

# Brazil market outlook for photovoltaic solar energy

## ABSTRACT

There is great concern worldwide about increased greenhouse gas emissions and the consequences of climate change. Photovoltaic solar energy emerges as an alternative source of renewable energy with low environmental impacts. Through a bibliographical review on the subject, this paper presents an analysis of the scale insertion of this energy in Brazil, demonstrating the benefits that can be generated of this technology, impediments and future perspectives. The conclusion is that Brazil has great potential for the energy generation, collaborating to reduce the environmental impacts as a reduction of the greenhouse gases emission. The barriers to introducing photovoltaic solar energy have been lack of investment, lack of more aggressive incentive programs, technological capacity and professional training.

*Keywords: Photovoltaic; Solar Energy; Renewable Energies; Climate Change.*

## 1. INTRODUCTION

Electricity has become an indispensable and strategic resource for the socioeconomic development of countries and regions. However, the growing interest in the search for new renewable sources of energy has been triggered by environmental impact due to pollution, depletion of resources and climate change, with some effects more worrying than others [1].

The temperature of the earth's surface is expected to increase over the years. It is very likely that heat waves will occur more often and last longer, and extreme events of precipitation will become more intense and frequent in many regions. The ocean will continue to heat and acidify and the average level of the oceans will rise. Continuity of high emissions will lead to mostly negative impacts on biodiversity, ecosystems, services and economic development and could increase the risks to livelihood, food and human security [2].

Due to the growing concern about environmental issues and the need to achieve a sustainable economy, there is a necessity to develop new solutions and energy sources strategies with less environmental impact and economically viable [3]. In this scenario, the technologies for generating energy from renewable sources with low greenhouse gas emissions become increasingly attractive [1]. In recent years, in Brazil, photovoltaic energy generation has been considered as a renewable and promising energy technology [4]. Implanted gradually, it offers an option that complements the Brazilian energy matrix [5].

Brazil is a privileged country for the installation of these systems, considering the possibility of using the high solar radiation indices in the country compared to the developed nations [6]. The possibility of using the solar radiation in the urban environment for the energy generation makes the city more sustainable [3].

For these reasons, given the importance of this subject in the world, this article analyze the photovoltaic solar energy insertion in the Brazil energy matrix, with the objective of verifying the implementation benefits, future perspectives and the new technology impediments to achieve large scale. This work aims to demonstrate that the increase of incentives can improve the economic and environmental results of the country.

## 39 2. METHODOLOGY

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41 The methodology used in the research was the bibliographic review on the proposed theme. The  
 42 research sought to identify, evaluate and interpret a set of documents available in academic  
 43 collections and institutions and energy sector entities.

44 The selection criteria took into account the following aspects: (i) titles of articles aligned with the  
 45 research theme; (ii) abstracts aligned to the research theme; (iii) result relevance filter; and (iv) full  
 46 text of articles aligned with the research theme. There was no temporal delimitation of the  
 47 publications. The analysis result of the information obtained was used for the article elaboration.

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## 49 3. RESULTS AND DISCUSSION

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51 This chapter presents the main concepts about the research basic theme, including considerations  
 52 about the current energy matrix in Brazil, the country solar potential and future perspectives of  
 53 photovoltaic solar energy in the world.

