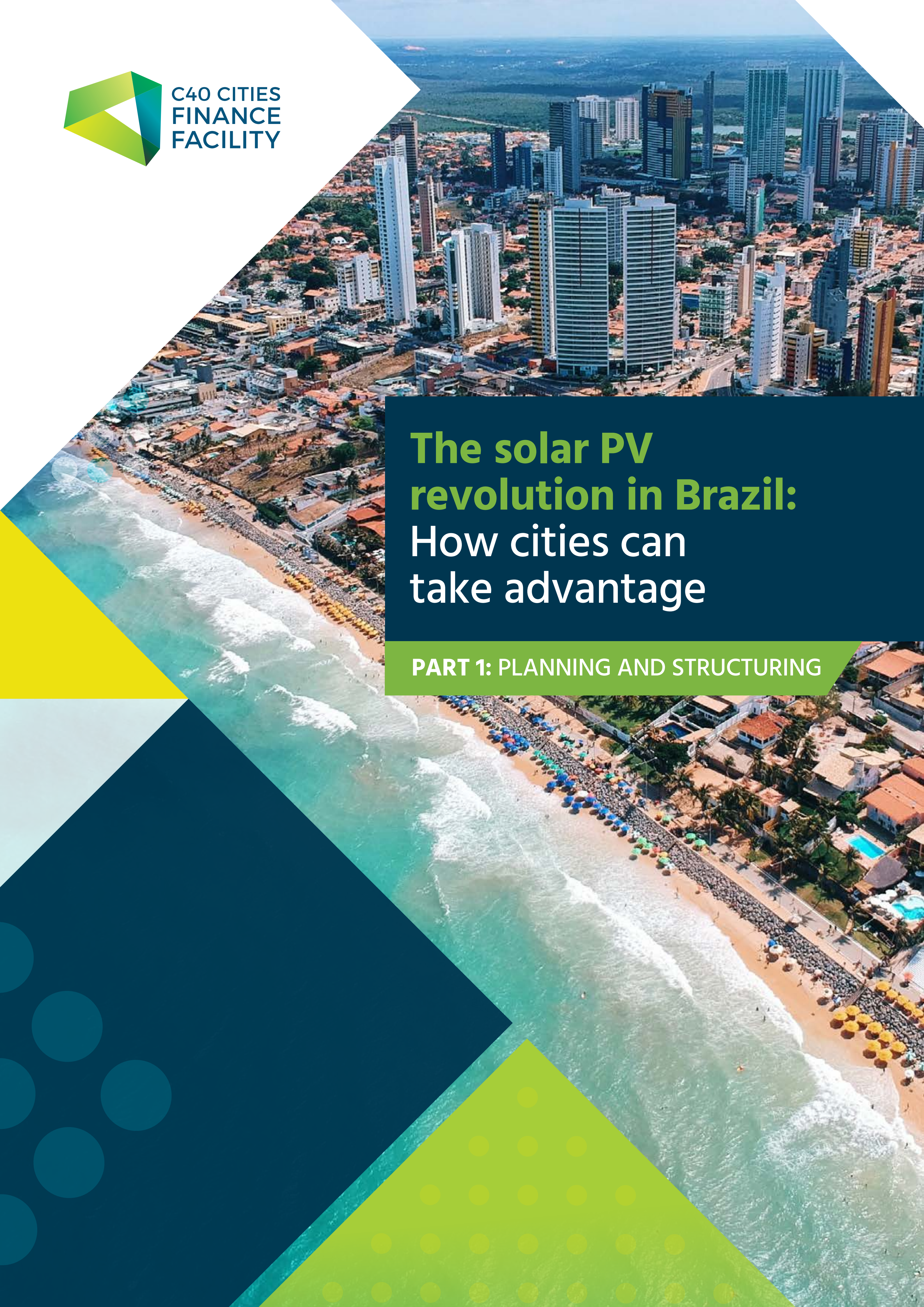
C40 CITIES FINANCE FACILITY

The solar PV revolution in Brazil: How cities can take advantage



PART 1: PLANNING AND STRUCTURING

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About the C40 Cities Finance Facility:

The C40 Cities Finance Facility (CFF) is a collaboration of the C40 Cities Climate Leadership Group and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The CFF supports cities in developing and emerging economies to develop finance-ready projects to reduce emissions to limit global temperature rise to 1.5°C and strengthen resilience against the impacts of a warming climate. The CFF is funded by the German Federal Ministry for Economic Development and Cooperation (BMZ), the Children's Investment Fund Foundation (CIFF), the Government of the United Kingdom and the United States Agency for International Development (USAID).

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Executive summary

Brazil has the potential to become a global leader in the use of solar PV. Hours and intensity of sunshine are high throughout the country, prices have plummeted in recent years, and legislation regulating on-grid distributed generation has been in place since 2012. These factors have contributed to an exponential adoption of this technology in Brazil.

Municipalities in Brazil are beginning to appreciate the many benefits of developing solar PV projects. Besides savings in electricity costs, new jobs and a potential boost to any administration's public image, solar PV can also reduce greenhouse gas (GHG) emissions by offsetting the use of non-renewable sources, such as oil and gas. The use of PV power by municipalities is also strategically linked to Brazil's commitment to increase the share of renewable, non-hydroelectric power sources in the national electricity mix in line with the country's Nationally Determined Contribution (NDC) goals to the Paris Agreement, signed at COP21 in 2015.

To take advantage of the opportunities presented by solar PV projects, municipalities should take the following steps:

Establish clear governance structures and make the initial planning decisions. These include:

- Setting up an expert committee in charge of the project(s), with representatives from across the municipality.
- Outlining clear objectives for the solar PV project and defining measurable indicators.
- Evaluating legal options.
- Assessing initial financing options.
- Engaging with all affected stakeholders.
- Finalizing the location(s) of the solar PV project.
- Defining a preliminary project timeline.

Conduct an initial technical assessment of the proposed project ('sizing'). This preliminary project preparation process should include:

- Determining the preferred generation modality (Self-Consumption, Condominium, Remote Consumption, Shared Generation).
- Calculating the electricity consumption patterns of the consumer unit(s).
- Calculating the average amount of solar irradiation that will shine on the PV array per day in a year.
- Estimating the PV nominal power needed to meet the yearly electricity generation expected.
- Calculating the number of panels needed and, consequently, the area the PV installation will occupy.
- Choosing between a roof- or ground-mounted system.
- Assessing required safety measures and considerations.
- Re-evaluating the project's feasibility if the preliminary technical analysis shows that it will not be feasible.

This preliminary analysis is designed to be an iterative process through which initial decisions may be revised before reaching a final decision. After concluding this initial process, municipalities can begin the design phase, which will require detailed considerations on procurement and financing.

Municipalities in Brazil are beginning to appreciate the many benefits of developing solar PV projects

Objectives of the report

This report presents an overview of the current situation of solar PV in Brazil, covering the technology's socioeconomic, environmental, and strategic benefits. It describes how municipalities can evaluate different business models for the deployment of solar PV and provides a step-by-step guide on how to plan and develop PV projects, including legislation, governance, and technical aspects.

