AN ECONOMIC ASSESSMENT OF GRID-CONNECTED RESIDENTIAL SOLAR PHOTOVOLTAIC SYSTEMS IN BRAZIL

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Abstract

This paper analyzes the economic competitiveness of grid-connected distributed solar PV generation through small scale roof top installations in five Brazilian state capitals. The chosen locations represent a comprehensive set of the two essential parameters for the economic viability of solar PV – irradiation and local electricity tariffs. For the assessment, levelized electricity costs (LEC) for solar PV generation and net present values (NPV) for a specific PV system are presented. The analysis comprises three different interest rate scenarios reflecting different conditions for capital acquisition to finance the considered installation; subsidized, mature market and country specific risk-adjusted interest. In the NPV analysis, revenue flow is modeled by the sale of generated electricity at current residential tariffs assuming net metering legislation. Using subsidized interest rates, the analysis performed shows that solar PV electricity is already competitive in Brazil as of today, while in the country specific risk-adjusted scenario, high capital costs make it economically unfeasible. At a mature market interest rate, PV competitiveness is largely dependent on the residential tariff for electricity. Economic competitiveness in this scenario is given for locations with high residential tariffs. The results obtained demonstrate the high potential of distributed electricity generation with photovoltaic installations in Brazil and show that under given conditions, grid-connected PV can be economically competitive in a developing country.

1. Introduction

A secure and sustainable energy supply is one of the big challenges that our society is facing at the beginning of the 21st century. Population growth and rising living standards put pressure on existing energy infrastructures and provision concepts. At the same time, fossil fuel reserves are running short and carbon-intensive energy sources contribute to climate change with unforeseeable consequences. The International Energy Agency (IEA) (IEA, 2010) predicts global demand of energy to grow at a rate of 1.5 % per year from 2010 until 2030, leading to increased consumption of oil by 22 %, natural gas by 42 % and coal by 53 % within this time frame of 20 years.

As fossil fuel resources are scarce and environmental impacts involved in today's predominant energy generation concepts create manifold problems like toxic waste, pollution and global warming, renewable energy sources can offer a secure, reliable and sustainable energy supply in the future. Electricity sectors with their particular characteristics and supply policies have been in the center of attention due to electricity's significant share of overall energy consumption and its decisive role to enable an adequate standard of living.

In Brazil, the current electricity generation matrix relies heavily on hydroelectric power plants often located in remote regions far from consumption centers on the Brazilian coast. Thermoelectric plants are used to generate electricity when hydro generation is insufficient due to low water levels. In 2010, the share of generation capacity accounted for by hydroelectric facilities was 73.36 %. During the humid months from January until June 2010, hydroelectric power generation was 92.3 % of total electricity production (MME, 2010a, 2010b). The distribution of total generation capacity in Brazil's electricity sector is shown in Table 1. On the one hand, the large amount of hydro generated electricity entails benefits like low costs of generation and marginal emission of greenhouse gases. On the other hand, supply security is reduced and social and environmental problems arise. Brazil experienced a severe electricity supply crisis in 2001 due to a period of extended drought when water storage in hydro plant reservoirs was insufficient to satisfy demand. In the wake of this event, several reforms have changed the electricity sector regulation to provide increased security of supply. Consequently, electricity tariffs have been rising and in 2010 averaged 0.17 € (Mitscher, 2010) (reaching as high as 0.27 € in Belo Horizonte), compared to 0.15 € in the European Union (EEP, 2010) and approximately 0.08 € in the United States (EIA, 2010). The main reasons for these exceptionally high tariffs include the inefficient regulation process and limited competition in the distribution sector, thermal generation units running with low capacity factors and considerable losses of the extensive and thus costly transmission infrastructure. Tributary charges to subsidize welfare tariffs for low income customers also significantly increase the average regular electricity price.

