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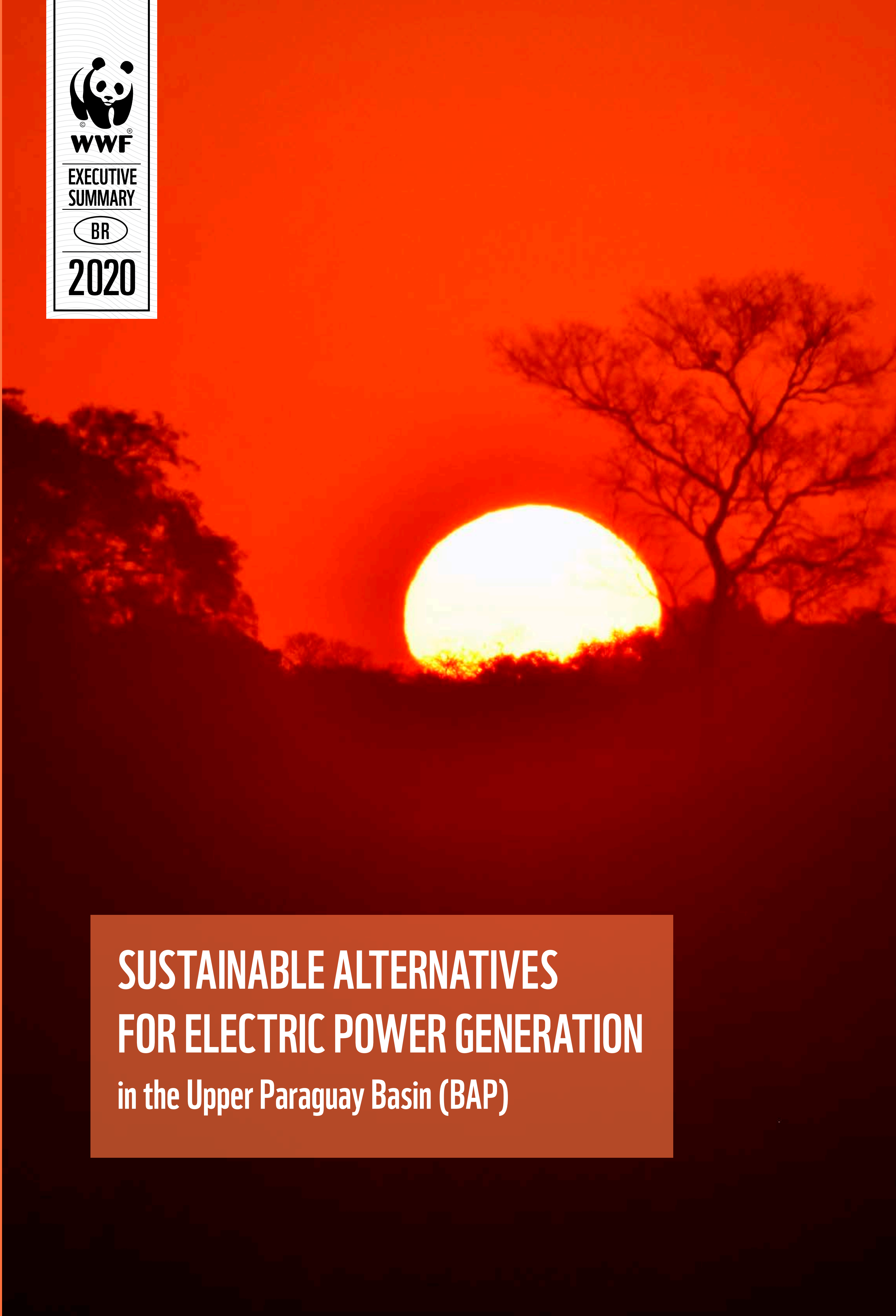

SUSTAINABLE ALTERNATIVES FOR ELECTRIC POWER GENERATION

in the Upper Paraguay Basin (BAP)

WWF-BRAZIL

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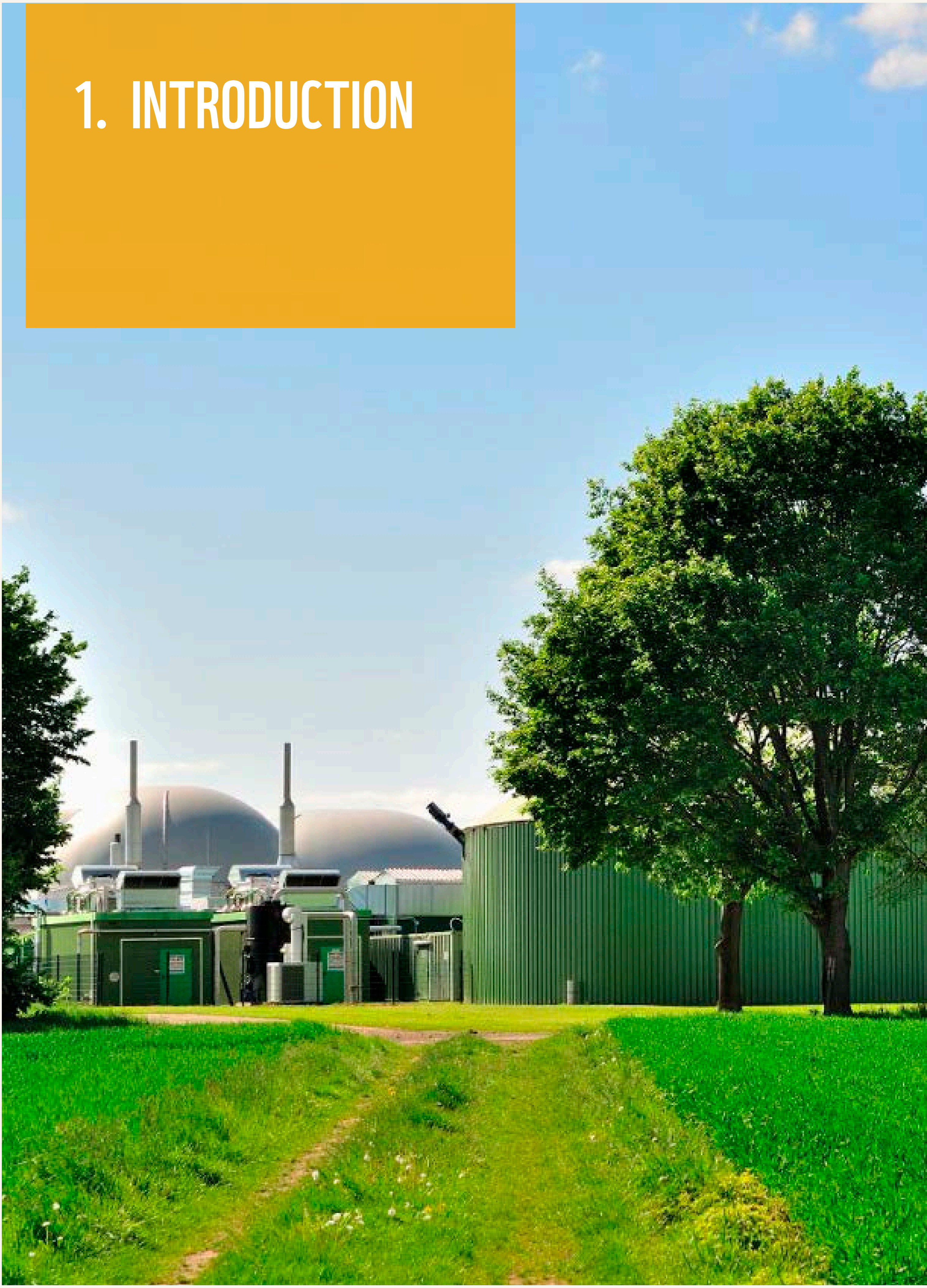
SUMMARY

1. INTRODUCTION



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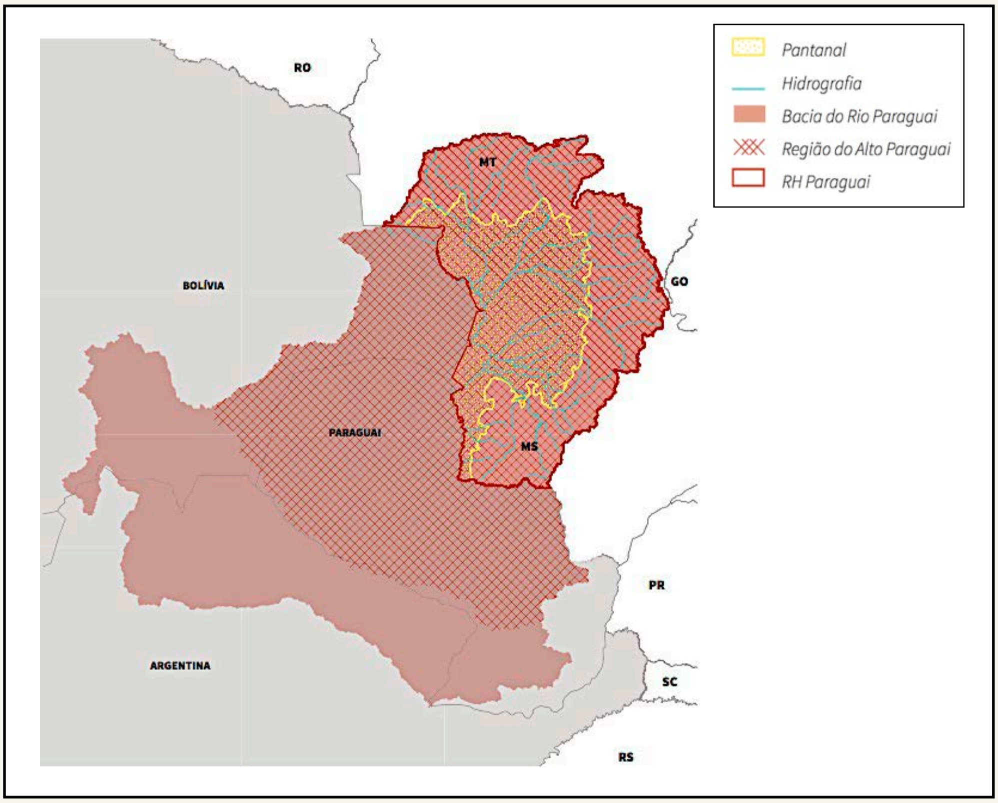
Today, there are over 125 hydroelectric power projects under study in Paraguay's hydrographic region. Most of them are small hydro (PCHs) projects. Data from the Water Resources Planning of Paraguay River Hydrographic Region (PRH – PARAGUAI) show that the explored hydropower potential of the area has a capacity today of 1.2 GW. (ANA, 2018).

Upper Paraguay Basin (BAP) encompasses an area of 1,100,000 Km², including the biomes of Pantanal and part of Cerrado. The Hydrographic Region is 4.3% of the Brazilian territory (363,446 km²), including parts of Mato Grosso and Mato Grosso do Sul, the largest part of Pantanal (61% of total), world's largest wetlands. The main watercourses are Paraguai river, Taquari, São Lourenço, Cuiabá, Itiquira, Miranda, Aquidauana, Negro, Apa and Jauru. (ANA, 2018) [1].



Picture 1 – Map of the Hydrographic Region of Paraguay. Source: ANA, 2018.

The area where BAP is located has a high rainfall index, and Pantanal is the world's largest wetland, regulating the flow of Paraguay river. The generation of hydroelectric power energy at BAP is one of the activities that may cause a drastic impact in the rivers of the basin.

1 http://www3.ana.gov.br/portal/ANA/noticias/ana-interrompe-temporariamente-concessao-de-outorgas-para-novas-hidreletricas-na-regiao-hidrografica-do-paraguai

According to PRH-Paraguai, the main issue with hydroelectric power projects are the socioeconomic impacts (specially fishing and tourism), caused by changes in watercourses and decrease in water quality, "creating challenges to ensure its multiple use, which requires incorporating constructive and operative specificities in future projects, besides rigorous environmental impact studies within its licensing".

Pantanal area is very sensitive to hydro projects due to its geographical and environmental unique characteristics. According to PRH-Paraguay, the "threats to water resources not always have a direct measurable impact due to diffuse and systemic effects, but it's acknowledged they affect quantity, quality, regime or access to water" and mostly "involve situations of environmental degradation".

One of PRH-Paraguai first recommendations is the incorporation of "constructive and operative specificities in the studies and projects for hydroelectric power usage aiming to minimize possible impacts and preservation of local environment". Besides, PRH-Paraguai recommends the energy sector to consider the current results obtained by Brazilian National Water Agency to evaluate the effects of implanting these hydroelectric projects in BAP, in a way that the conclusions meet the society's needs, providing the best energy use possible.

Within this context, WWF invited specialists in the subject, with focus on non-hydro renewables, to analyze the potential of other sources of clean energy that could be promoted and used in the states of MS and MT, guaranteeing the energy supply as stated in the 10-Year Energy Expansion Plan. The sources considered were solar photovoltaic energy, sugar cane biomass energy, urban solid waste energy (specially from the two main cities in the region, Cuiabá and Campo Grande), besides sanitary sewers and animal waste.

This study considers only these Brazilian states and their energy demands but intends to open the discussion about alternatives for the entire Upper Paraguay Basin, including the borders with Bolivia and Paraguay. It's important to highlight that until this moment, hydroelectric power projects for this area in the neighboring countries are not known of, which reinforces the importance of a specific look into Brazil, which may have consequences beyond borders.

THE HYDROGRAPHIC REGION IS

4.3%

THE BRAZILIAN TERRITORY

INCLUDING PARTS OF MATO GROSSO AND MATO GROSSO DO SUL, THE LARGEST PART OF PANTANAL.

2. ELECTRIC POWER GENERATION IN BRAZIL

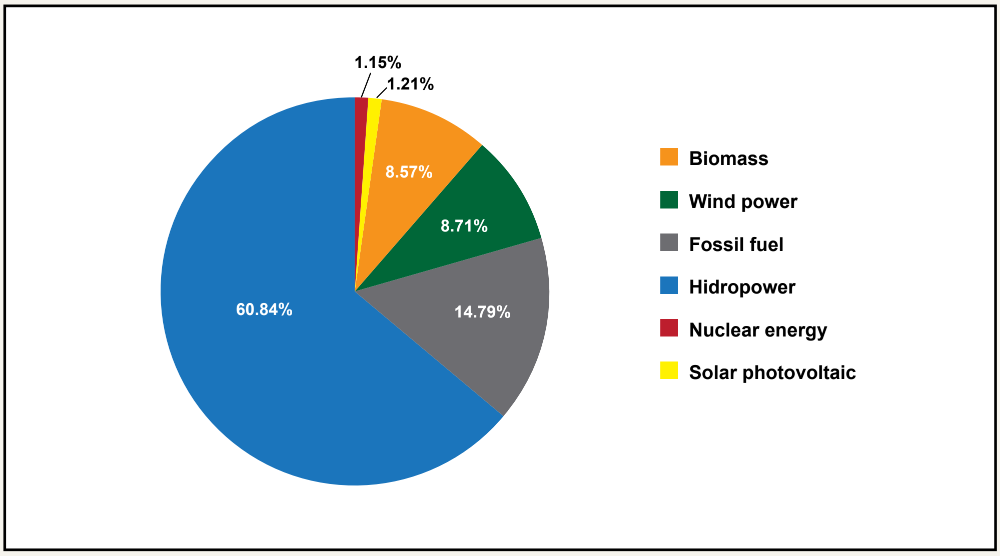

Foto: © ABiogás

Brazil is a country highly dependent on hydroelectric power, according to studies of the Brazilian Energy Balance (BEN, 2018), with more than 60% of electric generation depending on that source.

The second largest is thermoelectricity (gas, coal, diesel, etc.). Third is wind energy, with almost 8% of the country's capacity. The small hydro (PCHs) represent 3.2% of the capacity.

The Picture 2 shows how the energy generation is divided by source. Hydroelectric power generation is 63.1% of electric energy in Brazil; followed by thermoelectricity (fossil and biomass) and wind energy. The data allows quantifying how each of them contributes in Brazil.

THE STATE OF MATO GROSSO (MT) IS THE SECOND EMITTER IN BRAZIL, WITH A TOTAL OF 231.6 M tCO2 (GROSS) AND 192.1 M TCO2E (NET), LOSING ONLY TO THE STATE OF PARÁ.



Picture 2 – Participation of each source of electric power generation in Brazil. BEN, 2018. Source: EPE, 2019.