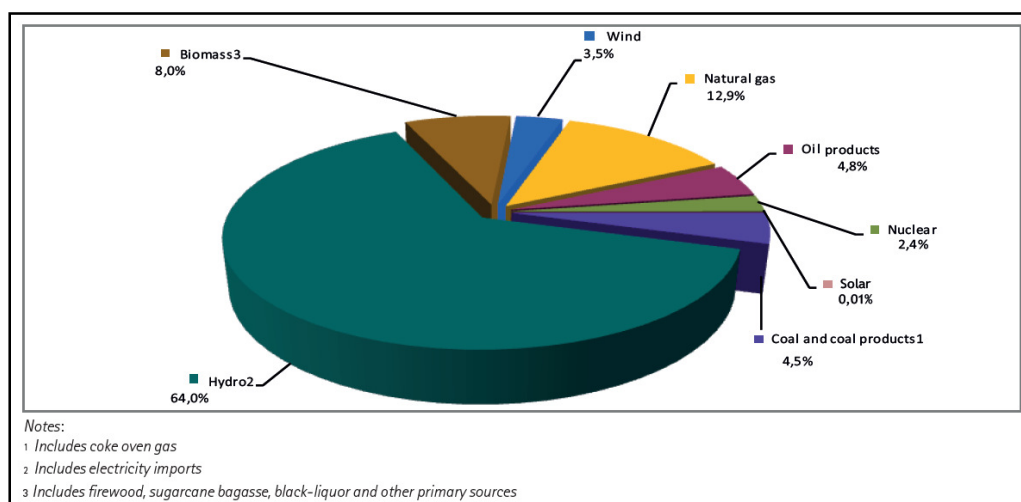
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### 55 3.1 Brazil Energy Matrix

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57 According to a report published by the Ministério de Minas e Energia [7], the Brazil electric energy  
 58 generation in public service and self-producers has reached 581.5 TWh in 2015. The energy matrix is  
 59 predominantly renewable, with hydraulics responsible for 64% of the domestic supply (Fig. 1).  
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Fig. 1. Internal supply of energy by source [8].

65 On the other hand, the solar energy is the less representative resource with only 0.01% in Brazilian  
 66 energy matrix. Thus, the next topics will present the expansion potential of the photovoltaic solar  
 67 energy, besides of the future prospects in Brazil.

### 68 3.1.1 Brazilian solar potential

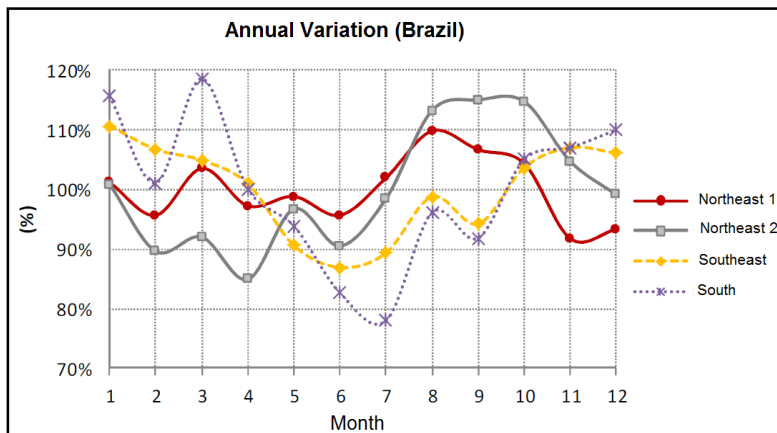
69 An inexhaustible energy source, the solar radiation use as both a source of heat and light is one of  
 70 the most promising alternative sources of energy for human development [9]. Despite the different  
 71 climatic characteristics observed in Brazil, the annual average of solar irradiation shows good  
 72 uniformity, with relatively high annual averages. In addition, the incidence in any region of the country  
 73 (1500-2500 kWh/m<sup>2</sup>) is higher than in most European Union countries, such as Germany, which  
 74 varies between 900-1250 kWh/m<sup>2</sup> and Spain 1200-1850 kWh/m<sup>2</sup>[10].

75 It is important to note that solar photovoltaic generation has a seasonal behavior differentiated by  
 76 geographic region (Fig. 2). Long-term trends and cycles are negligible, with temporal behavior not

77 correlated with other variable sources such as hydro and wind. Thus, it favors the integration of  
 78 photovoltaic energy into the electric system to reduce uncertainty regarding energy availability [4].

79 Under clear sky conditions, photovoltaic solar generation can be predicted with great precision.  
 80 However, at lower scales, the presence and random behavior of clouds may result in rapid variations  
 81 in solar irradiance. This extreme variability complicates the large-scale insertion of solar in  
 82 microgeneration (till 75kW) and minigeneration (till 5MW) into low voltage distribution circuits. The  
 83 inverters are also subject to shutdowns in case of frequency deviation, short circuits or main voltage  
 84 rapid variations. The generator parks spatial dispersion can significantly reduce the whole variability  
 85 [4].