In order to provide city managers, decision-makers, and public servants with information that will be useful to plan, design, fund, and implement solar PV systems, the following aspects are covered:

- Current status of PV in Brazil
- Benefits of PV for municipalities
- Laws and regulations of the PV sector in Brazil
- Business models that can be adopted by Brazilian municipalities
- Governance and initial planning of municipal PV projects
- Technical and economic feasibility assessments
- Step-by-step guide to design and develop PV systems
- Success cases from Brazil

A second report will follow, which will cover other aspects related to municipal solar PV projects, such as procurement and funding.

1. Introduction

Municipalities are key players in the fight against the climate crisis. Cities in many regions around the world are suffering increasing pressure from the effects of climate change, including severe droughts, floods, heat waves, fires, and storms. The United Nations' Intergovernmental Panel on Climate Change (IPCC) in 2018 (IPCC, 2018) warned that if global warming exceeds 2°C – a limit set forth by the Paris Agreement –, sea levels will continue to rise, fertile lands are likely to turn into deserts, and extreme weather phenomena will become more frequent.

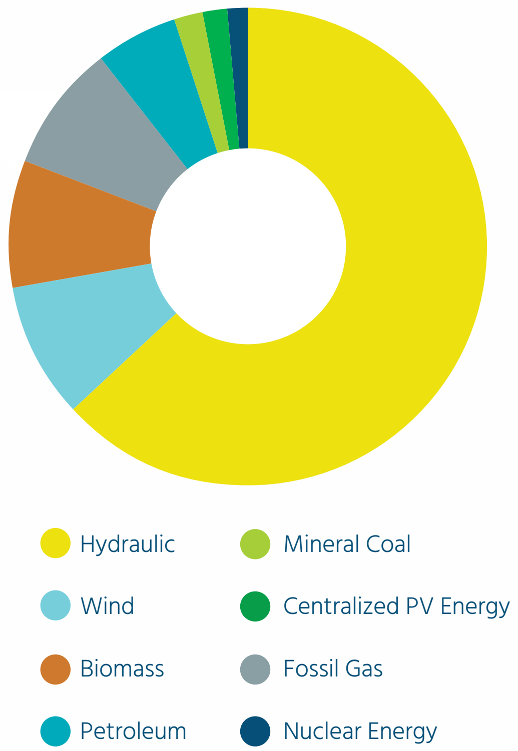


Figure 1: Brazilian Electricity Mix (Sistema de Informações de Geração da ANEEL, 2020)

All of this imposes enormous challenges to municipalities, home to 55% of the world's population. Cities account for approximately 75% of global greenhouse gas (GHG) emissions (REN21, 2019), two-thirds of which originate from the energy sector (IPCC, 2018). Therefore, to mitigate the effects of climate change, local governments have a very important role to play by taking concrete steps to increase the share of renewable sources for electricity generation, while also reducing energy consumption. Renewable energy projects such as solar PV offer cities the opportunity to not only reduce GHG emissions, but also decrease air pollution, improve public health, support their region's renewable energy industry, build resilient infrastructure, and achieve significant financial savings.

The Brazilian electricity mix (Figure 3) is already predominantly made up of renewable energy sources. However, the country's electricity needs are dependent on large-scale hydroelectric power, which is subject to fluctuations in rainfall and can cause negative social and environmental impacts. A viable alternative to diversify the electricity mix, reducing dependency on large-scale hydro and on fossil fuel power plants, is the use of renewable energies, such as solar photovoltaic (PV).

Worldwide, the use of renewable energy – including wind, solar PV, small hydropower, biomass, and geothermal energy – has increased significantly over the past decades, providing 27% of global electricity generation by the end of 2019 [3]. Solar PV is the fastest-growing renewable energy technology in this decade. It reached 627 GW of total installed capacity worldwide by the end of 2019 (REN21, 2020), with 39 countries with a cumulative capacity of 1 GW or more, including Brazil (REN21, 2020).

In addition, in recent years, the price of PV technology has decreased thanks to technological improvements, mass production, development of local supply chains, policy incentives and the growing maturity of the sector. Between 2010 and 2019, the global weighted average levelised cost of electricity (LCOE)[1] for solar PV fell by 82%, to USD 68.40 per megawatt-hour (MWh) (IRENA, 2020).

PV power capacity has grown exponentially in Brazil since on-grid distributed generation was regulated in 2012 with the publication of REN 482 by the Brazilian Electricity Regulating Agency (ANEEL). Before that, distributed generation in Brazil was largely limited to off-grid installations, using either solar PV or fossil sources, such as diesel. By May 2020, Brazil's solar PV capacity is estimated at 5.7 GW (ANEEL, 2020) - considering both centralised and distributed generation (see Box 1) – representing nearly three times the capacity (2.2 GW) in 2018.

[1] LCOE is the ratio of lifetime costs to lifetime electricity generation, both of which are discounted back to a common year using a discount rate that reflects the average cost of capital. OR: LCOE measures the lifetime costs divided by the electricity production of a power plant. Therefore, it calculates the present value of the total cost of building and operating a power plant over an assumed lifetime. LCOE is a measurement used to assess and compare alternative methods of electricity production.

Prices have also dropped significantly. Figure 1 shows the price reduction of small-scale PV installations from 2013 to 2018. By January 2020, these numbers dropped even further, with unitary prices per Wp falling to R$ 5.45 for small installations up to 5 kWp, R$ 4.03 for 6 to 30 kWp, R$ 3.52 for 31 to 100 kWp, and as low as R$ 3.22 for installations ranging from 100 kWp to 5 MWp (Greener , 2019).

Generally, Brazil has great potential for the generation of solar energy. Table 1 presents Brazil's solar irradiance in comparison to Germany, France and Spain. Brazil's least sunny region has an irradiance of around 4.25 kWh/(m^2.day), a value 25% higher than the solar irradiation of Germany's sunniest region, 3.42 kWh/(m^2.day).