The next table shows data by region (EPE, 2018). These data, from 2017 (BEN, 2018), shows Southeast is responsible for almost 50% of the electric power generation in Brazil.

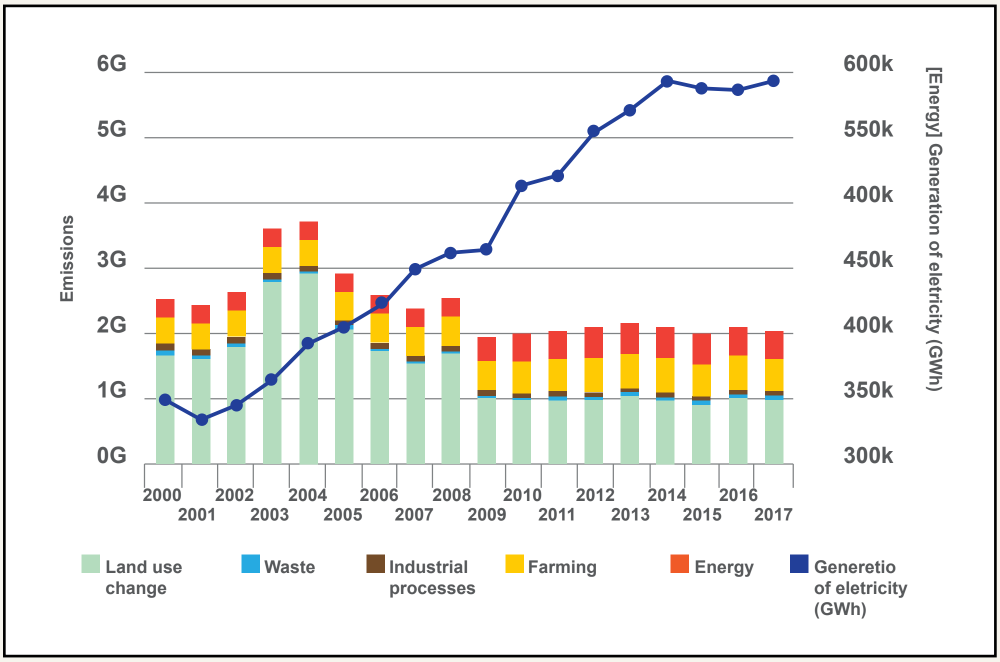
Table 1 – Electric Power Generation (GWh) by region. Source: EPE (2018).

Region	Generation (GWh)	Participation (%)
Southeast	232,515	49.77%
South	84,997	18.19%
Northeast	79,731	17.07%
Midwest	35,408	7.58%
North	34,510	7.39%

Despite representing only 7.58% of electric power generation in the country, the Midwest can raise its contribution by using solid waste (urban and rural), biomass and solar, all of them very significant in the region, and contribute for energy generation without the construction of new PCHs.

The hydroelectric potential in the BAP area has the capacity to duplicate the current electric power generation based on these studies, however, other sources can replace future projects, keeping the rivers "free" without human interference.

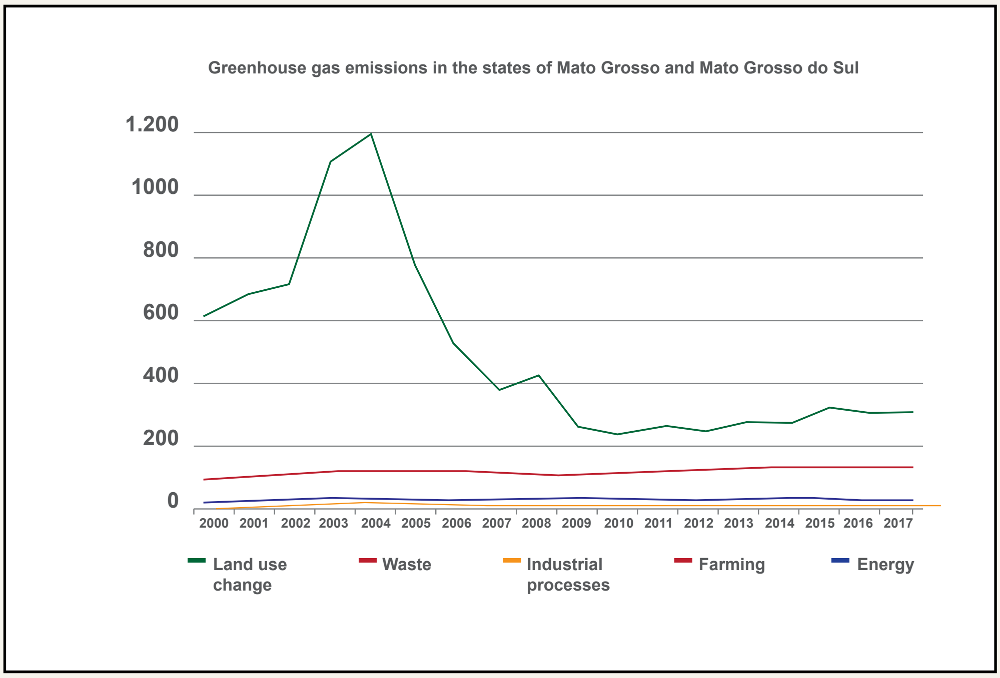
Diversifying the energy sources locally can contribute to reduce greenhouse gas emission (GHG). Considering data from the Electric Power Annual 2018, base year 2017, consumption of electric power in Brazil was 587,962 GWh, which is equivalent to the annual emission of 61.14 $MtCO_2$, around 11.1% of the energy generated in the MW. The data from the System for Estimating Greenhouse Gas Emissions (SEEG), base year 2017, published in 2019, show that around 21% of greenhouse gas emissions come from the energy sector (including transports).



Picture 3 – Total greenhouse gas emissions and energy generation in Brazil. Source: SEEG, 2019.

According to SEEG database, base year 2017, the state of Mato Grosso do Sul (MS) emitted 72.3 MtCO2e (gross) and 69.8 MtCO2e (net), occupying the 13th position in the national index. The state of Mato Grosso (MT) is the second emitter in Brazil, with a total of 231.6 M tCO2e (gross) and 192,1 M tCO2e (net), losing only to the state of Pará.

Considering only the electric power generation sector of each state, the emission of GHG in MS represents 12.2% of the state's emissions. In MT, it represents only 4.9% of the state's emissions. (SEEG, 2019).



Picture 4 – Historic series of GEE emissions in MT and MS. Source: SEEG, 2019.

2.1 HYDROELECTRIC POWER GENERATION IN THE HYDROGRAPHIC REGION OF PARAGUAY (RH – PARAGUAY)

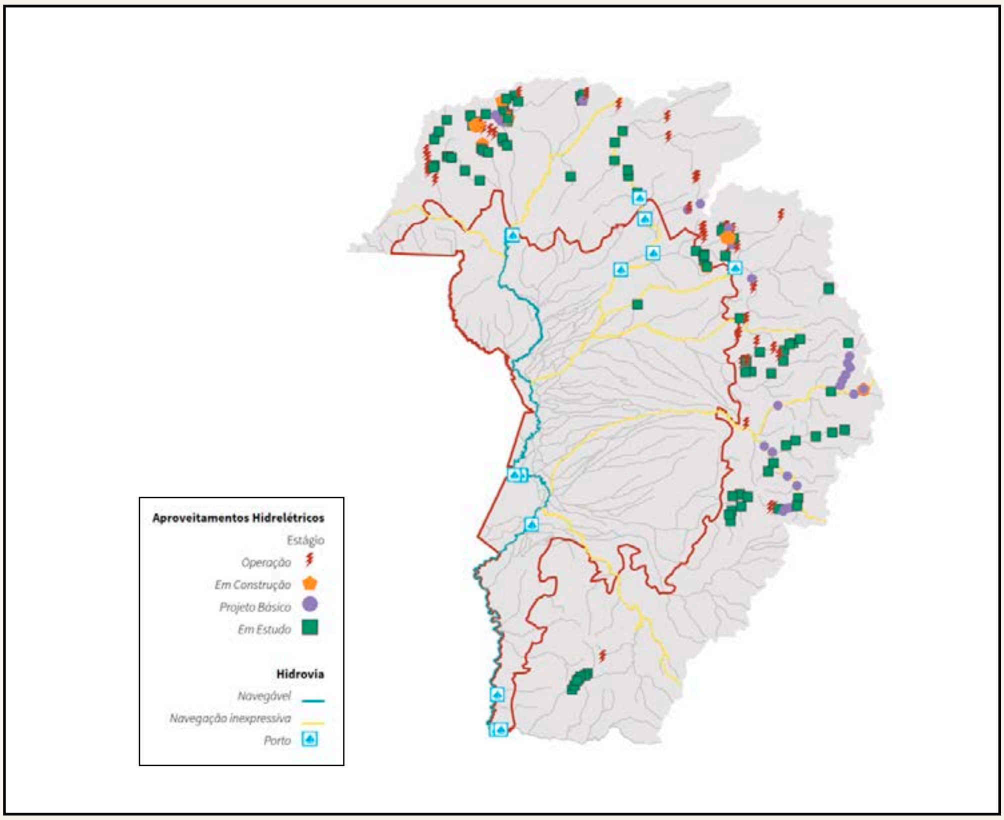
Small hydro (PCHs) are small plants with reduced power, mandatorily between 5 and 30 megawatts (MW), and, originally, with an area of 3km² at most, according to the Normative Resolution nº 652/2003 of Brazilian Electricity Regulatory Agency (ANEEL). In the 4th section, it's possible to change the criteria of the flooded area upon evidence that the size of the reservoir is related to other projects other than energy generation.

However, in November 22nd 2016, ANEEL published the Normative Resolution nº 745, updating the rules for projects in Energy Generation, including PCHs, changing the reservoir's area up to 13km² and power between 5 and 30 megawatts (MW).

Although characterized as a project with low environmental impact, PCHs need environmental licensing (previous license, installment license and operation license) and granting of the hydro resources rights to get the real dimension of the impacts in the biosystems, biotas, aesthetic and sanitary conditions of the environment, among social, economic and cultural aspects.

Today, the hydroelectric power potential of the hydrographic region of Paraguay (RH-Paraguai) is explored by 7 hydroelectric power plants (UHE), 30 small hydro (PCH) and 16 hydro dams (CGH), with a total capacity of 1.2 GW (ANA, 2018a).

However, the development of new hydroelectric projects raises a series of concerns regarding socioeconomic impacts, changes in the hydrological regime and decrease in water quality (ANA, 2018a).



Picture 5 – Hydroelectric projects and navigation on RH-Paraguai. Source: ANA (2018b)

Furthermore, ANEEL studies show that there's potential to double this capacity, adding 1.172 MW with the development of 125 new hydroelectric projects with a size of around 9.376 kW each PCH. Currently, the average capacity of PCHs in the MW is 17.336 kW (operating and under construction).

Considering that there are 125 projects under study, and, if each new project (PCH) use the maximum allowed reservoir area limit (13 km²), the theoretical limit of the area to be flooded and transformed into a reservoir is 1.625 km² (162,500 hectares) or around 228,000 soccer fields.

If these reservoirs formed one single lake, and if it had the shape of a square, it would be necessary 17 days (408 hours) to walk 1,625 km, which would be one of the sides of this square. If it was on a bike, it would be necessary 3.4 days (82 hours) to ride this same side.

TODAY, THE HYDROELECTRIC POWER POTENTIAL OF THE HYDROGRAPHIC REGION OF PARAGUAY IS EXPLORED BY 7 HYDROELECTRIC POWER PLANTS, 30 SMALL HYDRO AND 16 HYDRO DAMS, WITH A TOTAL CAPACITY OF 1.2 GW

