF	4.4883%
Campo Grande	MS	5.4720%
Cuiabá	MT	7.3917%
Curitiba	PR	6.5587%
Florianópolis	SC	4.1489%
Fortaleza	CE	5.3072%
Goiânia	GO	7.1526%
João Pessoa	PB	6.5699%
Macapá	AP	0.5768%
Maceió	AL	5.5559%
Manaus	AM	0.0000%
Natal	RN	5.7100%
Palmas	TO	7.6965%
Porto Alegre	RS	4.7216%
Porto Velho	RO	9.0571%
Recife	PE	5.5600%
Rio Branco	AC	5.0004%
Rio de Janeiro	RJ	5.0800%
Salvador	BA	6.1800%
São Luís	MA	6.8908%
São Paulo	SP	4.8658%
Teresina	PI	7.1859%
Vitória	ES	3.6650%

5. Method

The method developed by Montenegro (2013) was the basis to evaluate the investment on residential micro PV-DG systems in each one of the 27 Brazilian capital cities, presented in this article. These are the values and specifications adopted in the micro PV-DG systems investment analyses for the 27 capitals, for PV-DG system start-up in Jul/2019:

- Type of consumer: residential (excluding low income), with three-phase connection;
- Total monthly consumption: 250 kWh/month, constant throughout the year, and over the years;
- Energy tariff applied for the start-up of the PV-DG system: current B1 tariff, including taxes, in the

month of the start of the PV-DG system, that is Jul/2019 ("bandeira tarifária" costs are not considered in this investment valuation);

- Annual average increase in nominal residential tariff: 4% per year (a more conservative value than those raised in Table 1, considering the analysis of the data presented in Table 2);
- Monthly cost of availability (minimum charge in the electricity bill, even if there is no consumption to pay) (ANEEL, 2010): to the residential three-phase consumer, it corresponds to the equivalent amount for a monthly consumption of 100 kWh (*i.e.* if the consumption is less than 100 kWh, the consumer has to pay the amount equivalent to 100 kWh consumption);
- Monthly solar irradiation (kWh/m^2.month): monthly solar irradiation on a plane with a slope equal to the local latitude and facing true North, data collected in Pereira et al. (2017);
- Performance Ratio (PR) (Marion et al., 2005): 80% PR was adopted for the simulations – this is a conservative value, since it has been verified PR of 80 to 90% for PV systems installed from 2010 (Reich et al., 2012; Thevenard and Pelland, 2013; Fraunhofer ISE and PSE, 2018);
- Monthly Yield (kWh/kWp.month) (Marion et al., 2005): is numerically equal to the multiplication of monthly solar radiation on the plane of PV array by PR;
- Installed PV power: 1 kWp – with this PV system size, in no capital, in any month of the year, the monthly net consumption (monthly total gross consumption minus monthly PV generation) charged by the utility is below the 100 kWh corresponding to the monthly cost of availability;
- Annual Yield reduction: 0.5% per year, that is typical for Brazil (Viana et al., 2012);
- Installed Wp price: 5 R$/Wp (1.3 US$/Wp), considering the cost reduction between Jan/2019 (Figure 1) and Jul/2019;
- Monthly cash flow for expense and revenue analysis (it is important to remember that cash flow and MARR values must be on the same basis, either nominal or both real);
- MARR (Minimum Acceptable Rate of Return): 6.4% per year (SELIC) (BCB, 2019) – that index includes interest and inflation;
- Initial cost of investment: turnkey cost of the analyzed PV-DG system (Installed Wp price x Installed PV power = R$ 5,000);
- Annual O&M costs: 1% x Initial cost of investment (to simplify the calculations and due to the high uncertainty of these future values, no inflation correction of these values was made);
- Replacement costs: inverter replacement every 10 years: 30% x Initial cost of investment, each 10 years (to simplify the calculations and due to the high uncertainty of these future values, no inflation correction of these values was made);
- Service life of the PV-DG system (period considered for investment analysis): 25 years.

6. Results

Table 5 shows the results obtained in the investment valuation on PV-DG systems for the 27 Brazilian capital cities, for Jul/2019, considering the values and specifications mentioned in the previous topic. The most attractive capital city for this kind of investment is Belém - PA that for 1 kWp installed power has: NPV of R$ 22,932 (US$ 6,060), IRR of 40.0% (including inflation) and payback time of 3.5 years. The less attractive capital city for this kind of investment is Macapá - AP that for 1 kWp installed power has: NPV of R$ 9,985 (US$ 2,639), IRR of 21.5% (including inflation) and payback time of 6.8 years. Comparing these results with those obtained in the investment analyzes for May/2013 (Montenegro, 2013), the NPV for investment in micro PV-DG systems in the Brazilian capitals had an increase ranging from 326% (Macapá-AP) to 11553% (Porto Velho - RO) in a bit more than six years! The average NPV increase between the capitals was 1504% from May/2013 to Jul/2019.

Table 5: NPV, IRR and payback time for investment on micro PV-DG systems for the 27 Brazilian capital cities, for Jul/2019.

Capital city	State	NPV (R$/kWp)	NPV (US$/kWp)	IRR (% PY)	Payback time (years)
Aracaju	SE	17,244	4,557	31.8%	4.3
Belém	PA	22,932	6,060	40.0%	3.5
Belo Horizonte	MG	21,464	5,672	38.1%	3.7
Boa Vista	RR	14,770	3,903	28.3%	5.0
Brasília	DF	15,461	4,086	29.2%	4.8
Campo Grande	MS	17,324	4,578	31.9%	4.3
Cuiabá	MT	18,813	4,972	33.9%	4.1
Curitiba	PR	12,628	3,337	25.3%	5.7
Florianópolis	SC	11,151	2,947	23.2%	6.2
Fortaleza	CE	17,313	4,575	31.9%	4.4
Goiânia	GO	19,000	5,021	34.3%	4.1
João Pessoa	PB	18,905	4,996	34.3%	4.1
Macapá	AP	9,985	2,639	21.5%	6.8
Maceió	AL	19,707	5,208	35.3%	3.9
Manaus	AM	15,361	4,060	29.1%	4.8
Natal	RN	13,505	3,569	26.5%	5.3
Palmas	TO	18,687	4,938	33.9%	4.1
Porto Alegre	RS	13,134	3,471	26.0%	5.4
Porto Velho	RO	12,691	3,354	25.3%	5.6
Recife	PE	17,026	4,499	31.5%	4.4
Rio Branco	AC	15,462	4,086	29.5%	4.8
Rio de Janeiro	RJ	15,053	3,978	28.8%	4.9
Salvador	BA	17,410	4,601	32.1%	4.3
São Luís	MA	17,241	4,556	31.7%	4.4
São Paulo	SP	15,726	4,156	29.4%	4.8
Teresina	PI	17,331	4,580	32.5%	4.3
Vitória	ES	15,217	4,021	29.0%	4.8

7. Conclusions

This work shows that the average prices for turnkey PV-DG systems in Brazil had considerable price reductions in the last two years (2016 - 2019). This reduction of prices occurred due to the expansion in the PV-DG market in Brazil in the period. The number of new PV-DG systems installed in 2017 is 2.1 times the number installed in 2016, and the installed PV-DG power in 2017 is 2.4 times the power installed in 2016. The number of new PV-DG systems installed in 2018 is 2.5 times the number installed in 2017, and the installed PV-DG power in 2018 is 3.1 times the power installed in 2017.

The economic figures (NPV and IRR) and the resulting discounted payback periods using the proposed method demonstrate that rooftop PV is an excellent investment for the residential consumer in the 27 Brazilian capital cities.

8. References

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