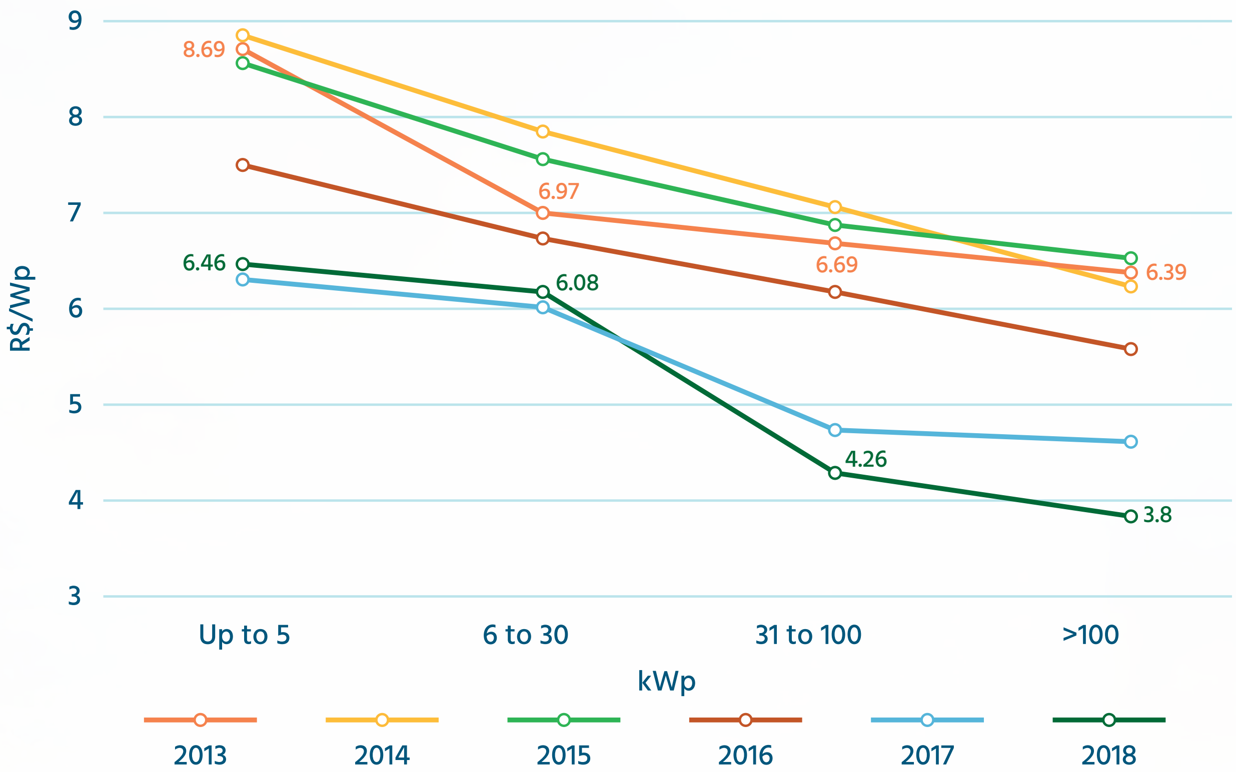


Figure 2: PV system prices by nominal range according to the Brazilian PV market study by Instituto IDEAL (IDEAL; AHK-RJ, 2019)

Solar irradiance (kWh/m^2/day)				
Country	**Minimum**	**Maximum**	**Average**	**Area (Thousand km^2)**
Germany	2.47	3.42	2.95	357.02
France	2.47	4.52	3.49	543.97
Spain	3.29	5.07	4.18	504.97
Brazil	4.25	6.75	5.50	8,515.77

Table 1: Photovoltaic solar potential – Brazil, Germany, France and Spain (SWERA, 2014)

[2] Wp (Watt-peak) or kWp (kilowatt-peak) refers to the nominal power of a PV module or array. This unit represents the amount of electric power that can be supplied by one PV module (or by an array) under Standard Test Conditions (STC). It is used to compare the output of PV modules from different manufacturers and to forecast the amount of electricity they can produce in "optimum" laboratory conditions.

BOX 1

Centralised generation

Centralised generation refers to large-scale power plants located far away from urban areas, requiring the use of transmission lines and energy substations to supply electricity to these centers.

In Brazil, centralised power plants have an installed capacity greater than 5 MW. Examples include large-scale thermal, hydroelectric, and nuclear plants, as well as wind and solar PV farms. Figure 3 presents the breakdown of Brazilian centralised electricity generation, with a 1.7% participation of solar PV.

Figure 3: Centralised generation

Distributed generation

Distributed generation refers to small-scale and decentralised electricity generation systems located close to consumers and distributed around the grid, such as rooftop solar PV systems. The net metering scheme, adopted since distributed generation was regulated in Brazil (2012), has made the distributed PV market grow exponentially. By May 2020, the total installed capacity of distributed generation systems in Brazil reached nearly 3 GW, of which solar PV represented over 90% (Figure 5) (ANEEL, 2020).

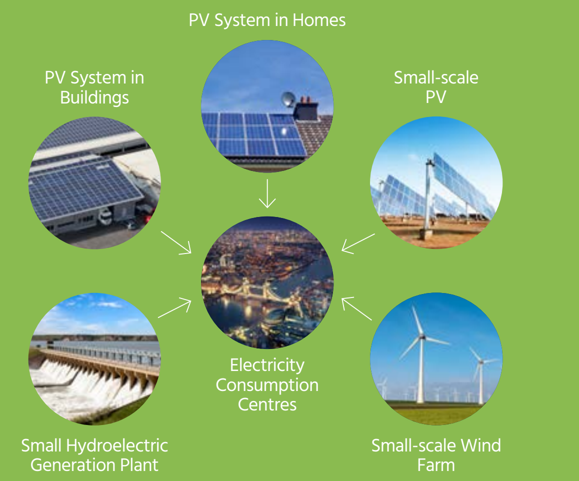


Figure 4: Examples of distributed generation systems

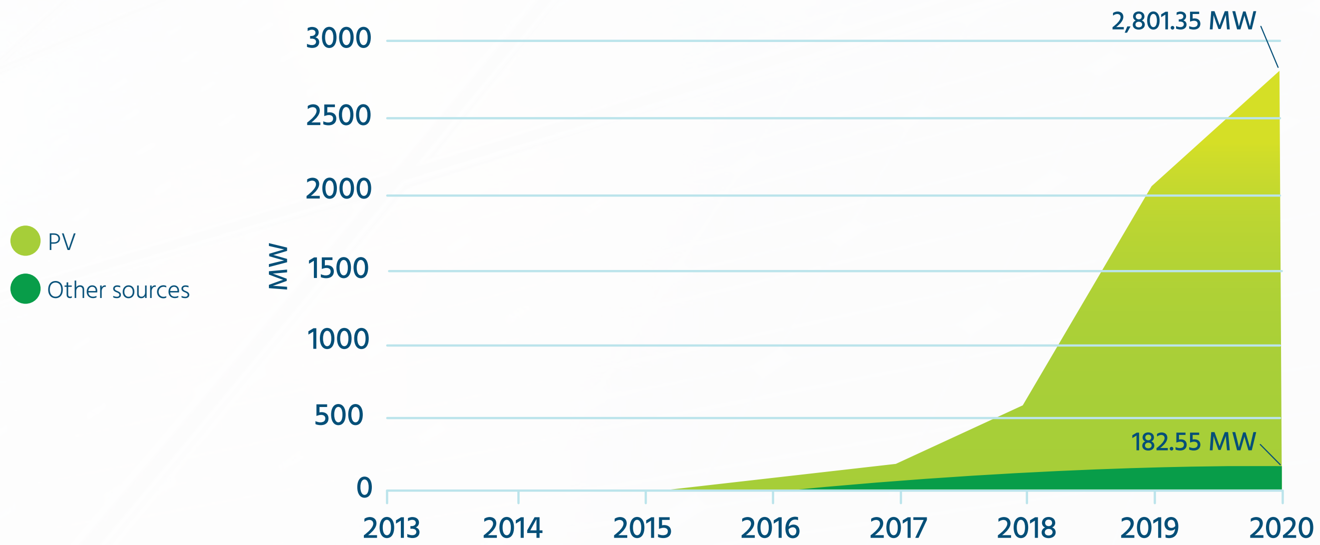


Figure 5: Distributed generation power capacity growth / Source: ANEEL, 2020

1.1. Benefits of solar PV for municipalities

The use of small-scale, decentralised solar PV has a host of benefits for municipalities in Brazil. These can be packaged in different ways to help make the case for solar PV projects, depending on the context.