3. SUSTAINABLE ALTERNATIVES FOR ELECTRIC POWER GENERATION

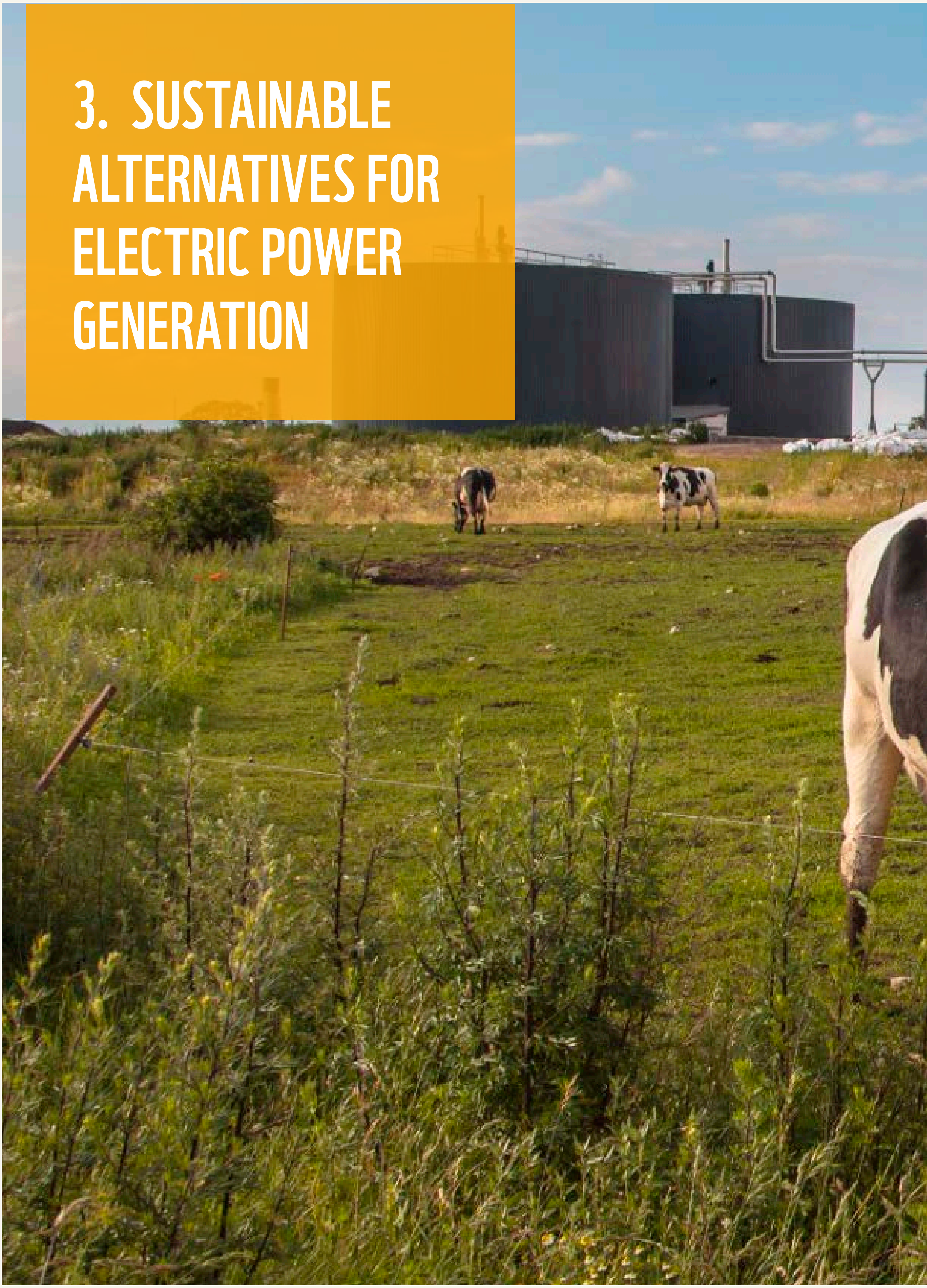



Foto: © ABiogás

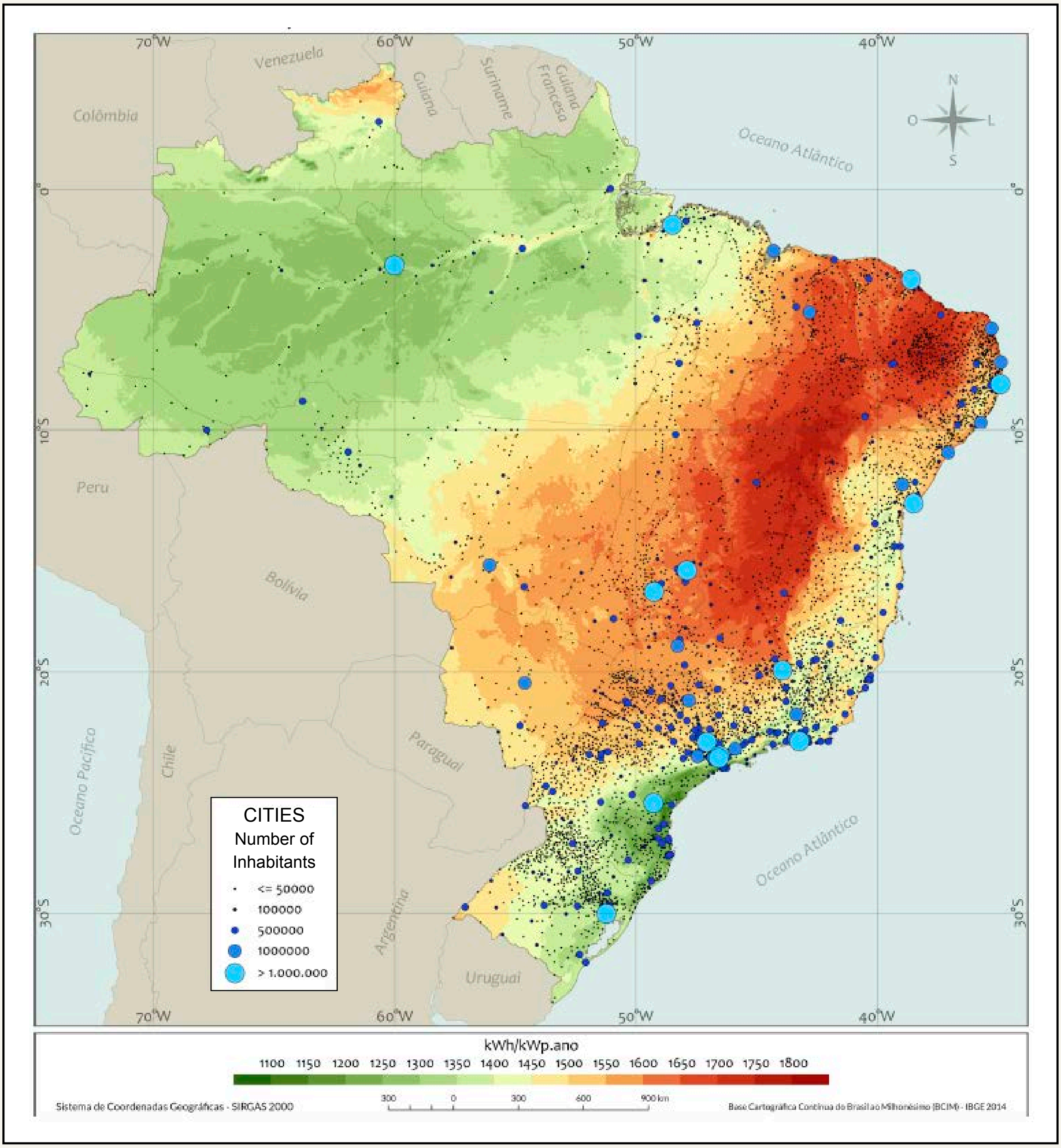
3.1 SOLAR ENERGY

The energy from the Sun can be used in many ways, but most of all for generation of electricity and thermal energy in houses and industries. The main ways are: (i) by using solar thermal collectors for water heating; (ii) by using solar concentrators (heliothermic energy or concentrated solar power (CSP) for uses both thermal and electric and; (iii) through direct conversion of luminosity in electricity, through photovoltaic modules and photoelectric effect.

This study will focus in photovoltaic solar technology, considering the set of equipment that form the photovoltaic solar power system. The photovoltaic system is an association of photovoltaic modules connected in series and/or parallel to produce electric power in the voltage determined by each project.

To dimension a photovoltaic generator, it is important to know the electric characteristics of the modules, such as: electrical current, voltage and power, and features related to the efficiency of these components, losses related to temperature, dust, etc. The guidelines change according to the manufacturer, construction's characteristics, type of semiconductor material, internal electric resistance, technology and place of installation. However, one of the most important data is to know the solar energy source potential available at the site.

The Brazilian Solar Energy Atlas shows long term rates of solar sources (the next picture shows the global horizontal irradiance - GHI), which is one of the climate phenomena that determines the potential for generation of solar energy in a specific location. Considering a global horizontal irradiance, the daily average in Campo Grande (MS) is 5.35 kWh/m². The daily average in Cuiabá (MT) is 5.36 kWh/m². According to the Brazilian Solar Energy Atlas, the annual average for the entire MW is 5.07 kWh/m².



Picture 6 – Photovoltaic solar generation potential ((kWh/kWp.year). Source: IBGE, 2014. INPE, 2018

Global Tilted Irradiation (GTI) is the total amount of direct and diffuse radiation received from above on a tilted surface. Compared to horizontal surface, the tilted receives a bit more of solar radiation reflected on the ground, hence the GTI value is higher than GHI value. For example, the daily average GTI in Campo Grande is 5.70 kWh/m^2.

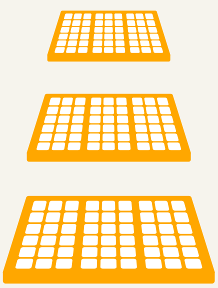
According to the Global Solar Atlas and Solargis[2], the estimated daily production of solar energy for each kWp (kilowatt-peak)[3] in the MW area is between 4.20 kWh/kWp and 4.40 kWh/kWp. When comparing Campo Grande (MS) and Cuiabá (MT) one can notice that the production varies from 4.39 kWh/kWp and 4.25 kWh/kWp, respectively. These values represent a relative variation between the cities of around 3%, which is a value below measurement deviations and accuracy.

The World Bank selected Solargis as the global electric power potential data and solar energy evaluation services supplier, based on the databank they own and keep. When compared to the data from National Institute for Space Research (INPE) in the second edition of the Brazilian Solar Energy Atlas, the values of Solargis and INPE are close and compatible with the scenario of regional electric power generation.

Therefore, it was considered an electric power production index of 4.32 kWh/kWp-day , which corresponds to 1,577 kWh/kWp-year, as shown in Picture 6.

Combining the solar potential to the regulation of distribution of the energy, Pantanal can have a substantial energy potential. Since ANEEL's Normative Resolution nº 482, April 17th 2012 – which regulated the distribution in the Brazilian energy matrix.

Consuming Units (CU), whether people or companies, who generate their own energy (Distributed Generation - DG) up to 5MW are included in the Registration System of Consuming Units with Distributed Generation by ANEEL, and they can put in the transmission network the energy which exceeded the consumption. It's not possible to sell these "leftovers", but it can be compensated in up to 5 years, in its own consuming unit or another, as long as it is in the same distribution company area.



After the Resolution 482/12, 83,000 photovoltaic systems were installed, 86 CGHs (small hydro with up to 5MW), 57 wind farms and 162 biomass power plants, with the total amount of 1,015 MW (~1 GW). Table 2 shows an overview of the DG systems installed until June 15th, 2019.

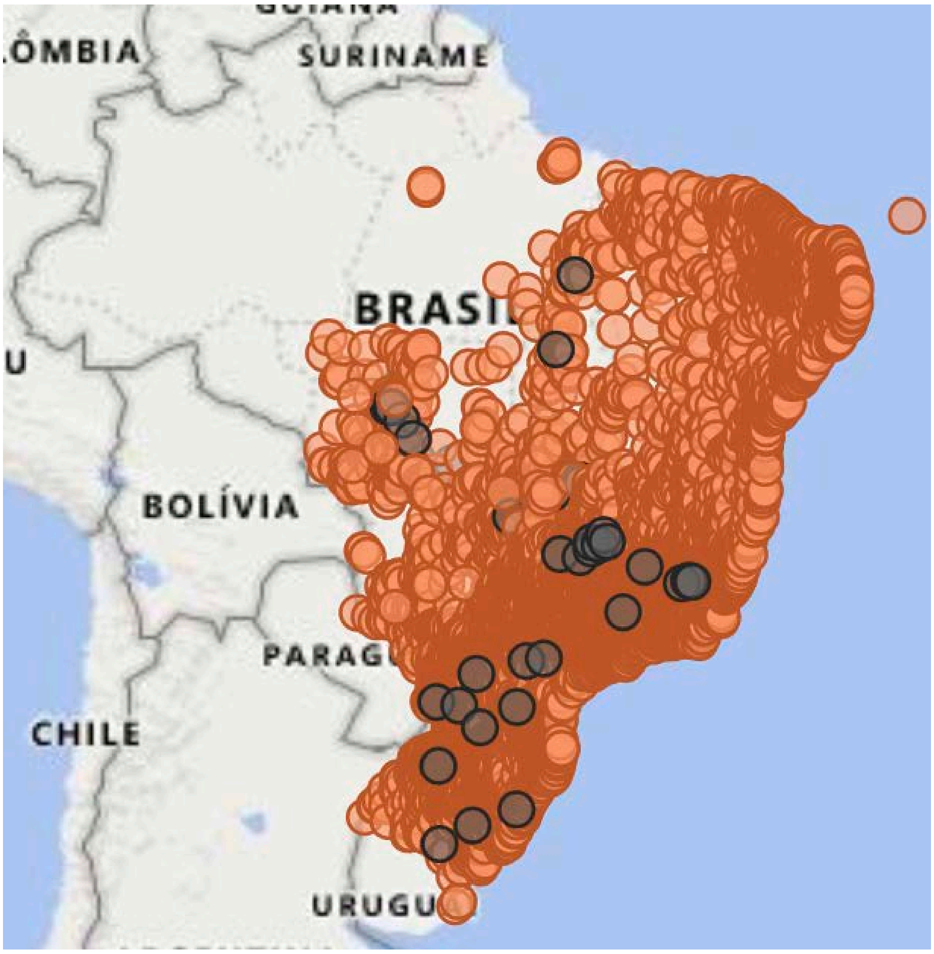
2 https://globalsolaratlas.info/?c=11.609193,8.261719,3

3 kWp representes the capacity of the solar PV system. It's associated to the full power installed in solar energy modules.

Table 2 – Overview of Distributed Generation in Brazil. Source: Aneel, 2019.

Type	Quantity	Power (kW)
Micro hydro	86	81,343,60
Wind	57	10,314,40
Solar PV	83,308	879,161,91
Thermal	162	44,795,78
TOTAL	**86,613**	**1,015,615.69**

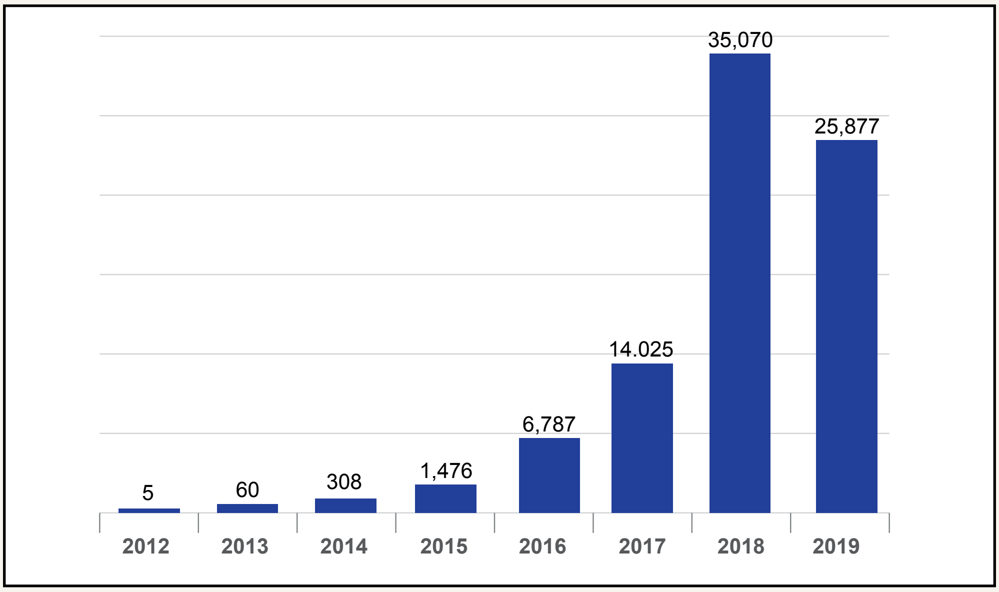
The map below shows how solar PV systems are distributed across Brazil.



Picture 7 – Distribution of solar energy systems in Brazil. Source: ANEEL, 2019. The maps shows the systems together with data sets according to registers from ANEEL, using the methodology "High-density Scatter Charts", which shows the number of systems by consuming unit, so every circle gives information about the GD system registered.

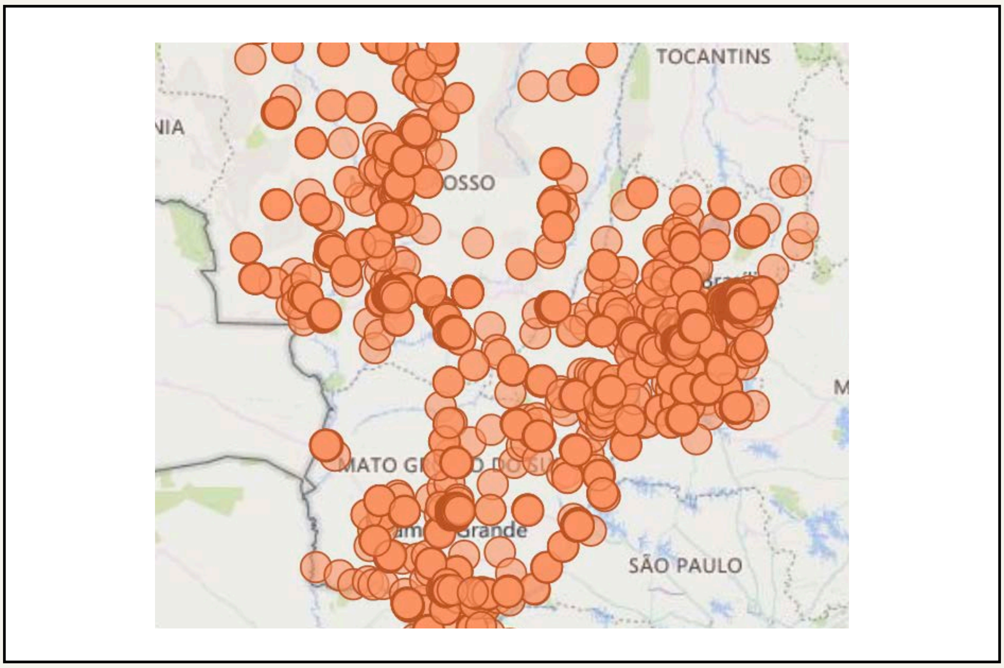
THE WORLD BANK SELECTED SOLARGIS AS THE GLOBAL ELECTRIC POWER POTENTIAL DATA AND SOLAR ENERGY EVALUATION SERVICES SUPPLIER, BASED ON THE DATABANK THEY OWN AND KEEP.

Picture 8 shows the number of DG systems that use solar PV as energy source. An increasing growth can be seen in the last years, starting in 2012 when the Normative Resolution RN 482/2012 was implemented.



Picture 8 – Number of solar PV systems in Brazil. Source: ANEEL, 2019.

Separating the data from the MW region, there are 9,292 PV systems installed until June 2019, with the total amount of 122,884 kWp, representing a little less than 14% of the installations in the country.



Picture 9 –Solar PV systems in the Midwest. Source: ANEEL, April 2019.

Like the rest of Brazil, in the last years, solar PV systems have grown in the MW, especially in residential and commercial sites. Residential units count 6,815 installations, with the total amount of 39,274 kW (average power 5.76 kWp) and commercial 1,654, with the total amount of 51,020 kW (average power 30.84 kWp).

Regarding the area, solar systems in residences in the states of the Midwest sum 235,644 m² (considering 6m²/kWp), around 33 soccer fields. Commercial ones sum 306,120m², around 43 soccer fields.

Another important data is about the type of generation. In the MW, the prevailing one is the generation at the consuming unit (next to the energetic charge), with 8,584 units, followed by 696 units in the remote consumption model and 12 in the shared generation model (in both cases, photovoltaic power stations far from the charge).

When looking at each state, distributed generation prevails in Goiás, followed by Mato Grosso, Mato Grosso do Sul and Federal District, as shown in the Table 3. The states of Mato Grosso and Goiás combined represent 75% of the installations in the MW.

Table 3 – Amount of solar PV DG units by state. Source: ANEEL, 2019.