Table 1: Generation matrix by energy source in the Brazilian electricity sector 2010 (Source: ANEEL)

Energy source	Number of plants	Installed capacity (kW)	% of generation
Hydro	851	79,170,386	73 %
Natural gas	127	12,331,101	11 %
Oil	837	6,265,714	6 %
Biomass	364	6,582,660	6 %
Wind	44	765,534	1 %
Coal	9	1,530,304	1 %
Nuclear	2	2,007,000	2 %
Solar	1	20	0 %
Total	2,235	108,652,719	100 %

Economic and population growth will make substantial expansion in the generation sector unavoidable. Current government plans focus on covering the bulk of needed additional capacity by harnessing Brazil's remaining potential of hydroelectric power. The ever more distant locations and increased costs for environmental licensing and impact mitigation will aggravate the mentioned drawbacks of strong hydroelectric dominance in the generation matrix. This paper analyzes the potential of grid-connected photovoltaic roof top systems of small size to diversify Brazil's present generation structure and improve energy security and sustainability.

Grid-connected photovoltaic systems of small size offer clean, carbon-free and ecologically sustainable electricity generation. Their distributed nature can reduce transmission losses and seasonal electricity supply shortages because of the complementary nature of PV and hydro generation peaks (sunshine vs. rain) besides protecting owners from continuing tariff increases. However, PV electricity as an alternative generation source to alleviate such problems is usually viewed as inappropriate in non-industrialized countries due to the elevated costs associated with the technology.

While this argument is true for most developing countries, in the case of Brazil the combination of high residential tariffs with superior solar radiation availability suggests that PV electricity might reach economic feasibility for grid-connected installations within the near future. The moment when PV electricity costs are equal to retail electricity prices is called grid parity and is often portrayed as the decisive milestone making the solar industry independent from subsidy policies and securing PV a significant share in generation portfolios. Grid parity for PV electricity shows a strong correlation to the local conditions insolation and electricity tariff. Due to Brazil's very favorable characteristics, grid parity will likely be reached there earlier than in most industrialized economies.

Besides the local conditions, the magnitude of future cost reductions will have significant influence on PV cost competitiveness. A common way to assess the potential of cost reductions in an industry is the application of learning curves, which for the solar sector predict a decline in cost of 20% for each doubling of cumulative capacity (van der Zwaan B, 2004; Parente et al.; 2002; McDonald and Schrattenholzer, 2001).

Grid parity conditions would enable private house owners to install small scale PV systems on their roof and produce electricity they can consume or sell back to the utility at no additional cost. To evaluate the economics of such an investment, it is necessary to define the cost of PV generated electricity and the overall financial performance of the project considering both expense and revenue cash flows. This work analyzed these indicators using levelized electricity cost and net present values and gives an impression of present economics and future potential of small photovoltaic roof top systems in the Brazilian context.

The potential of solar energy in Brazil has been evaluated by Martins et al. (2008) who distinguished between the potential of rural and grid-connected systems. They determined opportunities especially in the Amazon region without access to the National Interconnected System and for grid-connected PV installed in a distributed manner in urban areas with a mix of commercial and residential buildings. Jardim et al. (2008) studied the benefits of distributed PV generation in Brazil pointing out the peak shaving potential and its impact on firm capacity needs. They outlined the good correlation of PV generation with daytime peaking feeder loads in residential/commercial areas with load peaks caused by air conditioning. It was further determined that PV penetration of 20 % is possible with acceptable effective contribution to installed capacity of the considered feeder. Economics of PV in Brazil have been analyzed by Salamoni and Rüther (2007) who found grid parity to be achievable in selected Brazilian states by 2015 if certain conditions are met. Bhandari and Stadler (2009) evaluated the financial performance of PV systems for the city of Cologne in Germany using the net present value methodology and learning curves. In his work, we further determine a date for grid parity using an approach that values PV-generated electricity with a weighted average of wholesale and retail electricity prices. Singh and Singh (2010) developed a calculation method for levelized electricity cost and net present values that accounts for the variability of electricity prices by using a specific loan repayment scheme.

Cost reductions and learning curves in the PV and energy sector were studied by different authors like Neij (1997), Sagar and Zwaan (2006), Nemet (2006), Neij et. al. (2003), and many others. While Nemet (2006) highlights the importance of factors like economies of scale and module efficiency improvements for cost reductions, Neij et al. (2003) examine the suitability of learning curves to assess energy policy measures. A learning rate of 20 % per doubling of installed capacity has been derived for the solar industry and is a generally accepted value. Grid parity as a measure of solar competitiveness has been evaluated e.g. by Sinke (2009) and Yang (2009).