Socio-economic benefits

- Savings on electricity costs: funds that were previously spent on electricity can be reallocated to other priority issues in the municipality.
- Attraction of private investments and development of the solar PV supply chain.
- Generation of local, high-quality jobs.
- Training and technical qualification of new professionals in the municipality.

Environmental benefits

- Reduction in both GHG emissions and air pollution, when offsetting energy generated by thermal plants.
- Electricity production with no noise, low environmental impact and no emission of particulate matter.
- Low waste production, due to long service life of main PV components, such as modules and inverters.

Other benefits

- PV systems are modular, easy to transport and assemble, and adapt to existing buildings in public and private areas (schools, hospitals, parking lots, shopping centers, among others).
- Diversification of the Brazilian electricity mix, allowing less dependence on hydroelectric power, susceptible to changes in rainfall made even more pronounced by climate change, leading to increased energy security and reliability of the national electricity grid, as well as lower electricity tariffs.[3]
- Improvement of local level grid reliability;
- Postponement of grid reinforcements measures
- Reduction of transmission and distribution losses.
- Showcase of the municipality's concern for the environment.
- Contribution to national compliance with NDC goals.

[3] In Brazil, the electric grid is operated as such that thermal plants are activated only when necessary, in other words, when all other cheaper power sources, such as hydro and wind, are operating but are insufficient to meet the country's electricity demand. Therefore, the increase of renewable sources, such as solar PV, effectively reduces the number of operating hours of thermal plants, which are the most expensive power plants in Brazil. Consequently, the national cost of electricity generation decreases, which impacts the electricity tariffs passed on to consumers, either by reducing the tariffs or by lowering the rate of annual increases.

Impact on job creation:

The Brazilian Solar Photovoltaic Energy Association (ABSOLAR) estimates that for every 1 MW of PV installed, 25 to 30 direct jobs are created in the country (ABSOLAR, 2020). In 2019, the sector generated more than 130,000 jobs, and ABSOLAR forecasts the creation of over 100,000 new jobs in 2020 (ABSOLAR, 2020).

Climate impact:

The reduction in CO_2 emissions through the use of PV systems can be calculated by multiplying the electricity generated times the average national CO_2 emission factor for a given year. In 2019, with the average CO_2 emission factor in Brazil at 0.075 tCO_2/MWh, a PV system generating 100 MWh/year would prevent the emission of 7.5 tons/year of CO_2 into the atmosphere (MCTIC, 2019).

Nationally Determined Contributions (NDCs):

In 2015, Brazil submitted its NDCs to the Paris Agreement. The country's goal for the energy sector is to reach a 45% share of non-hydroelectric renewable energy in the energy matrix by 2030 (REPÚBLICA FEDERATIVA DO BRASIL, 2016). The expansion of solar PV is key to reaching these goals, and municipalities have an important role in leading this process.

Other benefits:

Solar PV projects are one of several ways to reduce municipal electricity costs and should be part of a larger sustainability strategy. Energy efficiency projects in public buildings, transportation, water treatment, street lighting, and other municipal services also help reduce electricity costs. Coupling PV projects with energy efficiency projects can greatly enhance positive impacts, improve financial indicators, and increase the range and likelihood of financing opportunities.

ABSOLAR estimates that for every 1 MW of PV installed, 25 to 30 direct jobs are created in the country

2. Distributed generation legislation in Brazil

In Brazil, distributed generation systems using renewable energy became a reality with resolution REN 482/2012. Since then, the legislation has gone through several changes. A timeline portraying the context and evolution of distributed generation regulation in Brazil is presented in Figure 6.

In January 2020, solar PV distributed generation reached the 2 GW milestone.

Figure 6: Timeline portraying the evolution of distributed generation regulation in Brazil. Source: Elaborated by the authors.

2.1. Distributed generation modalities according to ANEEL's Resolution

ANEEL's REN 482/2012 (ANEEL, 2012) regulatory framework allows individuals and any legal entities to generate their own electricity at the consumer unit location through a one-to-one electricity net-metering scheme (each kWh exported to the grid generates a one-kWh credit).

The energy credit can be used for a period of up to 5 years (60 months). However, even if the distributed generation system generates the same (or more) amount of electricity consumed in the consumer unit that it is connected to, the electricity bill will never be zero. There is a minimum monthly connection fee that accounts for the availability of the distribution grid to the consumer unit. The fee varies depending on the type of connection to the grid (i.e. voltage and number of phases).

ANEEL Resolutions REN 482/2012 and REN 687/2015 (ANEEL, 2012) (ANEEL, 2015) establish four modalities that can be used for distributed generation projects: (i) Self-Consumption, (ii) Remote Generation, (iii) Shared Condominium, and (iv) Shared Distributed Generation. When designing a business model, one of these distributed generation modalities must be chosen.

Self-Consumption ("Geração junto à carga")

On-site PV generation in the consumer unit itself is the most common alternative of distributed generation in the Brazilian market. In this modality, electricity is produced at the same location where it is consumed.

Figure 7: Self-Consumption, Maury Garrett, ENIC (2018)

Remote Generation ("Autoconsumo Remoto")

Applicable to consumers who have more than one consumer unit in their Individual Taxpayer Registry (CPF – *Cadastro de Pessoa Física)* or National Registry of Legal Entities (CNPJ – *Cadastro Nacional de Pessoa Jurídica).* Under this alternative, consumers may offset electricity credits in several units, with a pre-established percentage between them. One of the advantages of this model is that the electricity generation system can be located in an ideal location for production. Participating units must be within the same concession area, that is, served by the same electricity distribution utility company.

Figure 8: Remote Generation, Maury Garrett, ENIC (2018)

Shared Condominium ("Empreendimentos com múltiplas unidades consumidoras")

Shared condominiums are characterized by vertical or horizontal condos with a distributed generation system installed. The electricity generated is compensated among all the joint consumer units. This alternative can be applied either to residential or to commercial condos. All consumer units must be located at the same property.

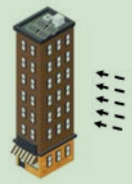


Figure 9: Shared Condominium, Maury Garrett, ENIC (2018)

Shared Distributed Generation Consortia and Cooperatives ("Geração Compartilhada")

Shared distributed generation can be structured either through a consortium or through a cooperative. Under the consortium mode, two or more companies make an agreement through a business contract in order to take benefits from sharing a distributed generation system. The consortium must subscribe to the National Registry of Legal Entities (CNPJ – *Cadastro Nacional de Pessoa Jurídica*) and own the consumer unit where the distributed generation system will be installed. Cooperatives are made up of individuals who wish to voluntarily join efforts, according to the cooperative's principles, to generate their own electricity through a distributed generation system. The electricity produced is compensated at the cooperative members' consumer units through net metering.