State	Amount od DG Units	Power (kW)	Percentage (%)
FD	982	13,083	11%
GO	3,218	33,645	27%
MS	1,653	17,650	14%
MT	3,438	58,504	48%
Total	9,292	122,844	100%

Considering a productivity of 1,577 kWh/kWp-year, the MW generates 193.73 GWh of solar energy annually, and, according to Table 1, the region generates 35,408 GWh of electric energy connected to the National System (SIN). The solar energy represents 0.54%, but it can be so much more.

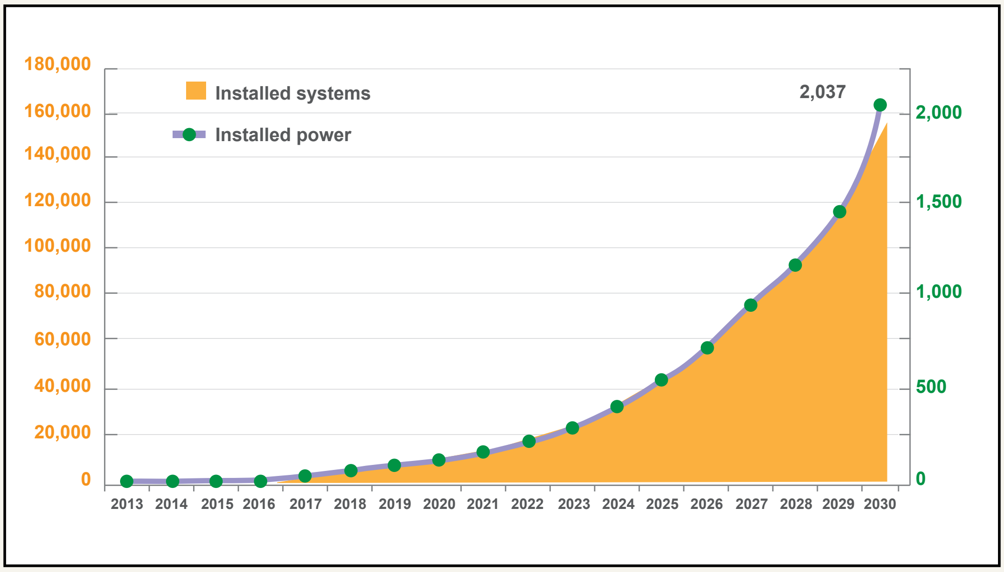
Another type of use of the solar power is the photovoltaic power plants, technically called Centralized Solar Power Generation (GC).

Unlike DG, GC is characterized by a transmission network for distribution connecting the power plant to consuming units. The authorization for these types of generating centrals with power higher than 5 MW should be requested to ANEEL through a series of procedures.

Solar PV technology used in GC is the same as in DG, the changes are in the power capacity and type of equipment, connection with transmission networks and other protection and control techniques. At a solar PV power plant, the production is higher, thus the cost is much lower.

3.1.1 DISTRIBUTED SOLAR ENERGY GENERATION PROJECTIONS

To project the DG type solar energy growth, the average growth of 33.56% from the last 5 years and annual growth of 1% were considered. It was also considered an average power of 13.22 kWp for each system installed, according to the average verified until now.



Picture 10 – Distributed solar energy generation projection by photovoltaic systems. Source: the authors themselves.

The projection for 2030 based in the scenario above is 3,212 GWh / year. This amount takes in consideration the average solar irradiation of 1,577 kWh/kWp-year, for the capacity of 2,036,520 kWp (2.04 GWp). In this scenario, the solar energy generation in 2030 would be enough to supply around 1 million families with an average consumption of 250 kWh. The area to install 2.04 GWp would be 12,219,120 m² , considering the current efficiency of photovoltaic modules.

The cost of investment considers the current cost of this technology, which is R$ 4,500 / kWp, with the total amount of around R$ 9.2 billion. Considering the technology will have a reduction in its cost of 5% until 2030, then the total amount would be R$ 7.6 billion.

Comparatively, if the alleged lake formed by the construction of 125 PCHs (1,625 km²) was covered with photovoltaic modules, the total power would be the same of a solar power plant with 270.83 GWp. Today, there is no more than 3 GW of photovoltaic systems currently in use in Brazil (DG and GC). This comparison is to show the potential of solar energy in Brazil (and the world).

3.2 SUGAR CANE BIOMASS

In Brazil, the sugar-energy industry has an important role in diversifying the energy matrix producing ethanol as fuel and generating electric power through a process of cogeneration (treated here as bioelectricity). In 2017, these sugar cane products represented around 17% of the energy supply in the country, with ethanol covering 16% of the energy in the transportation system and bioelectricity representing around 6.5% of the electric sector capacity (EPE, 2018). Today, there are 405 plants with a total amount of 11.4 GW of power, 60% more than the Brazilian part of Itaipu hydroelectric power plant (ANEEL, 2019). The cogeneration in sugar cane plants can contribute to the expansion and diversification of the electrical matrix in the states of MT and MS.

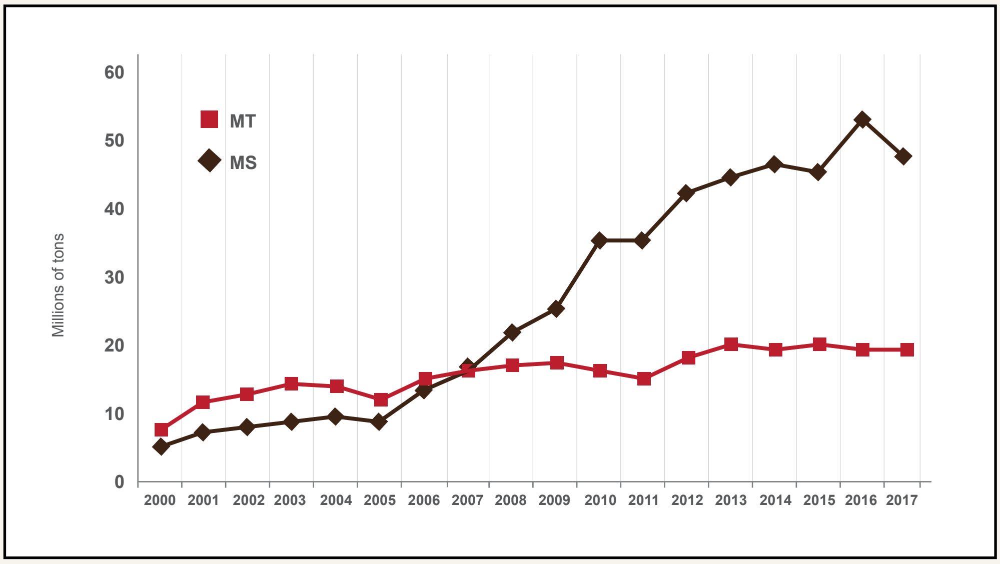
4.1.1 SUGAR CANE PRODUCTION IN THE STATES OF MT AND MS AND THE POTENTIAL FOR ELECTRIC POWER GENERATION

In the last two decades the sugar-energy industry went through major expansion, increasing the harvested area in 112% and 133% in the amount produced (IBGE, 2019a). This growth was boosted by the favorable circumstance of internal and external demand and the prices of sugar and ethanol.

Ethanol grew internally due to popularization of *Flex Fuel* cars specially after 2006. According to UNICA, these vehicles went from 6.1% in 2005 to over 76% of the Brazilian fleet in 2018 (UNICA, 2019). The 2027 Energy Plan – PDE2027 (MME/EPE, 2018) projects a growth of 4,3% per year in ethanol demand, with consumers changing gradually from gasoline to ethanol. PDE2027 also projects construction of 11 new plants and productive expansion in another 23 plants, that together with the existing ones will produce around 44 billion liters of ethanol in 2027.

The dynamics of this sector is deeply connected to sugar international markets. In the 2018/2019 harvest, Brazil was the second largest producer of this commodity, with the total amount of 29.5 million tons, and India was the main producer with 33 million tons. European Union was third with 18.2% million tons (FAS/USDA, 2019). Projections of OECD/FAO(2016) show the sugar global market will grow around 2.1% per year, and the total production will be 210 million tons in 2025. The same report by FAO estimates that Brazil will remain as one of the largest producers: 42 million tons in 2025.

In Brazil, the states of MS and MT are respectively the fourth and sixth largest producers of sugar cane, with a total amount of 66 million tons in 2017 (IBGE, 2019a). However, as shown in Picture 11, the extent of sugar cane production expansion has different patterns in both states. Between 2000 and 2017, the production in MS increased 700%, going from 5.8 million to 46.9 million tons. In the same period, the production in MT went from 8.5 million to 19.3 million tons, an increase six times smaller (IBGE, 2019a).



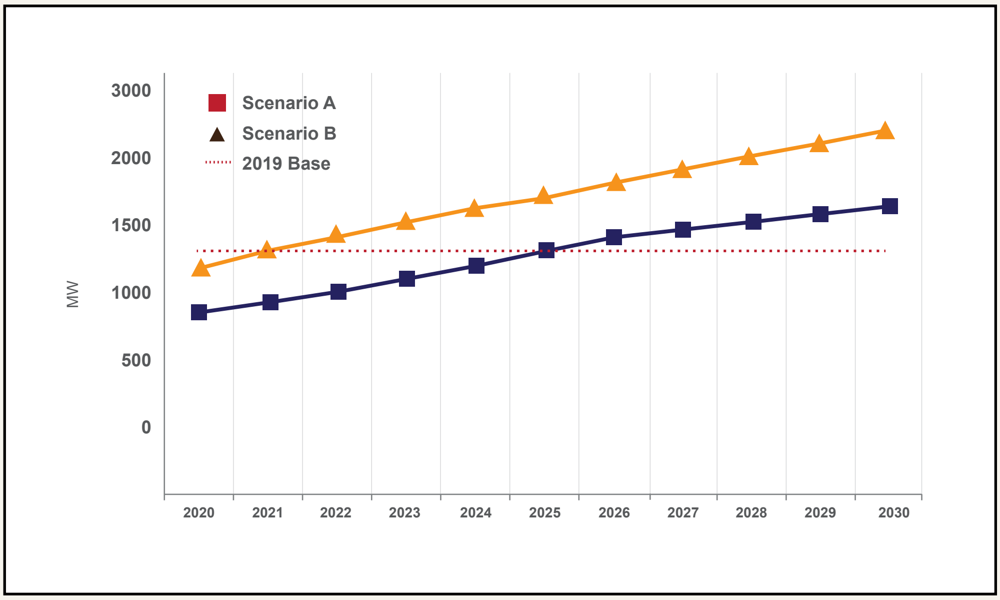
Picture 11 – Production of sugar cane in the states of MS and MT. Source: the authors themselves based on IBGE (2019a).

To project scenarios of energy generation through sugar cane waste cogeneration there are two main aspects: i) the rate of growth in the amount of sugar cane produced and ii) conversion rate of sugar cane into electricity. For the first one, it was considered the conservative pace of expansion[4] of around 8% per year in MS and 6% in MT. The capacity projections consider two technological scenarios according to the methodology developed in (Coelho et al., 2012):

- **Scenario A**: generation system with the capacity to produce 60 kWh per ton, with the plants operating only during harvest (April to November), with a total of 5,563 hours (around 63%);
- **Scenario B**: generation system with the capacity to produce 120 kWh[5] per ton, with the plants operating during harvest and off-season, with a total of 7,446 hours. This scenario assumes that different types of waste would be used, such as bagasse, cane tops, and straw.

4 Between the years of 2000 and 2017, the amount of sugar cane in the state of MS grew na average of 14% /year. (IBGE, 2019a).

5 New technologies make possible for other types of production that can reach up 160 kWh/t (Nova Cana, 2019).



Picture 12– Projection of capacity based on different scenarios. Source: the authors themselves based in Coelho et al. (2012) and IBGE (2019a)

BETWEEN 2000 AND 2017, THE PRODUCTION OF SUGAR CANE IN IN MS INCREASED 700%, GOING FROM 5.8 MILLION TO 46.9 MILLION TONS.

Today, there are 31 plants in the region that generate electricity, 23 in MS and 8 in MT. These plants together have a 1,263 MW capacity and show the adoption of the technological path as shown in Scenario B.

Picture 12 shows the evolution of the capacity considering two scenarios. In the scenario A the projection is that both states will sum 1,794 MW in 2030, which would mean adding around 531 MW to the current production of 2.9 TWh per year. In Scenario B, the power would almost double adding 1,132 MW, summing 2,395 MW. Looking at the parameters in Scenario B, this additional power could generate 8.4 TWh per year. That would mean expanding supply from 1.5 million houses in A, to 4,4 million houses in B[6].

The expansion of sugar-energy industry can happen by expanding and modernizing the existent plants (*Brownfield*) or by building new ones (*Greenfield*). The options require different levels of investment. In the case the expansion happens entirely with investments in *Brownfield* the total amount would be of around R$ 23 billion, and the *Greenfield* alternative would require R$ 32 billion. It's important to highlight that these investments could produce 3 billion liters of ethanol per year, besides 8.4 TWh of electricity per year, and sugar. When the investment is divided in these three products, the value falls to R$ 7,7 billion with *Brownfield* and R$ 10,8 billion with *Greenfield*.

6 Does not consider losses with transmission and distribution. Average monthly consumption of kWh per month. (MME/EPE, 2017)

3.3 URBAN SOLID WASTE – USW

It's estimated that in 2030 the Brazilian population will be 225 million people, of which 4 million will live in Mato Grosso and 3.1 million in Mato Grosso do Sul (IBGE, 2019b). If the patterns of production and consumption per capita stay the same, there's going to be 234,000 tons of urban solid waste (USW) a day that will demand 278 million TOE[7] of energy. The adoption of waste-to-energy technologies contributes to a sustainable future where efficient management of USW and energy generation are connected.

Waste-to-energy technology can be used in synergic way to help expand the energy supply in a decentralized way and help reduce the negative impact of inappropriate waste management. This is possible through the process of gasification, a thermochemical process that transforms the carbon in chemical structures by decomposing organic matter into gas.

The process of gasification occurs in equipment called gasifiers. The main types are:

- Fixed-bed gasifier: The matter to be gasified is moved by gravity. These gasifiers are built with a fixed bed, where fuel is over a grille, with an up-draft flow or down-draft flow. This is the most common, known and operationally mastered technology, and it has been implemented in small scale.
- To generate electric power, fixed-bed gasifiers has been used to feed internal combustion engines, in systems between 1kW and 200 kW.
- Fluidized bed gasifier: In this type of gasifier, the matter is kept suspended on a bed of fluidized material (usually sand), kept in movement by the air flow. The biomass is dragged on a fluidized bed. They can be of the bubbling type or the circulating type, according to the speed with which the matter crosses the bed. In the bubbling type the speed is up to 3 m/s and in the circulating type the speed can reach higher than 3 m/s, allowing a better mixture of the air with the fuel to be gasified.

3.3.1 URBAN SOLID WASTE (USW) IN THE STATES OF MT AND MS AND THE POTENTIAL FOR ELECTRIC POWER GENERATION

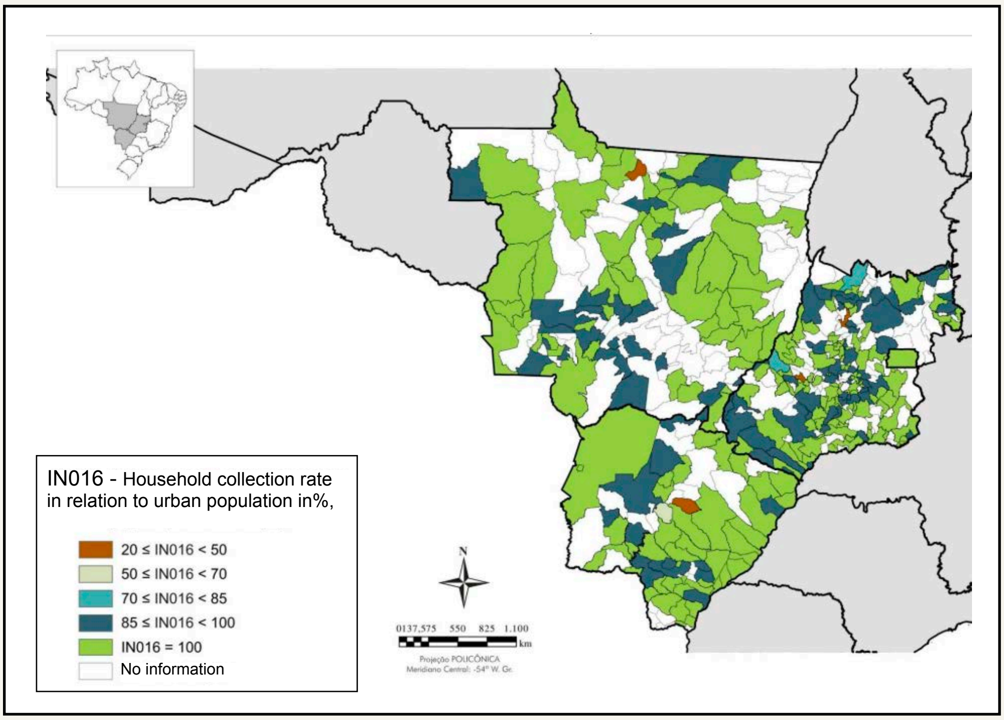
Approved in August 2010, the Brazilian National Policy on Solid Waste (PNRS, Portuguese acronym) is the most important milestone in solid waste management. The main goal is to promote healthy and sustainable ways of USW management in the 5570 cities of Brazil (Brasil, 2010). However, indicators show few advances in the

7 TOE: ton of oil equivalent, approximately 42 GJ.

first decade since PNRS was implemented. Between 2010 and 2016, the Brazilian population with access to solid waste collection decreased from 82% to 75%, and the proper management of the collected waste raised only 0.8% which resulted in around 81,000 tons of waste without proper management (ABRELPE, 2016; MCIDADES.SNSA, 2018; SNIS, 2016).