2. Methodology

To determine the economics of distributed photovoltaic electricity generation, this analysis presents net present values and levelized electricity cost for a 2 kWp crystalline roof top system owned by a private consumer. The system is completely debt financed. In Brazil until today no legislative framework for feeding of solar electricity has been established, and a net metering policy is assumed for the calculations. Conditions for capital acquisition in Brazil are tight with interest rates being among the highest in the world. Financing terms are of crucial importance for the determination of economic feasibility for investment in a PV system. We hence derived a set of interest rates that represent different possible scenarios of midterm development on the Brazilian capital market. Tables 2 and 3 show the most important system characteristics and assumptions underlying the conducted calculations:

Levelized electricity cost – LEC, and net present values – NPV of the project were calculated for five distinct locations that cover a range of solar radiation intensities and residential tariffs. The examined cities Rio de Janeiro, Sao Paulo, Brasília, Belo Horizonte and Florianópolis are state capitals that through their size and infrastructure are able to generate sufficient demand for an independent market if cost competitiveness is reached. In Table 4 the solar irradiation incidence and the residential tariff in 2010 is shown for each of the chosen locations:

Total costs for the PV installation under examination is 7,600 € (3,711.89€/kWp) which is financed to 100 % through a private loan paid back over the assumed system lifetime of 25 years. The size of the loan and the PV installation were chosen to guarantee that neither financial burden nor required roof area are prohibitively large for a majority of potential customers.

The levelized cost of electricity is the total lifetime costs of generation by a specific system divided by its total electricity production. Both cash and power flows have to be discounted to their present value to account for the lower worth of future consumption. LECs are derived by the following equation 1 below:

$$LEC = \frac{\sum_{t=1}^{n} \frac{\delta_t + \rho_t + \theta_t}{1 + i^t}}{\sum_{t=1}^{n} \frac{G_{in} \times (1 - \beta)}{1 + i^t}} \qquad \text{(eq. 1)}$$

δ_t: *annual debt installment*

ρ_t: *annual interest payment*

θ_t: *annual operating and maintenance expenses*

G_{in}: *system generation in the first year*

t: *year*

n: *system lifetime*

i: *discount rate*

The concept of LECs allows a comparison of generation costs over the life cycle of generation projects differing in size, lifetime or investment size. It has the advantage to convert very distinct expense and generation profiles for individual projects into a single metric easy to compare: €/kWh. Levelized electricity cost however only considers cost of generation, while revenues are not taken into account. It can therefore give an impression of the efficiency of electricity generation, but will not be able to give information on the economic performance of a generation project.

Table 2: Basic characteristics and cost composition of the considered PV roof top system

System characteristics		
Power [kWp]	2.05	
Number of modules	10	
Area [sqm]	13	
Efficiency [%]	16.06	
Cost components	€/kWp	€/system
Module cost	1622.00	3325.10
Inverter Cost	396.00	811.80
Taxes and customs	611.22	1253.00
Freight	27.00	55.35
Metallic structure cost	387.00	793.35
Rest of BOS	115.00	235.75
Installation cost	106.80	218.94
Inverter replacement cost	104.16	213.52
Interconnection fee	24.39	50.00
Vendor's margin	318.32	652.56
TOTAL cost /kWp	3711.89	7609.38

Financial performance of the PV system in this analysis is assessed with discounted cash flow methodology. Net present values are determined for the considered PV system in each interest rate scenario and for each location. The net present value of an investment is the sum of the present worth of annual net cash flows (revenues – expenses) generated by the project. NPVs are generally used for the financial appraisal of long-term projects and account for the so called "time value of money" by transforming cash flows into their values at a specified point of time (generally the present year). This present worth is calculated by discounting the actual cash flows over the system's lifetime with a discount rate using the following equation 2 below:

$$NPV = \sum_{t=1}^{n} \frac{Net\ cash\ flow}{1 + i^{t}} \qquad \text{(eq. 2)}$$

$t: year$

$n: system\ lifetime$

$i: discount\ rate$

Table 3: System and operating parameters assumed for the PV system efficiency and interest rate scenarios considered. All values are presented inflation-adjusted