Figure 10: Shared Distributed Generation, Maury Garrett, ENIC (2018)

2.2. Understanding the current revision process

ANEEL is currently revising REN 482/2012, and evaluating the role of each component in the electricity tariff, as presented in Figure 11.

These components are:

- **Energy Tariff (TE):**
  i.e. the remuneration of the energy generators, representing about 50% of the electricity tariff. Of this amount, 38% accounts for the energy itself and 12% for sector charges.
- **Distribution System Usage Tariff (TUSD):**
  i.e. the remuneration of the transmission and distribution utility companies, representing about 50% of the electricity tariff. This amount can be broken down into payment for transmission lines (6%) and distribution lines (28%), with energy losses (8%) and sector charges (8%) also accounted for.

ANEEL has proposed changes to how energy credits will be compensated in distributed generation systems (ANEEL, 2018). Five alternatives have been formally presented for public consultation. With each alternative, one or more of the electricity tariff components would no longer be compensated, as shown in Figure 12. Alternative 0 represents the current one-to-one credit compensation system framework in place today. On the other hand, Alternative 5 represents the worst-case scenario for "prosumers"[4]: if this alternative is selected, only 38% of the electricity produced by a distributed generation system would be compensated.

The outcome of this revision process will have a significant impact on the economic feasibility of decentralised electricity generation projects. Project managers and proponents of solar PV projects must always remain up-to-date with the legislative process and include possible changes in risk assessment scenarios.

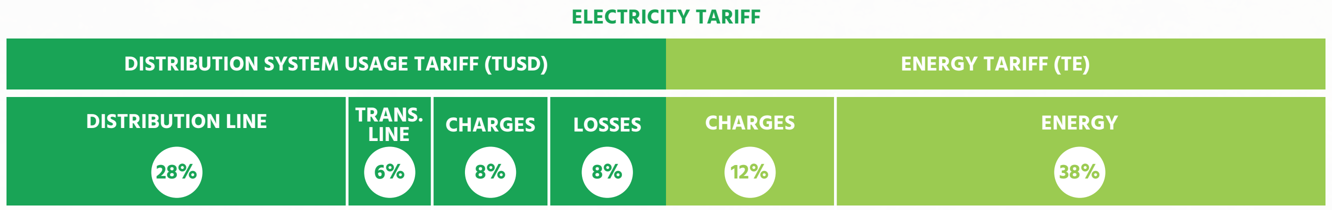


Figure 11: Electricity tariff components. Source: Elaborated by the authors.

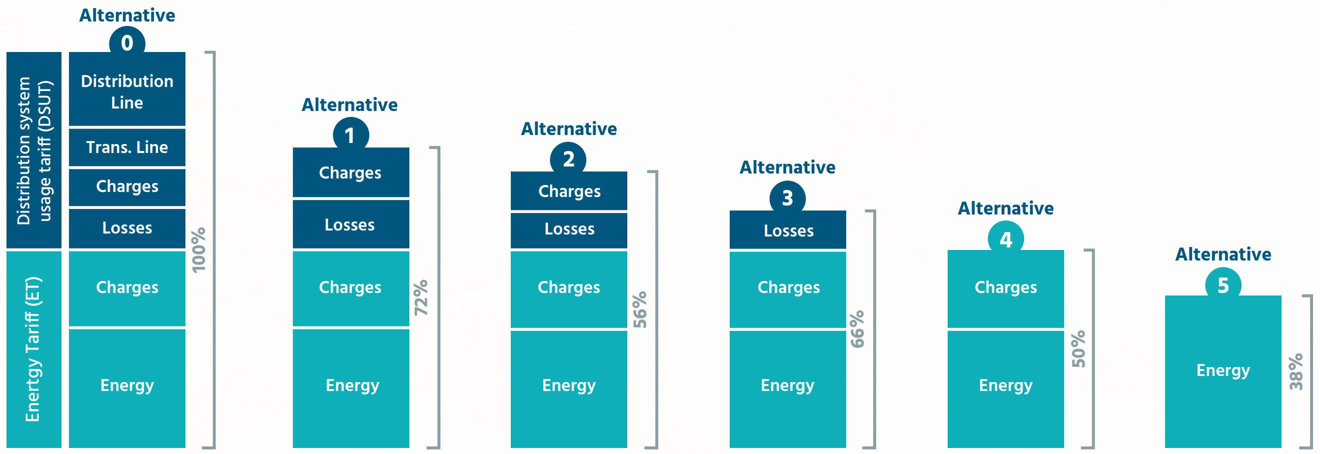


Figure 12: Alternatives formally proposed by ANEEL for public consultation as part of the distributed generation regulation revision process.

[4] Prosumer refers to a person who both produces and consumes a product. In this case, a person who consumes and produces electricity through a distributed generation system.

3. Governance and initial planning

Municipalities can implement PV systems in:

- **Urban areas:** Public buildings, social housing, bus stops, public transport stations, landfills, road signage.
- **Countryside:** Public buildings, water pumping stations, among others, depending on each municipality.
- **Street lighting:** The use of solar PV in public lighting can eliminate the need for additional distribution lines and expensive infrastructure investments.

When a municipality considers installing one or more solar PV systems, there are certain aspects to consider, explained below. Although they are presented here as steps, please note the steps are not exactly sequential, but, rather, occur somewhat simultaneously, and that the exact order in which they occur varies depending on the municipality, the context, and the project.

STEP 1: Governance

The first step is to establish a formal committee, often called a PIU (Project Implementation Unit), which will be responsible for planning and overseeing the entire project. The PIU should be multidisciplinary and include members from various municipal departments. Key departments include planning and management, environment, finance/treasury, procurement and contracts, public works, urban services, and departments responsible for buildings or areas where PV is considered, such as education and health. Some cities have a transversal department dedicated to institutional relations or strategic partnerships, whose participation would also be crucial. The mayor's office should be represented to ensure their political support of the project. The PIU should have a leader, and roles and responsibilities should be clearly defined. It should include both high-level officials, such as secretaries, as well as technical personnel.

STEP 2: Establishing clear objectives and timeframe

The municipality must also establish clear objectives for the solar PV project. The PIU must aim to answer the following questions, at a minimum:

- Why is the municipality considering solar PV?
- What does it wish to achieve?
- Are the motives environmental, social, financial, educational or political?
- What impacts are envisaged?
- What are the timeframes and expectations in the context of a typical 4-year political mandate?

The exercise of delving into these key questions will help the municipality make several important decisions from the start and allow the PIU to define indicators and establish measurable goals.

STEP 3: Legal framework

National regulations on solar PV already exist (REN 482/2012). The municipality may have to establish legislation of its own, which the city council will need to approve. For example, certain types of procurement or financing require local laws; the establishment of the PIU itself may be formalised by decree; or a bill may be necessary to define how financial savings generated by the project will be distributed. The definition of the legal framework must an analysis of any environmental restrictions or whether environmental or other permits are necessary, and if the legal status of the intended public buildings or land allows for the installation of a solar PV plant.