In the Midwest, around 99% of the population has access to USW collection (Picture 11), but only 13.9% of the cities manage this collected waste properly (sanitary landfill). The proper management considers ways of environmental protection and occupational safety that aim to reduce or eliminate contamination of water, soil and air. The use of gasification has important synergies with the expansion of USW proper management, such as: i) reduce the volume of waste that goes to the landfills, ii) reduce the risks of soil contamination, iii) reduce greenhouse gas emissions, and iv) generate distributed electricity and closer to great urban areas.

IN THE MIDWEST, AROUND 99% OF THE POPULATION HAS ACCESS TO USW COLLECTION, BUT ONLY 13.9% OF THE CITIES MANAGE THIS COLLECTED WASTE PROPERLY.



Picture 13 – Household collection rate in relation to urban population in%, (indicator IN016). Source: (Brasil, 2019)

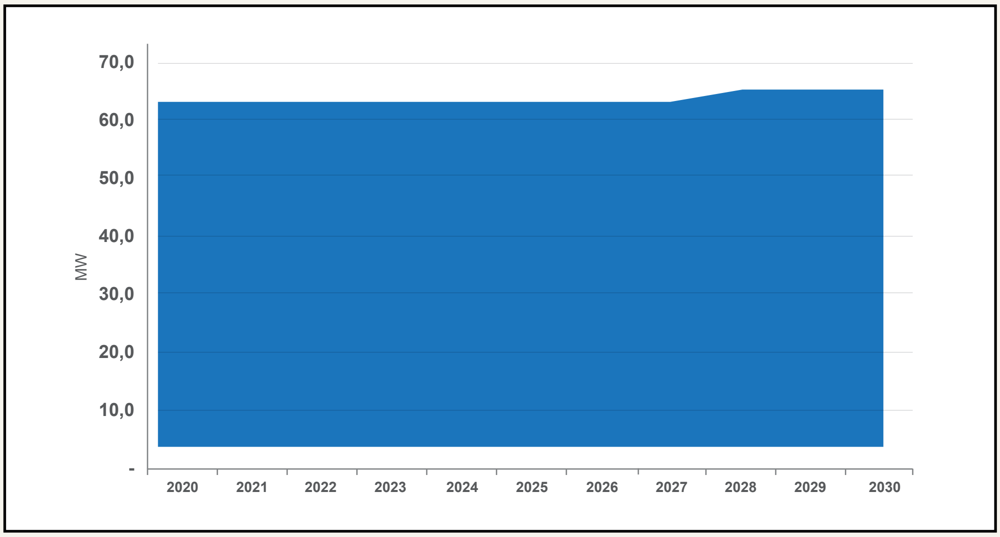
To understand how USW gasification can contribute to the expansion of energy supply in the states of MS and MT, two main factors were considered. The first one is populational growth in the cities of both states between 2019 to 2030, which was estimated considering populational projections calculated by IBGE (2019b). This data is important to estimate the amount of waste by each city and later have a dimension of the processing units. The second factor is the minimum size of the power plant, so the project is economically viable.

The manufacturers indicate the viability of projects that can meet the needs of 20,000 people (Carbogás, 2019), but this study adopted a minimum of 45,000 people to keep conservative estimates and close to the investors scale of attraction.

Between 2017 and 2030, the population in the state of MS is estimated to grow around 12%, going from 3.5 to 3.9 million people. The population of MT will grow less, 11%, going from 2.8 to 3.07 million. These growth rates, when applied to cities, showed that the number of cities with more than 45,000 people will grow from 23 to 25. Considering the consumption and waste production patterns are kept in the next years, the daily production of solid waste in these cities will grow from 5.9 to 6,500 tons.

Picture 14 shows the estimated evolution of capacity potential in electric power generation projects through USW gasification. By the end of the analyzed period, the estimate is an expansion of the capacity in around 64,7 MW, with the potential of 567 GWh per year, supplying 295,000 houses with an investment around R$ 1.3 billion. One can notice in the diagram the growth in capacity in 2028, which can be explained by two cities that grow big enough to get the minimum necessary for the construction of a gasification plant.

BIOGAS IS ONE OF THE BYPRODUCTS PRODUCED BY ANAEROBIC DIGESTION OF ORGANIC COMPONENTS OF LIQUID EFFLUENTS, AND DUE TO ITS COMPOSITION CAN BE USED A SOURCE OF RENEWABLE ENERGY.



Picture 14 - Estimated evolution of capacity potential in electric power generation projects through USW gasification. Source: the authors themselves based in Carbogás (2018) and IBGE (2019b)

3.4 WASTEWATER TREATMENT

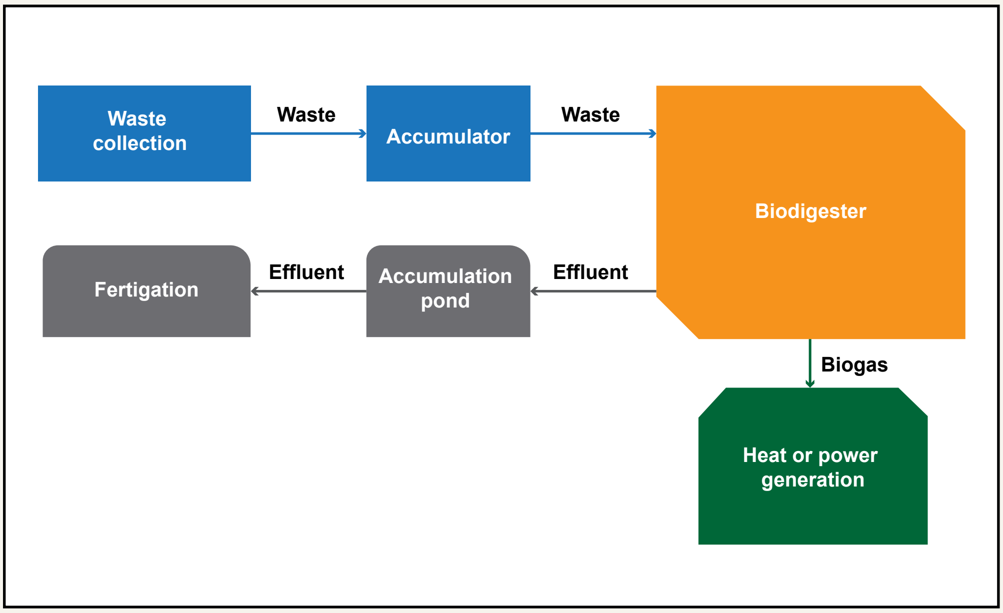
3.4.1 ANIMAL PRODUCTION

Traditionally, Brazil is one of the major animal protein producers in the world. In 2017, it was the biggest cattle producer, with a total amount of 215 million heads of cattle. It's the fourth biggest chicken producer, with a total amount of 1.4 billion chickens, and the third biggest swine producer, with a total amount of 41 million animals (FAO, 2019). Even though there are positive economic impact, the animal production is associated with two major environmental problems: greenhouse gas emission (GHG) and large amounts of animal waste.

In 2016, livestock industry was the second biggest source of emissions in Brazil, almost 500 million tons of CO_2, mainly composed of enteric fermentation, animal waste management and nitrous oxide from the use of nitrogen fertilizers (OC - Observatório do Clima, 2018). These types of animal production waste are rich in organic matter that release carbon in the atmosphere during decomposition. This high organic concentration leads to the second great environmental impact; when they are not properly managed, they can pollute local water sources (Coelho et al., 2018).

However, the use of biodigesters as an alternative technology can produce biogas and generate electric power and reduce the negative impact of animal production waste.

Biogas is one of the byproducts produced by anaerobic digestion of organic components of liquid effluents, and due to its composition can be used a source of renewable energy. Usually, the gas is composed of 60% methane (CH4), 35% carbon dioxide (CO_2), and 5% other gases, such as: nitrogen, ammonia, hydrogen sulfide gas, carbon monoxide and oxygen, among others (Coelho et al., 2018). The potential for energy use is because of the high methane concentration that can be used for heating – replacing fossil fuels in vehicles, for electricity and as a biofertilizer.

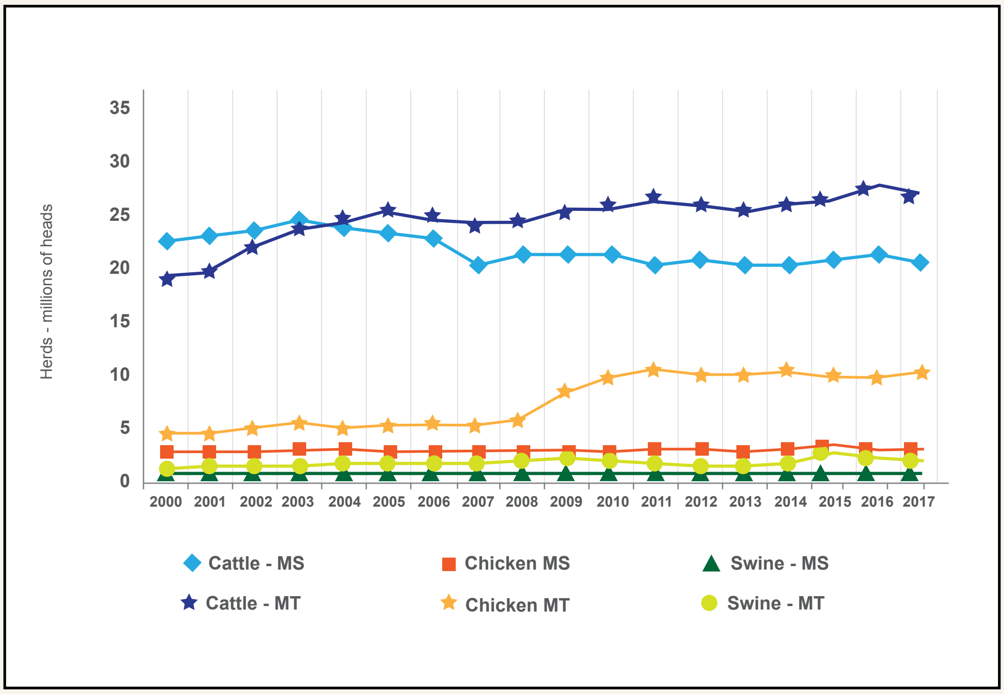


Picture 15 – Process of biodigestion of animal waste. Source: the authors themselves based in Coelho et al. (2018)

The use of biogas for electric power generation consists on the transformation of chemical energy in the gas into mechanical energy, which is then converted into electric energy. Different from other renewable sources, the generation of electricity through biogas is constant and can be used to alleviate the intermittency of the generation system.

3.4.1.1 ANIMAL PROTEIN PRODUCTION IN THE STATES OF MT AND MS AND THE POTENTIAL FOR ELECTRIC POWER GENERATION

In the last two decades, the animal protein industry went through important transformation in the states of MT and MS. Analyzing the types of herd between 2000 and 2017, livestock production was the one with the smallest variation, growing 57% the number of cattle in MT and a decrease of 3% in MS. The swine herd grew around 200% in MT and 110% in MS, while chicken industry grew 158% in MT and 49% in MS (Picture 20). This expansion is naturally followed by the raise in the number of animal waste, with a production of around 191.1 million tons in 2017.

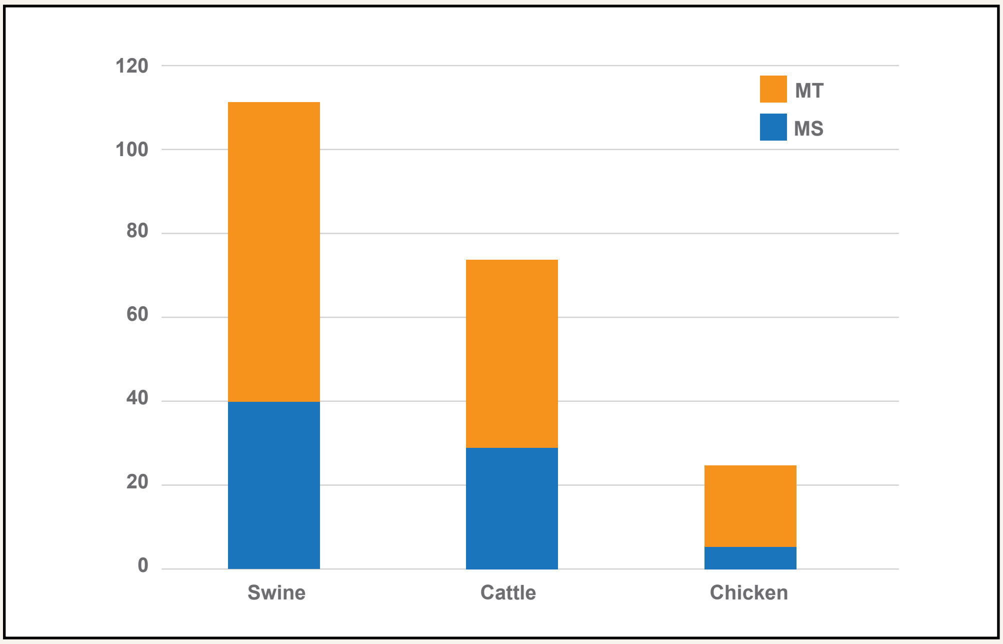


Picture 16 – Historic evolution of herds in the states of MT and MS. Source: the authors themselves based in (IBGE, 2018)

BIOGAS AND ELECTRICITY GENERATION IN SWINE INDUSTRY BENEFITS FROM THE HIGH LEVEL OF ORGANIC MATTER AND THE HERD'S CONFINEMENT.

To understand how animal waste biodigestion can contribute to the expansion and diversification of the energy matrix in the region, the generation potential for each type of waste was estimated. It was considered the total number of chicken and swine produced in 2017, analyzed by Municipal Livestock Survey (IBGE, 2018). The largest part of cattle production in Brazil is extensive, which makes impossible to collect and biodigest the waste. That's why it was considered that 2%[8] of the herd is kept confined, thus have the potential for biodigestion.