Parameters for the conducted calculation	
Performance ratio [%]	80
Annual system efficiency loss [%]	1
Discount rate [%]	6.5
Annual electricity price increase (year 0-10) [%]	3
Annual electricity price increase (year 10-15) [%]	2
System lifetime	25
Operating & maintenance cost [% of initial investment]	0.5
Interest rates	
"Subsidized" [%]	3.50
"Mature market" [%]	10.50
"Country specific risk adjusted" [%]	18.75

Table 4: Insolation and residential tariffs for the five Brazilian state capitals studied

City	Insolation (kW/y*sqm]	Tariff [€]
Florianópolis	1624	0.18
Brasília	2124	0.15
Rio de Janeiro	2008	0.19
São Paulo	1807	0.17
Belo Horizonte	2051	0.27

The NPV methodology factors in both annual expense and revenue cash flows and determines the overall economic profitability of the investment. If a net present value is positive, the project is profitable for the investor.

From the equation it is easily understood that the discount rate has strong influence on the result of the equation. This strong volatility to a subjectively set parameter has caused criticism towards NPV analyses and should be kept in mind when interpreting its results. Another point of criticism is the implicit assumption that earned revenues can be reinvested yielding a return equal to the assumed cost of capital acquisition. NPV analysis further assumes a perfect market for capital goods.

The cash flow structure generated by the examined PV system can be described as follows: a stable debt installment payment, annually declining interest payment (interest rate x remaining debt) and a stable annual payment for operation & maintenance constitute the expense cash flows. Revenue cash flows originate from electricity sold and priced with the current utility tariff. Generation declines at a rate of 1 % per year while the electricity tariff is assumed to increase at a variable rate of 2 to 3 % per year. Total revenue flows hence are increasing annually. The discounted net cash flow is the yearly sum of all expenses and revenues. In this work we have analyzed the economics of grid-connected PV under three interest rate scenarios: **subsidized** capital, with an interest rate of 3.50 %; **mature market**, with an interest rate of 10.50 %; and a **country-specific, risk adjusted** scenario with an interest rate of 18.75 %.

3. Results and Discussions

As shown in Tab. 5, in the subsidized capital scenario, (interest rate = 3.50%), PV-generated electricity costs range from 0.16 € in Brasília to 0.21 € in Florianópolis. Procurement of foreign capital on a mature market (interest rate = 10.50%), leads to electricity generation costs between 0.27 € and 0.35 €. If all country specific risks are factored in and money has to be obtained at the respective higher interest rate (18.75%), costs between 0.40 € and 0.52 € per kWh arise for electricity generation with a PV installation. For each scenario, levelized costs vary according to the different radiation profiles, resulting in the lowest overall cost in Brasília and the highest in South Brazil's Florianópolis. The range of difference in costs is considerable between each of the examined cities and amounts to roughly one third of the lowest costs that are calculated for Brasilia's solar irradiation profile. The range of cost difference increases with higher interest rates as higher total costs have to be divided by a steady amount of generated electricity. While in the subsidized scenario, the distance from lowest to highest tariff is 0.05 €, it increases to 0.08 € and 0.12 € in the other scenarios respectively.

Table 5: Levelized electricity cost of solar generation with a 2kWp roof top PV installation for different interest rate scenarios in five different Brazilian state capitals

Levelized PV Electricity Cost (€)		Location				
		Belo Horizonte	Brasília	Florianópolis	Rio de Janeiro	São Paulo
Scenario	"Subsidized"	0.17	0.16	0.21	0.17	0.19
	"Mature market"	0.28	0.27	0.35	0.28	0.32
	"Country-specific risk adjusted"	0.41	0.40	0.52	0.42	0.47

Variation in LECs is significant for a given location when switching from one interest rate scenario to another. If the mature market scenario (interest rate = 10.50%) is considered a base case, switching to a subsidized interest rate (interest rate = 3.50%) on average reduced LECs by 40 % of the original costs. Examining the same figure for the country-specific risk adjusted rate (interest rate = 18.75%), a cost increase of 47 % on average could be observed. These values illustrate the essential importance of access to low cost financing for the economic viability of PV systems. In the case investigated, increasing the interest rate by one percentage point raised levelized electricity cost by 6 %. Obviously, the country-specific interest rate results in economically prohibitive generation costs for PV installations while at subsidized capital costs LECs are today already in the range of residential tariffs in all considered locations.