STEP 4: Preliminary considerations on financing

Although this may be defined in detail later, the municipality must review different project financing options available and whether there are any restrictions on access to those options. Is there a preference for using internal resources or for securing a loan? Does the municipality's credit rating allow it to issue debt in the amount required? Is the local government open to innovative models, such as PPPs (public-private partnerships), performance contracts or leasing? If national or international development financing is considered, are there specific requirements or processes that must be met and that should be planned from the beginning? These are the type of questions that should be considered by the PIU.

STEP 5: Stakeholder engagement

Projects tend to be most successful when all interested parties are involved early in the process. In municipal PV projects, this may include the local electricity utility company, city council, relevant municipal departments, state government, financial institutions, potential suppliers and service providers, as well as civil society. Drafting a communication plan that indicates who will engage which stakeholder, how, and when, is a key step in the process.

STEP 6: Deciding where to implement

The municipality must define the initial scope of the PV project, keeping in mind the objectives defined earlier. It may choose to use a small number of buildings with high solar potential (e.g. large unobstructed roof areas), for instance, or to roll out a large-scale PV program on small, replicable constructions, like schools and health units. Ground-mounted systems in open areas, such as urban landfills, may be considered as well. A pilot project may be chosen to raise the profile of the technology, such as an iconic building in which the PV system can be easily seen. In any case, technical and financial criteria should guide the decision-making process, seeking to maximise benefits (not only energy savings, but also positive environmental, social and educational impacts) and optimise the return on investment. As described in the next section, the initial project scope may eventually need to be modified depending on preliminary calculations, in an iterative process.

STEP 7: Deciding when to implement

The PIU can now set a preliminary project timeline. Aspects to consider include whether to begin with a small-scale pilot project; available human and financial resources; special target dates, such as elections; and other external factors, like inaugurations, local festivals, and even seasonal weather patterns.

4. Technical aspects and sizing of the PV system

Once the initial planning has taken place, the municipality should consider the technical details of the PV project.

First, the municipality must determine which consumer unit(s) the PV system will generate electricity to be compensated for and where the system will be installed. At this stage, it may be possible to identify the best distributed generation alternative for the project: Self-Consumption (Geração junto à carga), Remote Generation (Auto-consumo remoto), Shared Condominium (Empreendimento com Múltiplas Unidades Consumidoras) or Shared Generation (Geração Compartilhada).

Secondly, the municipality should calculate the system's size and identify if the area available for the PV system is enough to meet electricity consumption. It should also consider the location where the PV system will be installed. For example, will it be roof- or ground-mounted?

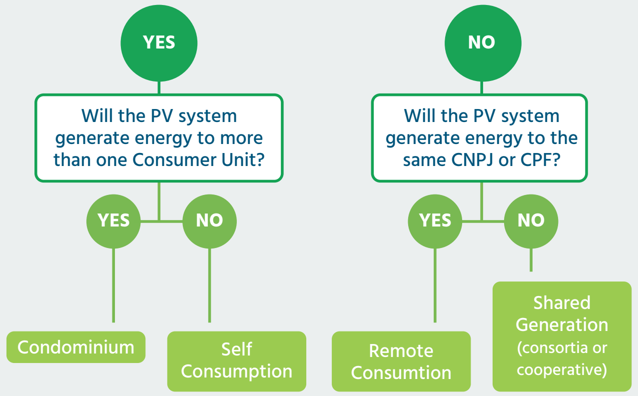
Thirdly, after analyzing these aspects, the municipality should conduct a reevaluation of the original project idea: after going through the evaluation, the PIU may realise that the selected area is not large enough or does not have the proper solar irradiation or security conditions for the installation of a PV system. It might be necessary to reconsider the installation site(s) and, consequently, the modality of distributed generation initially chosen.

Box 2 presents a simplified step-by-step process to guide PV system project planning. This sequence is intended to enable a preliminary technical and economic assessment. The final system's design planning and site evaluation should be done by a specialised professional.

BOX 2

STEP 1: Distributed generation modality:

Are the PV system and the Consumer Unit in the same place?



STEP 2: Electricity consumption:

Understanding the electricity consumption patterns of the consumer unit(s) that will receive the energy credits from the PV project is an essential step for calculating the system's size. The PV system can be designed to satisfy a considerable fraction of the consumer unit's electricity consumption, if enough area and upfront financial resources are available. This decision will depend on the energy needs, expectations, site availability, and budget restrictions for the project. To calculate the electricity consumption, take the most recent electricity bills from the consumer unit(s) and calculate how much electricity was consumed in one year. Use this number in STEP 4.

STEP 3: Solar irradiation:

Solar irradiation is the amount of solar energy that reaches a surface per unit area during a given period. It is usually expressed in a unit of Wh/(m^2.day). Identifying the solar irradiation where the PV system will be installed is an essential step for sizing the PV system required to meet a given electricity consumption. This step aims to quantify the average amount of solar irradiation that will shine on the PV array per day in a year. Refer to the Appendix to discover the annual average irradiation for the municipality where the PV system will be installed. The number found here will be used in STEP 4.

STEP 4: PV system nominal power:

With the average electricity consumption and solar irradiation numbers in hand, it is possible to estimate the PV nominal power needed to meet the yearly electricity generation expected. Table 6 (Appendix) presents approximations of the nominal power (in kWp) that the PV system should have to meet the required electricity consumption.

STEP 5: Necessary area:

Once the PV system's nominal power is estimated, the municipality can calculate how many panels will be needed, and, consequently, the area the PV installation will occupy. Refer to the Appendix to find out the area needed for the quantity of panels the project will require.

STEP 6: Roof or ground?

Based on STEP 5, it is possible to evaluate now if the available area meets the size required to install the PV system nominal power that was estimated in STEP 4. Will the system be placed on a roof or will it be ground-mounted?

If roof-mounted, remember that the azimuth and inclination of the roof might not be in the ideal conditions that were considered in the calculations (most probably, they will not be) and that there may be shading obstructions. Therefore, the municipality must consider that the calculated area might need to be bigger to meet the electricity generation expectations. These considerations will help the municipality to evaluate if the selected location presents a feasible alternative.

STEP 7: Safety measures and considerations

Depending on whether the PV system is ground- or roof-mounted, the safety measures and considerations might differ.

Roof:

- The municipality must evaluate the electrical conditions in the building where the PV system will be installed. For example, are any electrical refurbishments/upgrades needed?
- The structural conditions of the roof must withstand the permanent additional weight of the PV modules. A qualified professional must be consulted to evaluate the structural conditions of the roof.
- Climate conditions must also be taken into account, e.g. areas with strong winds. This might reveal that some type of reinforcement for the PV support and for the roof structure is needed.

Ground:

Ground-mounted PV systems are more susceptible to vandalism, vegetation growth, dust accumulation on the panels' surface, and new surrounding constructions that can cause shade in the future.