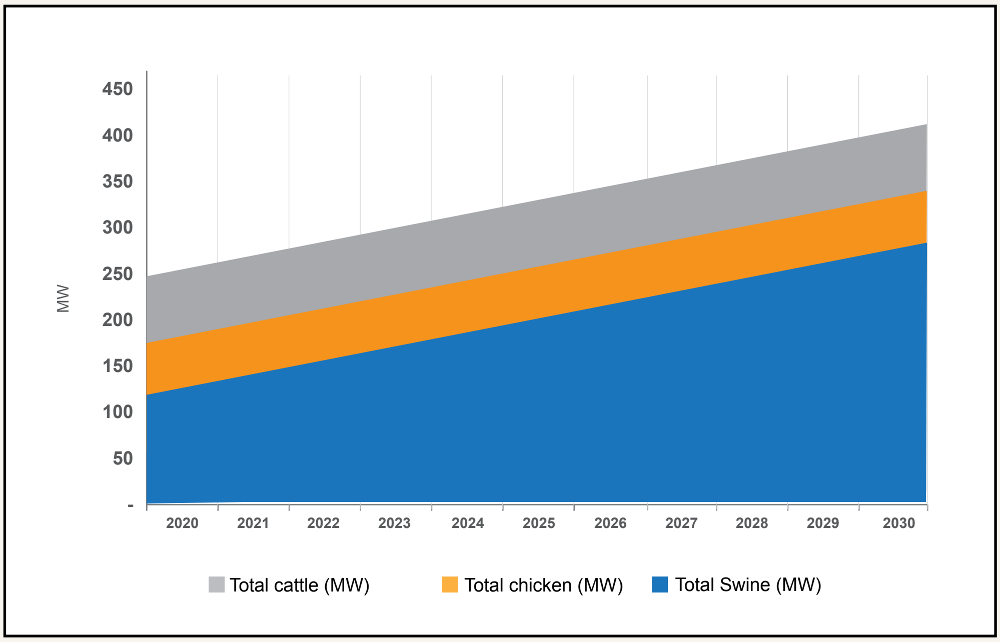
According to Picture 17, the use of this technology has the potential to add 211 MW to the region's energy matrix according to the production in 2017. The state of Mato Grosso is the one with the biggest potential, 134 MW. Biogas and electricity generation in swine industry benefits from the high level of organic matter and the herd's confinement. The swine industry today has the biggest generation potential, with 110 MW. Cattle has the second biggest potential, with 72 MW, but it can double this number in 13 years if confinement rates keep growing like it is today.



Picture 17 – Estimation of electric power generation potential from animal waste biodigestion, Source: the authors themselves with data from (IBGE, 2018) and methodology developed by (Coelho et al., 2012)

Picture 18 shows the estimated capacity projection for biodigestion projects for electric power production keeping the growth rates constant in the three types of herd: swine, cattle and chicken. In 2030, the total power can reach 410MW and generate around 3 TWh per year, making it possible to supply electricity to around 1.5 million houses with an investment around R$ 1.57 billion. The swine production has the biggest capacity, representing 63% of power, followed by cattle with 23% and chicken with 14%.

8 National average of cattle confinement. (Molin, 2018).



Picture 18- Estimated capacity projection for biodigestion projects for electric power production by type of herd. Source: the authors themselves based in Coelho et al. (2012) e IBGE (2018)

3.4.2 MUNICIPAL WASTEWATER (SANITARY SEWER)

The expansion in the use of technologies that use biodigestion for sanitary sewers contributes with the mitigation of two important challenges: the national basic sanitation deficit and the need for power generation. In Brazil, although there were important advances in expanding basic sanitation in the last decade, there's still a huge difference of access to its major elements: water supply and sanitary sewers. In 2017, around 93% of urban population had access to water supply, but only 60% had access to sanitary sewers (SNIS, 2019a).

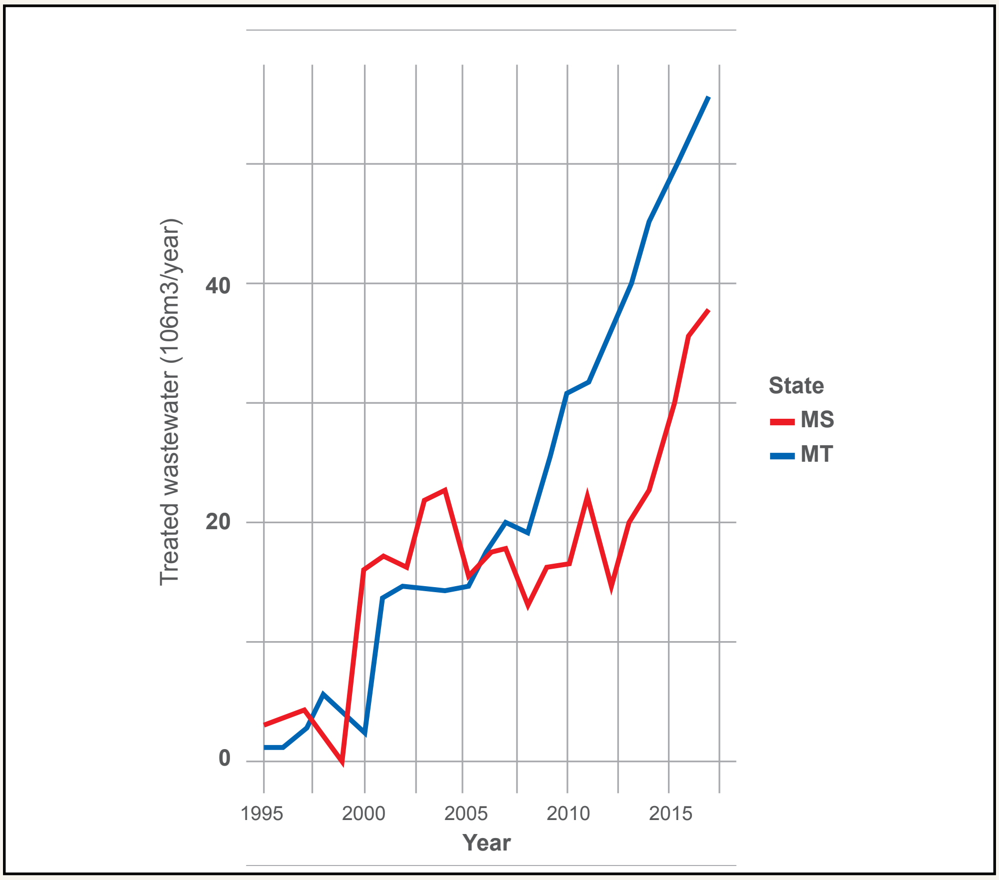
In the states of MT and MS there's a similar pattern: while water supply access is around 97% (MT) and 99% (MS) for urban population, sanitary sewer network is only 49% (MT) and 59% (MS). Absence of collecting and treatment of wastewater has severe environmental impacts - polluting water and soil, and people's quality of life, since sewage is a large disease disseminator (Santos et al., 2016).

In Brazil, biodigestion in sanitary landfills is not yet widespread and there are few power plants operating. Two great examples are ETE Arrudas in Belo Horizonte/MG and ETE Ribeirão Preto/SP. The first one supplies energy for 1.7 million people, with 2,4 MW using 12 microturbines; while the second supplies energy for 600,000 people, with 1.5 MW (Brasil, 2016).

3.4.2.1 SANITARY SEWER IN THE STATES OF MT AND MS AND THE POTENTIAL FOR ELECTRIC POWER GENERATION

Picture 19 shows the historic evolution in wastewater treatment in the last two decades. There are two moments of great expansion, first one in the 2000's, growing six times the treated volume, and the second one from 2010 to 2017, when the treated volume in MT went from 16.7 million m³ to 38.4 million m³, and 31.1 million m³ to 56.1 million m³ in the state of MS. This trend creates a favorable scenario for investments by raising the scale and treatment plants.

IN BRAZIL, BIODIGESTION IN SANITARY LANDFILLS IS NOT YET WIDESPREAD AND THERE ARE FEW POWER PLANTS OPERATING.

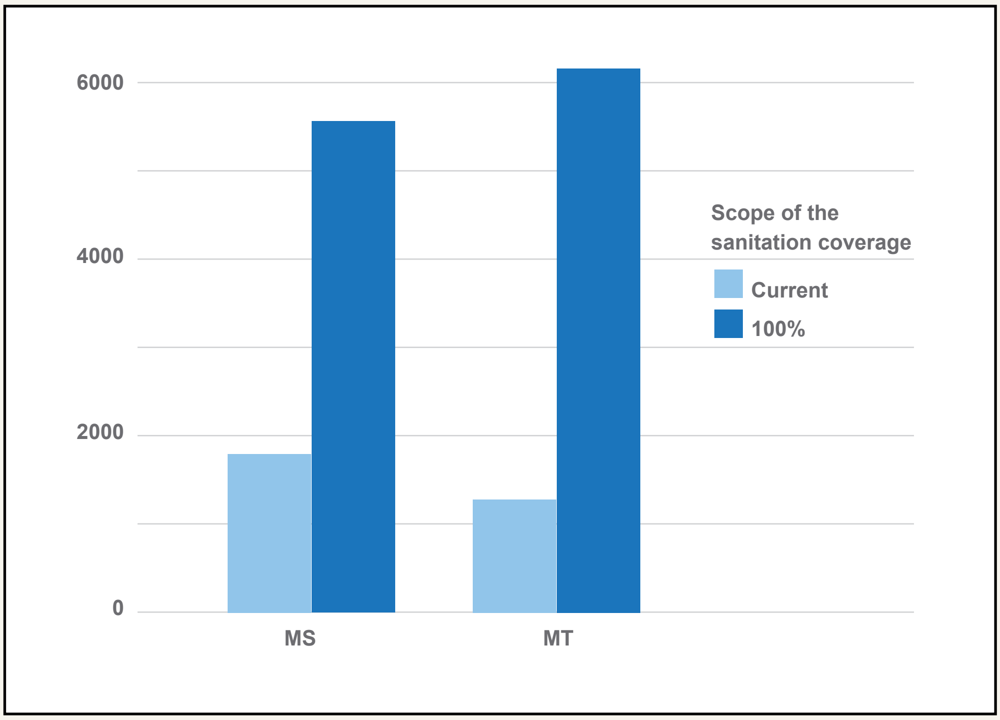


Picture 19 – Treated wastewater volume in Mt and MS. Source: the authors themselves with data from (SNIS, 2019b).

Aiming to understand how electric power generation through wastewater treatment (WWT) can contribute to the expansion and diversification of the energy matrix, the theoretical generation potential was estimated under two scenarios. In the first one, identified as "Current", the current level of treatment coverage was considered, which is 40% of urban population in MT and 59% in MS. In the second one, hypothetically, 100% of the population would have access to wastewater collection and treatment. Both scenarios assume that the entire volume is biodigested and biogas is converted into electric power.

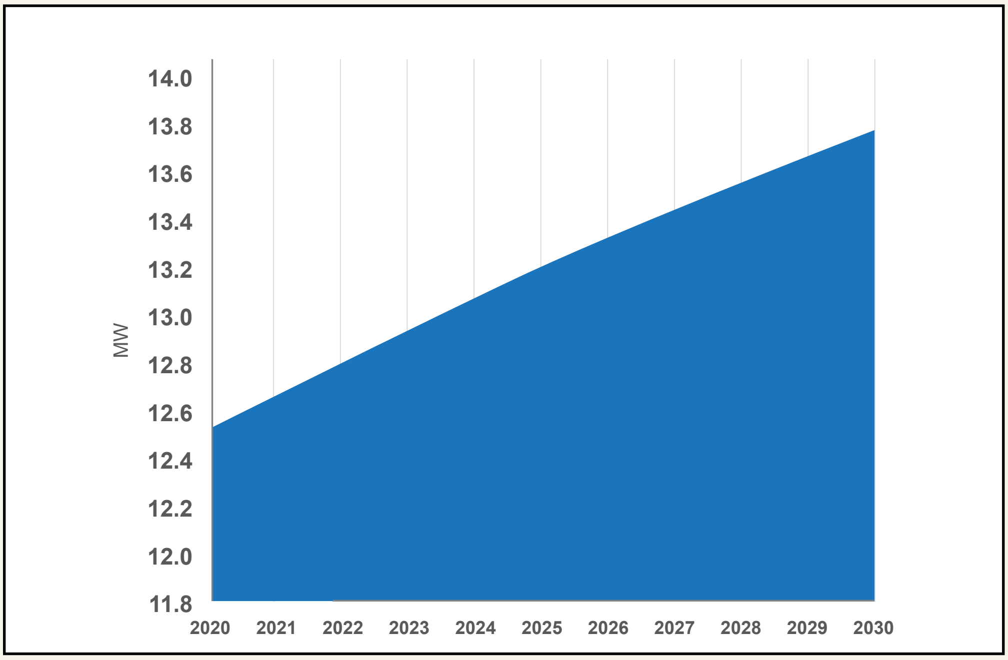
CONSIDERING THE JOB CREATION GLOBAL AVERAGE PER SOURCE, THE IMPACT ON THE LOCAL JOB MARKET DUE TO IMPLEMENTATION OF GENERATION PROJECTS BY OTHER RENEWABLE SOURCES PROPOSED IN THIS STUDY WAS ESTIMATED.

As shown in the Picture 20, the "Current" scenario estimates a potential of 1.8MW in MS and 1.2 MW in MT, with a total amount of 3 MW. In the "100%" scenario the potential is around 12 MW, 5.6 MW in MS and 6.4 MW in MT, enough to supply around 34,000 people.



Picture 20 – Comparison of electric power generation potential considering two sanitation coverage scenarios: Current and 100%. Source: the authors themselves based in (SNIS, 2019b)

The projected expansion of generating capacity is illustrated in Picture 21. This scenario considers the official projections of populational growth by state according to IBGE (2019b), the maintenance of urbanization rate of 85.6% in MS and 81.9% in MT, collecting and treatment of 100% of wastewater produced by urban population. According to the projections for 2030, the electric power generation projects through biodigestion of wastewater can add around 14 MW, generate 101 GWh per year, with investments around R$ 522 million.



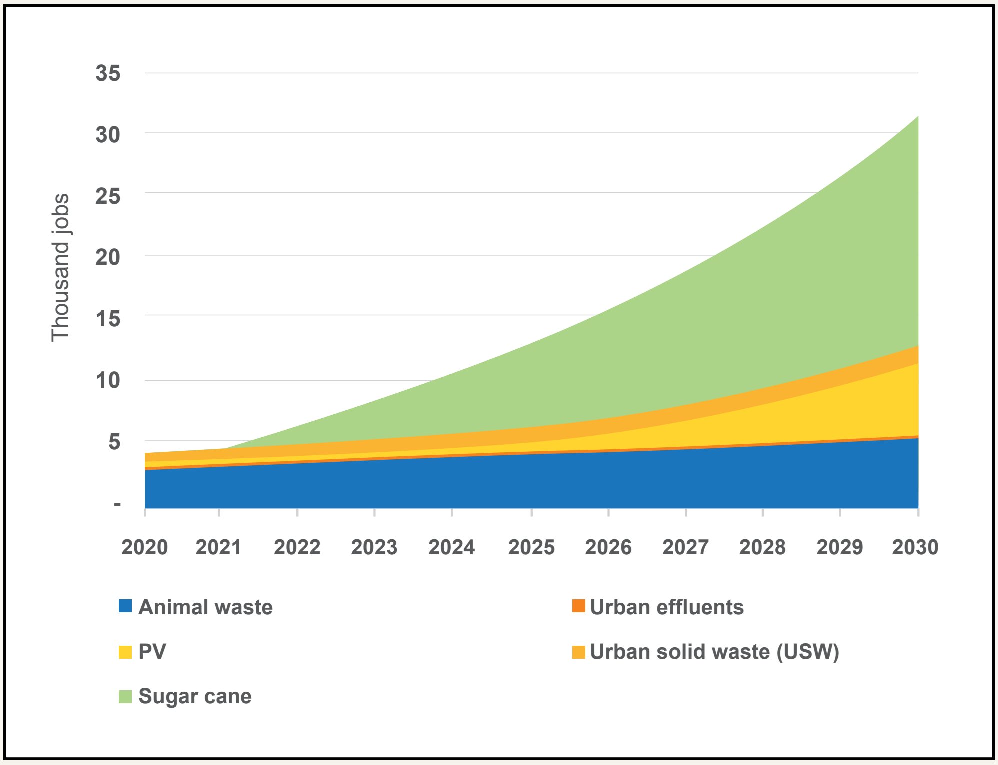
Picture 21 - Projected expansion of urban sewage electricity generation capacity. %. Source: the authors themselves based in Coelho et a. (2012) and (SNIS, 2019b)

3.5 JOB CREATION

Renewable energy employs over 11 million people around the world (data from 2018). The types of production that create the most jobs are photovoltaic (3.6 million), biofuel (2.1 million) and hydroelectric power (2.5 million). However, when the amount of jobs created is analyzed by capacity, biogas, biofuels and solar power, they create respectively, 20 jobs/MW, 9.9 jobs/MW and 9 jobs/MW (IRENA, 2019).

Considering the job creation global average per source, the impact on the local job market due to implementation of generation projects by other renewable sources proposed in this study was estimated. Picture 22 shows these results, where one can notice that three biggest job creators are, respectively, sugar cane bioelectric power, photovoltaic and animal waste biodigestion. In 2030, the total amount of people employed by these industries would be around 29,000, with potential to raise salaries in the states in about R$486 million[9] per year.