To facilitate the interpretation of these numbers, LECs for small solar systems from recent literature (as well as auction prices for other electricity sources as a good estimation of LECs) are presented in Fig. 1. Due to the volatility of LECs for PV electricity with respect to financing assumptions and radiation, the values differ over a considerable range. It can be stated that LECs for solar electricity in Brazil show competitive or superior levels to published values for LECs depending on the underlying interest rate scenario. It should be noted, however, that PV costs should always be compared with residential tariffs (far right bar in Fig. 1), and not with centralized generation busbar costs.

Overall economic performance of the considered system in the five state capitals is presented in Table 6. Positive net present values are realized for all locations under the low interest rate scenario, meaning that if low capital costs can be realized, PV electricity is economically competitive in year 2010 even in low radiation sites like Florianópolis. Economic feasibility in the developed PV financing market scenario is only given for system owners in Belo Horizonte where high residential tariffs boost revenue flow from solar-generated electricity. Highly negative present value figures are obtained in the country-specific risk adjusted scenario, which underpins the already mentioned prominence of interest rates in the determination of economic viability. Again, it has to be kept in mind that LECs for photovoltaic electricity are always compared to retail electricity tariffs due to the distributed nature of the assumed generation concept.

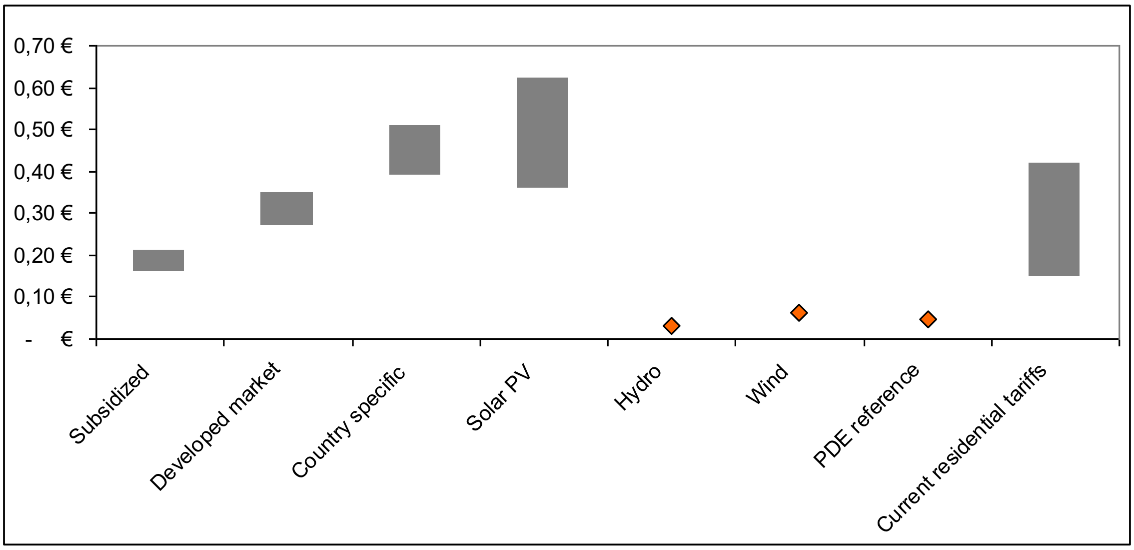

Fig. 1: Comparison of levelized electricity costs in Brazil for three interest rate scenarios with common PV LEC estimations and conventional generation costs in the Brazilian electricity sector and current (2011) residential tariffs range for the five Brazilian capital cities analyzed. The PDE reference refers to the average cost of newly installed capacity from the Brazilian government's Plano Decanal de Energia" (PDE).

Table 6: Net present values of an investment in a 2 kWp roof top PV installation for different interest rate scenarios in five different Brazilian state capitals

Net Present Value (€)		Location				
		Belo Horizonte	Brasília	Florianópolis	Rio de Janeiro	São Paulo
Scenario	"Subsidized"	6,544	1,332	668	2,634	863
	"Mature market"	2,604	-2,609	-3,273	-1,306	-3,077
	"Country-specific risk adjusted"	-2,040	-7,253	-7,916	-5,950	-7,721

From the data presented, a direct conclusion can be drawn to the financial attractiveness of investing in the PV system put forward in this work. Not considering the additional value added through the benefits of distributed, emission-free and silent generation, it would still be advisable for private persons or commercial entities in year 2010 to install PV systems on their roof if they have access to capital at an interest rate of 3.5 %, e.g. from the Brazilian development bank BNDES. Residents in Belo Horizonte will benefit financially even if the developed PV financing market rate of 10.50% is applied. However, investment in PV technology has no case in Brazil at current turn-key system prices, if all country specific risks are accounted for in the determination of risk premiums for loans to obtain PV installations.