The municipality should consider the following questions:

- Are there any zoning or land use restrictions in that location?
- What is the soil type?
- Are there any mechanical requirements for installation of supporting structures?
- Is the area prone to floods?
- What are the requirements for maintenance?
- What is the type of soil and likelihood of subsidence?
- Are there any safety requirements that might be needed to avoid vandalism, like fences and security guards and/or cameras?

STEP 8: Re-evaluation:

After going through these steps, the municipality may realize that some of the project ideas are not as feasible as they seemed after a first analysis. The location that was initially considered for installing the PV system may not be capable of supporting the weight of the PV system, or it might not be large enough to reach the intended electricity production. It may even be necessary to re-consider the distributed generation modality initially selected. If this is the case, the municipality should restart the project preparation process at STEP 1.

5. Success cases

5.1. Curitiba Mais Energia" – Curitiba More Energy

Curitiba City Hall participated in a lighting retrofit project, with replacement of low efficiency lamps by LED and installation of a PV system on its roof. This project received funds from the Energy Efficiency Utility Program (PEE - Programa de Eficiência Energética) of Copel Distribuição (Curitiba's electricity distribution utility), an initiative regulated by ANEEL.

Generation Capacity (kWp)	Electricity Generated (MWh/year)	Annual Mitigation (tCO2e/year)	Financial Savings (R$/ year)
144	212	15.9	100,000

Table 2: Results of the PV project in Curitiba City Hall

Figure 13: Curitiba City Hall (2019)

The C40 Cities Finance Facility (CFF) is supporting another project in the Curitiba More Energy program. The project includes the installation of PV systems in 5 locations: Caximba Deactivated Landfill (5 MWp), Intermodal Railway Bus Terminal (0.9 MWp), Santa Cândida Bus Terminal (0.7 MWp), Pinheirinho Bus Terminal (0.8 MWp), and Boqueirão Bus Terminal (1.4 MWp).

Generation Capacity (kWp)	Electricity Generated (MWh/year)	Annual Mitigation (tCO2e/year)	Financial Savings (R$/ year)
8,757	11,158	3,107	5,263,229

Table 3: Expected of results from the "Curitiba mais energia" project

5.2. Distributed generation and energy efficiency through public-private partnership in Fortaleza

The municipality of Fortaleza is seeking, through a public-private partnership (PPP), a 15% reduction in electricity costs in municipal schools, daycare centers and administrative buildings of the education department.

The municipal education department of Fortaleza has 490 buildings, which together consume approximately 13 GWh per year.

The project foresees the construction of seven PV generation plants, which will supply electricity through remote generation (7,270 kWp), and another eight PV systems on the roof of some of the schools, supplying electricity through local self-generation (214 kWp).

Generation Capacity (kWp)	Electricity Generated (MWh/year)	Annual Mitigation (tCO2e/year)	Financial Savings (R$/ year)
7,484	13,174	3,668	6,214,175

Table 4: Expected results from the PPP Fortaleza project

5.3. Guerreira Zeferina – Social housing residential complex in Salvador

A partnership between the city of Salvador and the local electricity distribution utility, COELBA, gave rise to the PV generation and energy efficiency project in the Guerreira Zeferina – Social housing complex.

This project received funds from COELBA, also in the context of the Energy Efficiency Utility Program (PEE). The main objective is to reduce electricity costs for low-income families living in the complex. The photovoltaic system supplies electricity to the common areas of the residential complex, to the adjacent community daycare, while the surplus electricity is used to reduce electricity costs for the municipality.

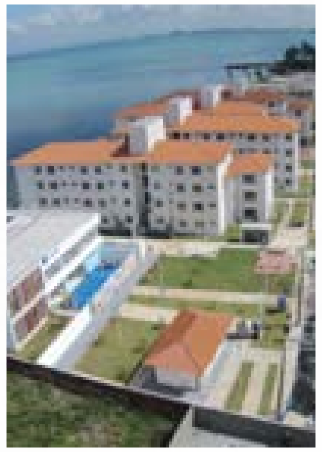


Figure 14: Guerreira Zeferina Before the Project (2018)

Figure 15: Guerreira Zeferina after the Project (2018)

Generation Capacity (kWp)	Electricity Generated (MWh/year)	Annual Mitigation (tCO2e/year)	Financial Savings for City Hall (R$/year)
194,6	297	82.7	140,000

Table 5: Results of the PV project in Guerreira Zeferina

5.4. Better and more sustainable education in Imperatriz

Out of concern with the comfort and the academic performance of students from public schools in Imperatriz, the municipality installed air conditioning equipment in 139 elementary and basic education units. However, the city has estimated that this action would increase energy consumption three-fold. To reduce this financial impact on the municipality, the city is deploying PV generation plants in 32 schools. The electricity generated will be used to reduce the expenses of all teaching units in the municipality.

The total investment is R$10.1 million and was financed by the Fund for Maintenance and Development of Elementary Education and Appreciation of Teachers (FUNDEF - Fundo de Manutenção e Desenvolvimento do Ensino Fundamental e de Valorização do Magistério).

Figure 16: Elementary school in Imperatriz (2020)