9 Average income in the states of MS and MT in 2018: R$ 1,412.50 (IBGE, 2019c)



Picture 22 – Projection of the number of workers involved in electric power generation activities, by source. Source: the authors themselves based in (IRENA, 2018)

Patrik Oening Rodrigues - Concurso Áreas que Protegem a Vida – Pantanal/WWF-Brazil

IN BRAZIL, ALTHOUGH THERE WERE IMPORTANT ADVANCES IN EXPANDING BASIC SANITATION IN THE LAST DECADE, THERE'S STILL A HUGE DIFFERENCE OF ACCESS TO ITS MAJOR ELEMENTS: WATER SUPPLY AND SANITARY SEWERS.

4. COMBINING ALTERNATIVES FOR ELECTRIC POWER GENERATION – 2030

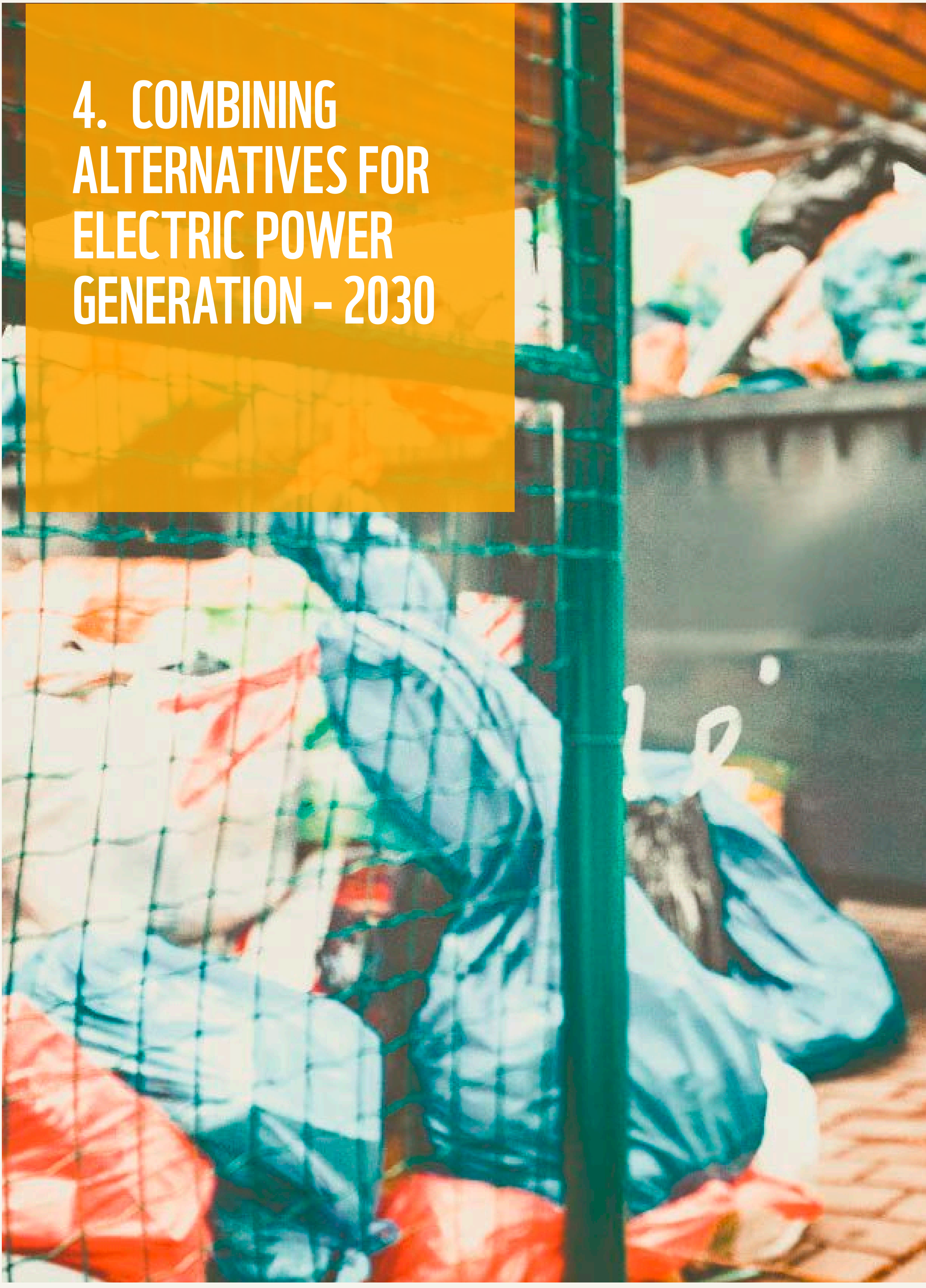
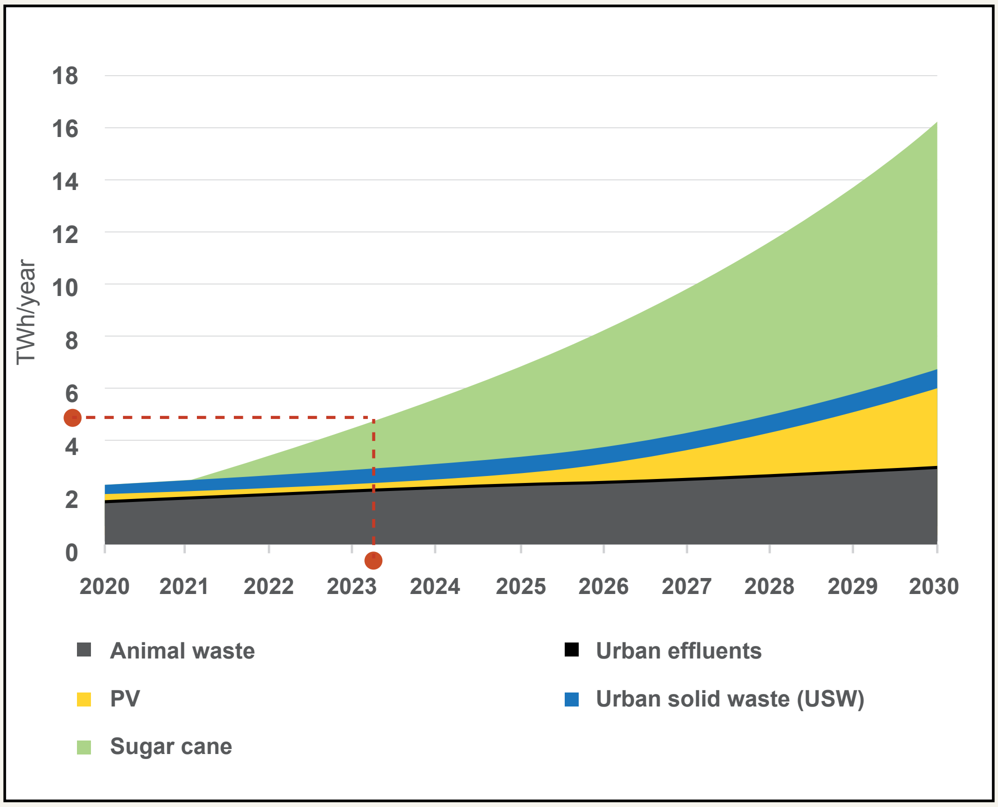


Foto: © ABiogás

Picture 23 shows the results of projections on all electric power generation alternatives mentioned in this study. The three main sources are sugar cane cogeneration, solar PV and animal waste biodigestion, representing, respectively, 55%, 21% and 20% of the energy in 2030.

By the end of the period mentioned in the scenarios, these projects could generate approximately 3,690 MW, which is three times more than the power of 125 new PCHs planned for construction in the Hydrographic region of Paraguay. By 2030, these PCHs would generate around 15.3 TWh, which is equivalent to the annual consumption of 7.9 million houses.



Picture 23 – Projections of electric power generation in the states of MT and MS. Source: the authors themselves based in (Coelho et al., 2012; IBGE, 2019, ANEEL, 2019)

When considering the construction of 100% of the new PCHs (adding 1.72W to the MW energy matrix in 2023) and a 50% average capacity factor, the energy potential would be 5 TWh per year (5,000 GWh/year).

According to Picture 23, as indicated by the red line, the same amount of energy produced by PCHs could be generated by alternative sources (solar PV, biomass, USW, wastewater and animal waste), without the need to build more dams. The socioenvironmental benefit would be preservation of existing ecosystems without harming the hydro regime.

The investment for these alternative projects is estimated in R$ 20.3 billion, around R$ 5.5 million per MW (Table 4). Data from Brazilian Association of PCHs and CGHs show the economic viability of PCHs projects between R$ 5 million and R$ 6 million per MW (ABRAPCH, 2017). The cost to choose for other types of sources are quite similar to the cost estimated by the hydroelectric sector.

Table 4 – Investment cost and investment per MW by alternative source

Source	CAPEX (R$ Billion)	MM R$/MW
Animal Waste	1.6	3.8
Wastewater	0.5	37.9
Solar PV	7.6	3.7
USW	1.3	20.3
Sugar cane (Bioelectricity)	9.3	8.2
Total	20.3	5.5

Note: In December 2019, the dollar to real conversion rate was on average US$1 = R$ 4. Source: Banco Central do Brasil

Three important characteristics of this alternative generation system must be highlighted. The first one is the renewable aspect, which can use solar power as well as economic activities waste. The second is the combination of sugar cane waste cogeneration and animal waste biodigestion; which can compensate the issue of light hours in solar PV systems. Furthermore, the use of waste for energy generation allows a proper management, meeting the current regulations. The third characteristic is the energy generation would be distributed, raising the levels of security in the system, decreasing costs and losses with transmission in long distances.

THE SOCIOENVIRONMENTAL BENEFIT WOULD BE PRESERVATION OF EXISTING ECOSYSTEMS WITHOUT HARMING THE HYDRO REGIME.

One can conclude that is possible to generate energy in the Midwest in a distributed way, meeting the demands of populational and economic growth very easily, by using renewable sources of energy and aligning them with the region's production. This decentralized model of energy development could place MW ahead of the rest of Brazil when it comes to this subject.

The highlight is the sugar cane biomass energy, followed by animal waste, both largely available in the region. Third is solar PV, which can overcome by 2030 the power from the 125 new PCHs currently under study, but in a smaller area than the lakes formed by the hydro plants.

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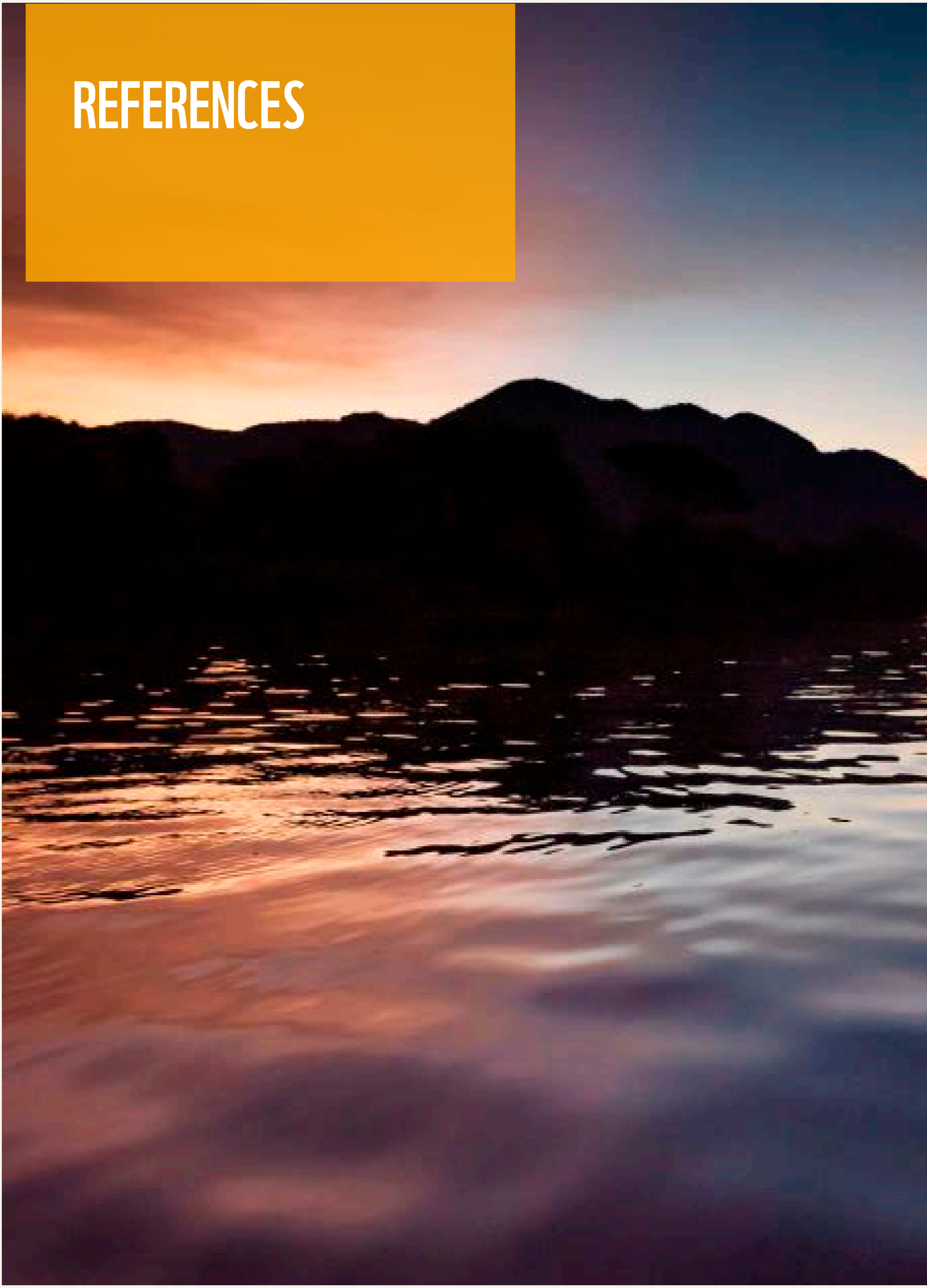

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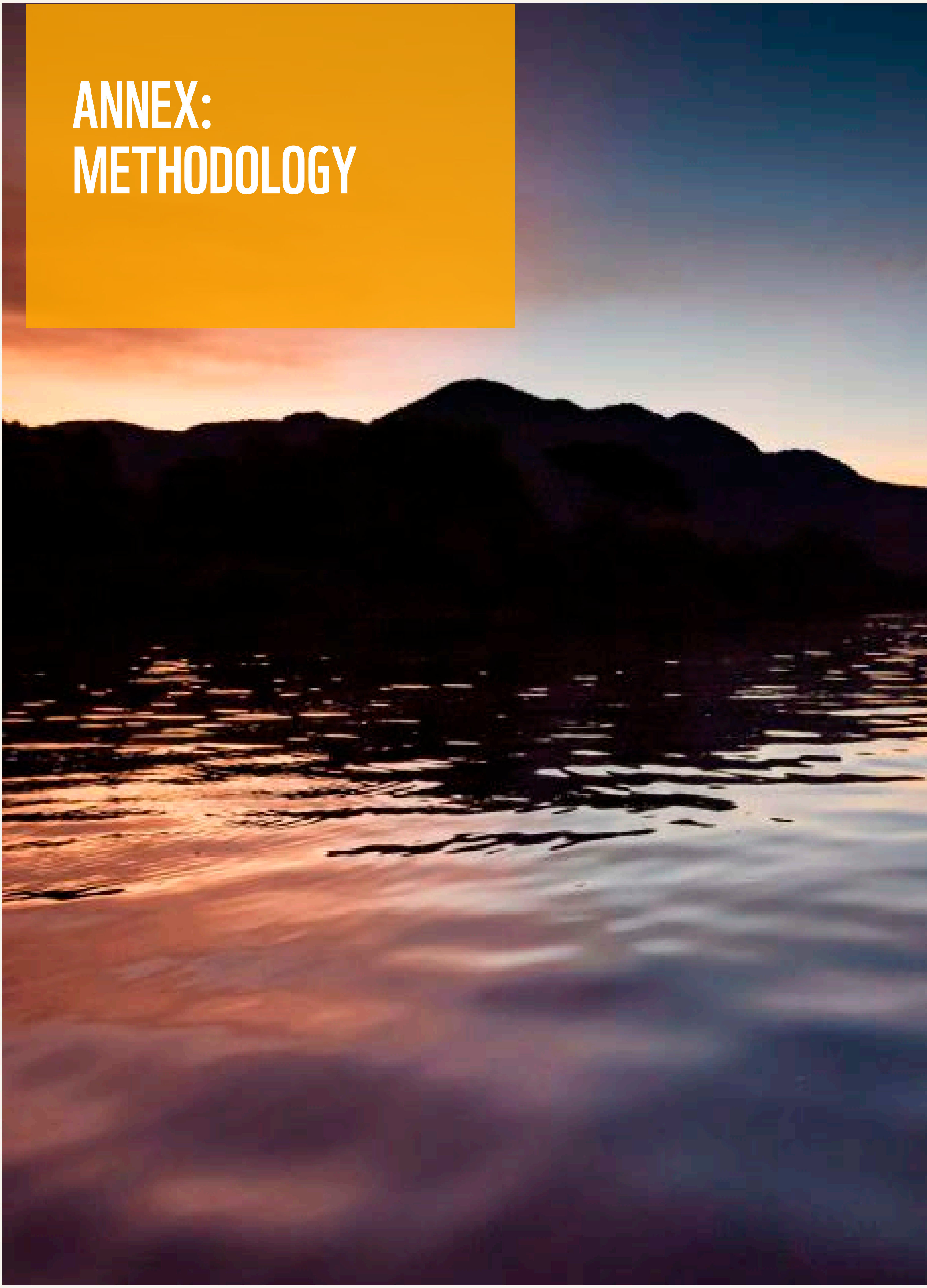
ANNEX: METHODOLOGY