To classify each of the chosen locations and their implicit conditions with respect to grid parity, PV-generated LECs and residential tariffs have to be compared. In Table 7, the gap between PV-generated LECs and residential prices are shown. Our calculations show that in the first scenario, PV-generated LECs are almost competitive in all observed state capitals and significantly inferior to the residential tariff in Belo Horizonte. Table 7 also descriptively highlights the importance of interest rate and utility tariff as the two most relevant figures determining grid parity conditions in the case of Brazil. On the one hand, for the case of exceptionally high residential tariffs as in Belo Horizonte, PV-generated LECs of solar electricity can undercut the utility price by 0.10 € and even beat the distributor's price in the developed market scenario, while for the other locations the cost premium for solar generation at this interest rate ranges from 0.10 € to 0.17 €. On the other hand, even extraordinarily high utility tariffs will not compensate the impact of interest rates in exceeding the 10 % threshold like the values assumed in the developed market and country-specific scenarios. Another mentionable result that can be derived from Tables 6 and 7 is that LECs meeting or undercutting grid parity are not a necessary condition for a PV system to be economically rewarding. Net present values for Brasília, São Paulo and Florianópolis are positive despite levelized electricity costs that are above the residential rates.

Table 7: Difference between levelized electricity cost 2 kWp roof top PV installation and residential tariffs (2010) for different interest rate scenarios in five different Brazilian state capitals

Tariff difference (€)		Location				
		Belo Horizonte	Brasília	Florianópolis	Rio de Janeiro	São Paulo
Scenario	"Subsidized"	- 0.10	- 0.01	0.02	- 0.01	0.04
	"Mature market"	0.01	0.10	0.16	0.10	0.17
	"Country-specific risk adjusted"	0.14	0.23	0.33	0.24	0.32

4. Conclusions

We have shown that debt financed grid-connected solar systems on Brazilian roof tops at low interest rates and current PV system turn-key prices can be economically feasible already in 2010at this stage of solar industry development. It was further shown that the cost of capital in the case of Brazil is the decisive parameter in the determination of PV competitiveness with conventional generation sources. For that reason, the provision of financial market conditions that enable low cost long term financing is an essential requirement for PV to become an economically justifiable generation alternative. If Brazil's optimal irradiation conditions could be combined with low interest rates, grid parity and economic viability of distributed generation units are conceivable in the short term in several Brazilian cities with current PV system prices. With the declining costs of PV, this scenario will lead to even more favorable conditions. PV electricity installed at considerable capacity in those regions with best insolation/tariff profile could also alleviate the aforementioned problems of electricity security, environmental and social impacts and transmission and distribution costs. However, at current lending costs, PV roof top systems still have a financial performance which is by far inferior to regular electricity purchase from the local utility. It should be mentioned here that a suitable legislative framework is imperative for the successful introduction of PV technology in Brazil and steps by the government will have to be taken before the present conclusions can be transformed into actual projects. The final and most important conclusion derived from the data presented here is that the Brazilian market holds huge potential for distributed PV systems of small size. The solar industry can take advantage of the exceptionally favorable conditions in certain Brazilian cities with insolation and residential tariffs like those of Belo Horizonte and start to stepwise develop Brazil as a market where no governmental financial aid or premium prices are needed for economic justification of solar installations. The Brazilian government should evaluate whether providing subsidized funding to PV installations, similar to what is currently available for large hydro projects, could contribute to improve the actual electricity provision infrastructure. Four factors will be crucial for the progress of PV competitiveness in Brazil: the interest rate development, the development of electricity prices, the creation of a comprehensive set of laws and regulations providing the basis for PV systems feeding into the public grid and the continually falling of PV system prices. If government and industry can achieve to improve these fundamental factors, Brazil might soon become a booming market for PV technology with no need of subsidies.

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