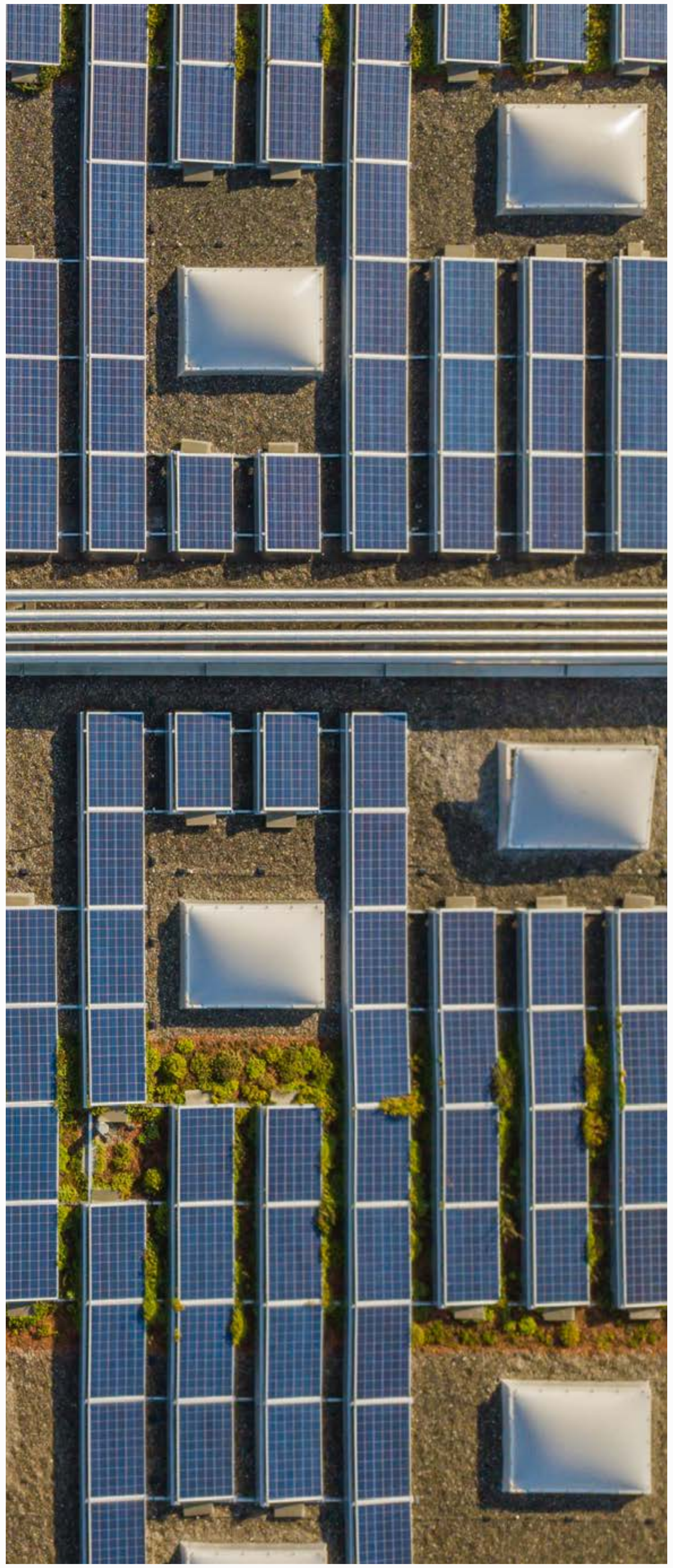
6. Conclusion

Once the initial planning has taken place, the municipality should consider the technical details of the PV project.

A nationwide adoption of solar PV use is key to diversifying the electricity mix, reducing national emissions and prices. Solar PV is an attractive option for municipalities seeking to reduce costs and contribute to climate change mitigation, offering numerous social, economic, environmental, and strategic benefits. By taking the important decision to implement solar PV, municipalities will position themselves as leaders of innovation and sustainability.

To take advantage of these opportunities, municipalities should note that:

1. Current legislation in Brazil allows PV projects up to 5 MW to be connected to the electricity grid, known as micro- and mini-distributed generation. Four different distributed generation alternatives are available, all of which result in cost savings through a net-metering scheme.
2. Municipalities planning to install PV systems should begin by establishing a clear governance and legal framework. Setting objectives and securing stakeholder engagement are crucial early steps.
3. Municipalities should perform a preliminary review of financing options available, considering their financial preferences and any restrictions.
4. Cities can estimate the size and output of their PV systems internally, even before hiring consultants or PV suppliers. Inputs for this task include knowledge of electricity consumption, the initial locations for the PV systems, available area, and local solar irradiation. There are publicly available tools to aid with inputs and calculations.
5. Preliminary sizing of PV projects can be an iterative process through which initial decisions, such as business models and system locations, may be revised before reaching a final decision.
6. After concluding this initial process, municipalities can begin the design phase, which will require detailed considerations on procurement and financing. These will be the subject of a separate report to follow.



7. Appendix

This appendix describes in more detail the calculations proposed in the "Technical aspects and PV system sizing" chapter, regarding STEP 3, STEP 4, and STEP 5.

STEP 3: Solar irradiation:

The most complete database for solar irradiation in the Brazilian territory can be found at the Brazilian Solar Atlas. This data can be accessed at:
http://labren.ccst.inpe.br/atlas_2017.html

1. Once at the Brazilian Solar Atlas database, download the .csv file entitled "Irradiação no Plano Inclinado" and search for the data from the municipality where the PV system will be installed.
2. The data are presented as an average in Wh/(m2.day) for each month. Calculate the annual average from those months and save this number for STEP 4.

STEP 4: PV system nominal power:

The abacus[5] presented in Table 6 was designed to assist in determining the PV nominal power (in kWp) needed to meet an annual electricity consumption (vertical axis) for a given yearly average solar irradiation on a surface (horizontal axis).

It is important to highlight that the numbers found here consider that the PV array is installed in ideal conditions, i.e. considering that the PV modules are facing the Equator (towards North in the Southern Hemisphere and towards South in the Northern Hemisphere), tilted at the inclination equal to the location's latitude, and with no shading obstructions over its surface.

It is also important to keep in mind that this is a rough calculation. However, it gives a good estimate of the PV system size required in a specific situation.

STEP 5: Necessary area:

The quantity of PV panels is the result of the division of the total nominal power of the PV system by the nominal power of each panel (usually in Wp).

1. Locate the PV panels' technical information on the manufacturer's website and download the corresponding datasheet. This will provide the most updated information.
2. If this information is not available, use as rule-of-thumb a nominal power of 340 Wp and an area of 1.95 m2 per panel.
3. Divide the nominal power required calculated in STEP 4 by the nominal power of the module. The result will b the number of panels needed to meet the PV system nominal power estimated. Remember that in STEP 4, the abacus gave you the nominal power in kWp. Therefore, multiply it by 1000 to convert to Wp.
4. In most cases, the result will be a decimal number: round this figure up to the nearest whole number. Remember, this is a rough estimate.
5. Multiply the number of panels times the area of one panel, in order to find an estimate of the total area required.

$$\frac{\text{PV sytem nominal power found in STEP 4 x 1000}}{\text{A single PV panel nominal power}} = \text{Number of panels needed}$$

Annual Energy Consumption (kWh/year)	Solar irradiation [Wh/(m².day)]												
	4,000	4,250	4,500	4,750	5,000	5,250	5,500	5,750	6,000	6,250	6,500	6,750	7,000
60,000	54,8	51,6	48,7	46,1	43,8	41,7	39,9	38,1	36,5	35,1	33,7	32,5	31,3
120,000	109,6	103,1	97,4	92,3	87,7	83,5	79,7	76,2	73,1	70,1	67,4	64,9	62,6
180,000	164,4	154,7	146,1	138,4	131,5	125,2	119,6	114,4	109,6	105,2	101,2	97,4	93,9
240,000	219,2	206,3	194,8	184,6	175,3	167,0	159,4	152,5	146,1	140,3	134,9	129,9	125,2
300,000	274,0	257,9	243,8	230,7	219,2	208,7	199,3	190,6	182,6	175,3	168,6	162,4	156,6
360,000	328,8	309,4	292,2	276,9	263,0	250,5	239,1	228,7	219,2	210,4	202,3	194,8	187,9
420,000	383,6	361,0	340,9	323,0	306,8	292,2	279,0	266,8	255,7	245,5	236,0	227,3	219,2
480,000	438,4	412,6	389,6	369,1	350,7	334,0	318,8	304,9	292,2	280,5	269,8	259,8	250,5
540,000	493,2	464,1	438,4	415,3	394,5	375,7	358,7	343,1	328,8	315,6	303,5	292,2	281,8
600,000	547,9	515,7	487,1	461,4	438,4	417,5	398,5	381,2	365,3	350,7	337,2	324,7	313,1

[5] This abacus considers a conservative Performance Ratio (PR) of 75%. PR is the ratio of the energy effectively produced (used) with respect to the energy which would be produced by a "perfect" system continuously operating at Standard Test Conditions (STC) under same irradiance.

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