David Wentworth Frey – Concurso Áreas que Protegem a Vida – Pantanal/WWF-Brasil

1. CALCULATION OF POTENTIAL OF ELECTRIC POWER GENERATION IN MT AND MS STATES

1.1 PHOTOVOLTAIC

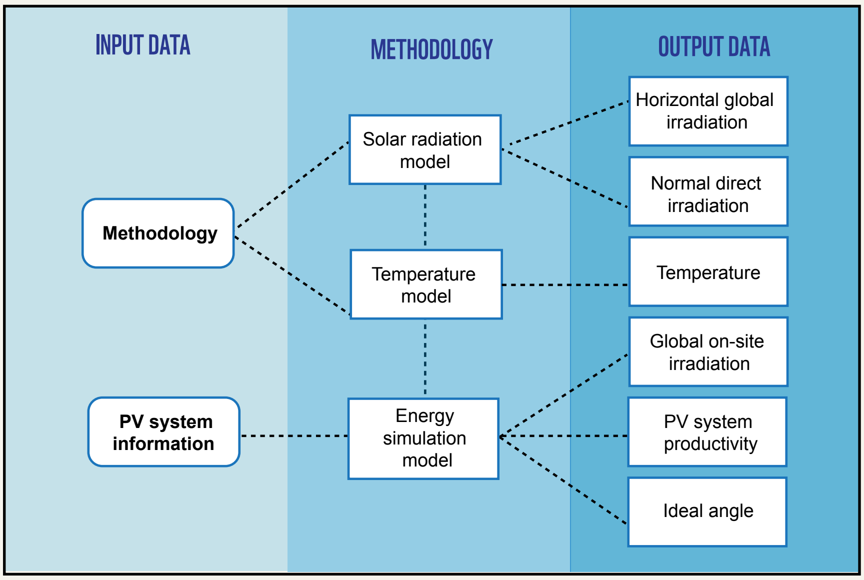
Calculation of the potential of electric power generation by using solar PV was based in the tool "Global Solar Atlas" used by the World Bank and managed by Solargis. The specific information found in the Atlas involves three methodologies: solar radiation, air temperature and photovoltaic power simulation.

Solar radiation and air temperature result in a series of pre-calculated data that can be used for any place in the world. Additional information about the type of PV system wanted and its basic configuration are introduced to simulate solar power, which is calculated case by case using algorithms and internal databank from Solargis and the World Bank.

According to this methodology, the terms solar resource or solar radiation are replaced by two terms: (i) solar irradiance, which is the radiant flow (power) by surface unit, which is kW/m^2, and (ii) solar irradiation, which is the energy or integral solar irradiation over time, represented by kWh/m^2.

The chart below provides and overview of information regarding the methodology used.

SOLAR RADIATION AND AIR TEMPERATURE RESULT IN A SERIES OF PRE-CALCULATED DATA THAT CAN BE USED FOR ANY PLACE IN THE WORLD.



Picture 1 – Chart with information about the calculus methodology for solar energy production. Source: Solargis and World Bank, 2018.

Table 5 – Parameters and characteristics to calculate solar energy production. Source: Solargis and World Bank, 2018.

Parameters	Units	Theorical data	Small system	Medium system	Big system
PV system capacity	[kWp]	1	Defined by user		
Module Surface Reflection	-	0,16	0,16	0,16	0,16
Nominal Operating Cell Temperature	[°C]	46	52	48	44
Cell temperature coefficient	[°C/W]	0,0325	0,04	0,035	0,03
Module losses by temperature	[%/°C]	-0,45	-0,44	-0,44	-0,44
Inverter Efficiency	[%]	97,5	97,5	97,5	97,5
Losses DC: Pollution / Snow	[%]	4,5	4,5	4	3,5
Losses DC: Cable	[%]	2,5	1	1,5	2
Losses DC: Incompatibility	[%]	0,5	0,5	0,5	0,5
Losses AC: Transformer	[%]	1,0	0	0	0,9
Losses AC: Cable	[%]	0,5	0,2	0,3	0,5
Availability	[%]	100	97	98	99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The method used in the solar radiation model takes in consideration the solar radiation reduction when passing through atmosphere until it heats the surface. To calculate solar resources parameters, Solargis model uses geostationary satellites data and meteorological models.

Besides solar radiation and air temperature, photovoltaic modules temperature is the most important factor to simulate solar energy. The Global Solar Atlas works with data based in time series of local air temperature data. Meteorological data for global models has lesser spatial and time resolution regarding the data modeled by solar resources. Global meteorological data must be post-processed to provide parameters with local representation.

An electric power production simulation model through a PV system depends on many external factors. The most important one is the amount of solar radiation over PV modules surface, which in turn depends on local climate conditions, as well as the modules setup and etc.

Notes:

If solar radiation was the only parameter to influence the PV module power, the task to estimate the energy performance of a PV system in long term would be reduced to simply know the average global irradiation. However, temperature is a second important factor.

Since the PV energy production in the Global Solar Atlas is simulated in a time series from several years and sub-times of solar radiation and air temperature, it was considered that the result is precise enough to simulate a scenario.

PV production is based on the implementation phase of a PV project, and the natural model deterioration in long term is not considered. This deterioration represents an average annual loss of 0.4%, reaching 15% in 25 years.

1.2 SUGAR CANE

To project sugar cane waste electric power generation there are two main aspects: i) the amount of produced sugar cane growth rate and ii) sugar cane into electric power conversion rate. For the first one, sugar cane production data from IBGE (2019a) was used and a conservative expansion rhythm of around 8% per year in the state of MS and around 6% in MT. The electric power generation capacity projections considered three scenarios according to the methodology developed in (Coelho et al., 2012):

- **Scenario A:** considers the generation system with a 60 kWh capacity for ton of sugar cane, power plants operating during harvest (April to November), with a total of 5,563 hours. To calculate the electric power generation potential, the followed formula was used:

$$Potential\ (MW/year) = \frac{(t\ sugar\ cane * 60kWh/t)}{1000 * 5563} 1{,}2\text{-}1$$

- **Scenario B**: considers the generation system with a 120 kWh capacity for ton of sugar cane, power plants operating 95% of the year, with a total of 8,322 hours. This scenario assumes that other types of waste would be used, like bagasse, cane tops and straw. To calculate the electric power generation potential, the followed formula was used:

$$Potential\ (MW/year) = \frac{(t\ sugar\ cane * 120kWh/t)}{1000 * 8322} 1{,}2\text{-}1$$

THE METHOD USED IN THE SOLAR RADIATION MODEL TAKES IN CONSIDERATION THE SOLAR RADIATION REDUCTION WHEN PASSING THROUGH ATMOSPHERE UNTIL IT HEATS THE SURFACE.

Data from NME/EPE (2018) was used to calculate the investments, as presented below:

Table 6 – Average investment for the construction of new units and expansion of existing plants.

CAPEX	R$ (dez. 2017)/tc
Expansion of Existing Units	256.0
New units (greenfield)	359.8
Industrial (includes optimized cogeneration)	27.6
Agricultural Machinery (includes trucks)	67.9
Rentals (Midwest region)	4.3
Note: For conventional sugarcane mills, CAPEX was given per tonne of sugarcane, a part of the production may be used for sugar (unlike presented in the E2G and Corn Ethanol units).	
Source: EPE based on CTBE (2018) and UNICA (2014)	

1.3 URBAN SOLID WASTE (USW) IN THE STATES OF MT AND MS AND THE POTENTIAL FOR ELECTRIC POWER GENERATION

To calculate the electric power generation potential through solid urban waste processing, the use of fluidized bed gasifiers was considered.

To calculate the projections of amount of USW by state, the followed formula was use:

$$AUSW = Pop * Urb * M$$

Where:

- AUSW = Amount of urban solid waste collected by city in tons per day;
- Pop = Populational projections from IBGE (2019);
- Urb = Urbanization rate by state. 81.9% in MT and 85.6% in MS.
- M = Mass per capita collected by city. The average by city in the Midwest is 1.12 kg/hab/day according to Brasil (2019).

THE GLOBAL SOLAR ATLAS WORKS WITH DATA BASED IN TIME SERIES OF LOCAL AIR TEMPERATURE DATA. METEOROLOGICAL DATA FOR GLOBAL MODELS HAS LESSER SPATIAL AND TIME RESOLUTION REGARDING THE DATA MODELED BY SOLAR RESOURCES.

To calculate the electric power generation potential only the cities with AUSW higher than 45 tons a day were considered. The amount of energy produced and average investment by plant size are presented in table 7.

Table 7 – Electric power generation potential and fluidized bed gasification plants CAPEX, by amount of waste processed per day.

Plant ton/day USW	Produced energy	CAPEX
	MWh	R$
50	0,95	28,090,000.00
100	1,89	33,920,000.00
150	2,84	47,000,000.00
200	3,78	56,000,000.00
250	4,73	66,500,000.00
300	5,67	72,000,000.00

1.4 WASTEWATER TREATMENT

1.4.1 ANIMAL PRODUCTION

To calculate the electric power through animal waste the methodology developed by USP Bioenergy Group (GBio) during the development of Brazil Bioenergy Atlas (Coelho et al., 2012) was used, here presented in the equations:

$$Q_{CH4} = \frac{(num.days/month*num.heads*Et*Pb*Conc.CH_4)}{VE} \quad 1.4.1\text{-}1$$

and

$$Q_{CH4} = \frac{(num.heads*0{,}2295*0{,}60*1{,}37)}{8760} \quad 1.4.1\text{-}2$$

Historical herd data was obtained in the Municipal Livestock Survey (IBGE, 2018). The potential amount of methane from animal manure follows the formula

$$Q_{CH4} = \frac{(num.days/month*num.heads*Et*Pb*Conc.CH_4)}{VE} \quad 1.4.1\text{-}1$$

and uses data references presented in Table 8. By using mostly intensive livestock, the total number of swine and chicken was considered (IBGE, 2018). However, for the cattle potential calculus only 2% was considered, representing the confined cattle national average.

$$Q_{CH4} = \frac{(num.days/month*num.heads*Et*Pb*Conc.CH_4)}{VE} \quad 1.4.1\text{-}1$$

Where:

- Q_{CH4} = Methane flow per month ($m^3CH_4/month$)
- Num.days/month = wastewater treatment number of days (days/month)
- Num.heads = amount of generating units
- Et = Manure (manure in kg/day/generating unit)
- Pb = Biogas production (kg biogas / kg manure)
- $Conc.CH_4$: methane concentration in biogas (%)
- VE: Methane specific volume (KgCH_4/m^3CH_4), which is 0.670 kgCH_4/m^3CH_4
- PCI (biogas – 66% methane) = Biogas lower calorific value with 66% methane = *7,260 kcal/Nm³CH₄*

- PCI (biogas – 60% methane) = Biogas lower calorific value with 60% methane = 6.600 $kcal/Nm^3CH_4$

When calculating biogas potential production through chicken waste, chicken manure production must also be considered. The following formula is used:

$$Q_{CH4} = \frac{(num.heads*0,2295*0,60*1,37)}{8760} \quad 1.4.1\text{-}2$$

Where:

- Q_{CH4} = Methane flow per month ($m^3CH_4/month$)
- 0.2295 = methane generation average (m^3/kg);
- 0.60 = methane concentration in biogas;
- 1.37 = amount of waste from chicken manure (kg/chicken);
- 8760 = time (hours/year)

Table 8 – Energy conversion values for each type of waste Source: Motta (1986)

Animal	Total manure (kg-waste/day/animal)	Biogas production (kg-biogas/kg-waste)	Conc. CH_4	PCI biogas ($kcal/Nm^3$)
Swine	2.25	0.062	66%	7,260
Cattle	10	0.037	60%	6,600
Chicken	0.18	0.055	60%	6,600

The investment cost was calculated according to the average from the data gathered by Coelho et al. (2018). These average values are presented in Table 9.

Table 9 – Investment costs for animal waste energy projects

Item	Value
Reactor RAFA R$/$m^3$ treated per day	700
GD services and technologies (R$/kW)	459
Investments in R$ in Generating Groups (R$/kW)	3,189

1.4.2 MUNICIPAL WASTEWATER (SANITARY SEWER)

To calculate the electric power generation potential, the methodology used was developed by USP Bioenergy Group (GBio) to develop Brazil Bioenergy Atlas (Coelho et al., 2012), presented in the equations:

$$Q_{CH_4} = \frac{\phi efl * DBO_{efl} * \eta * 0.25}{0.72} \quad 1.4.1\text{-}1 \quad \text{and} \quad Q_{CH_4} = \frac{\phi efl * DBO_{efl} * \eta * 0.25}{0.72} \quad 1.4.1\text{-}1$$

Historical data regarding treated wastewater volume by city was obtained through National Sanitation Information System (SNIS, 2019b).

- Methane production potential (CH_4):

$$Q_{CH_4} = \frac{\phi efl * DBO_{efl} * \eta * 0.25}{0.72} \quad 1.4.1\text{-}1$$

Where:

- Q_{CH_4} = methane from anaerobic treatment (m^3/h);
- ϕefl = effluent flow (m^3_{efl}/h);
- DBO_{efl} = biochemical demand of effluent entrance (kgDBO/m^3_{efl}) = 0.312$kg_{DBO}/m^3_{efluente}$;
- η = ηtrat = treatment's efficiency (%) = 95%;
- 0.25 = methane potential generation ($kg_{methane}/kg_{DBO}$removida);
- 0.72 = methane density ($kg_{methane}/ m^3_{methane}$);

- Electric power production potential:

$$P = \frac{Q_{Biogás} * PCI_{Biogás} * \eta_{Motor}}{860} \quad 1.4.2\text{-}2$$

Where:

- P = available power (kW);
- Q = biogas flow (m^3/h);
- PCI (biogas – 50% methane) = Biogas Lower Calorific Power with 50% methane = 5.500 kcal/ Nm3 biogas;
- η_{Motor} = 0,38 = engine efficiency;
- 860 = conversion factor from kcal/h to kW;

To calculate CAPEX the reference value used was R$8,975,802,00 for every 100,000 people, as estimated in Brazil (2016).

SUSTAINABLE ALTERNATIVES FOR ELECTRIC POWER GENERATION IN THE UPPER PARAGUAY BASIN (BAP)

29.5 MILION TONS

was produced of sugarcane in Brazil in 2018/2019, the world's second largest producer

29,000

would be the total amount of employees by renewable energies in Pantanal region by 2030, with potential to raise salaries in about R$486 million per year.

15.3 TWH / YEAR OF ELECTRICITY

can be generated in total by 2030 using alternative sources of clean energy. That means supplying almost 8 million more homes - and without the creation of new hydroelectric dams.

R$ 1.57 BILLION

is the estimated investment to generate an installed capacity of 410 MW of biogas by 2030, making it possible to generate about 3 TWh per year and serve 1.5 million homes.