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87

88 **Fig. 2. Internal supply of energy by source [8].**  
 89

90 Regarding to electrical demand of the cities, the typical behavior of most capitals in Brazil is peak  
 91 demand in the daytime, where the consumption of commercial buildings dominates, coinciding with  
 92 the greater availability of the solar resource and night demand peaks in residential regions [10, 11].  
 93 For this reason, it is essential to analyze the regions where their use brings the greatest benefits [11].  
 94 In addition to analyzing the solar supply, it is necessary to study solar demand and supply in all  
 95 periods of the year. The research highlights that as the south region has high consumption in the  
 96 summer, importing energy from the southeast and west regions, and that in these months solar supply  
 97 is the highest among all Brazilian regions, the insertion of photovoltaic energy in the south region may  
 98 result in enormous benefit to the electrical system besides the economic advantages like jobs  
 99 generation.

100 This type of energy does not replace the expansion of the installed electric system capacity, but can  
 101 be seen as a clean energy source [4, 12]. During drought, the reservoirs volume in hydroelectric  
 102 power plants is reduced by the lack of rainfall and energy diversity can take advantage of the lack of  
 103 rainfall to complement the energy generation with solar photovoltaic generation, because precisely in  
 104 the dry season with fewer clouds the sun shines with greater intensity [12].

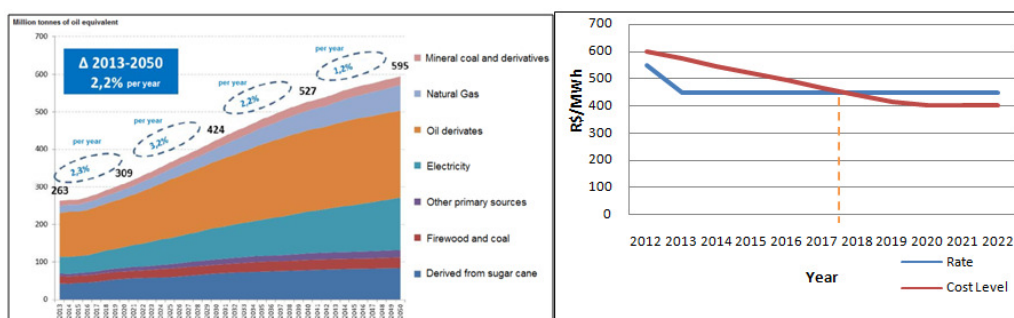
105 **3.1.2 Brazilian solar energy current situation**

106 According to the Ministério de Minas e Energia and its projections for energy use [8], in 2050, the  
 107 world will possibly present a reality quite different from what is known today. The Brazilian economy  
 108 growth, bottlenecks resolution in infrastructure, social mobility improvement, and access to goods and  
 109 services more elaborated due to the better quality of life of the population will lead to the need to  
 110 increase the average consumption energy per capita. In this sense, it will be essential to seek new  
 111 energy efficiency actions to reduce the need to expand energy supply in the long term, avoiding, for  
 112 example, environmental impacts resulting from new projects. The Empresa de Pesquisa Energética  
 113 (EPE) forecasts that between 2013 and 2050 total energy demand will increase slightly more than  
 114 twice (Fig. 3a), with emphasis on natural gas, electricity and oil products.

115 In December 2015, the country made a commitment to the Paris Agreement during the United Nations  
 116 Climate Conference to contribute to the reduction of global warming and to prevent global warming in  
 117 excess of 1.5°C. In order to comply with this agreement, Brazil will need to reduce coal and gas  
 118 power plants, and increase the share of renewable energy in its energy matrix in the coming years  
 119 [13].

120 Based on these goals of reducing greenhouse gases and aiming to expand the energy matrix and for  
 121 the country to present excellent conditions for all technologies for solar utilization, the Agência  
 122 Nacional de EnergiaElétrica (ANEEL) forecasts that by 2023 there will be an increase in the installed  
 123 photovoltaic capacity of 1,173 MW in Brazil [14]. This increase is extremely relevant in terms of  
 124 environmental benefits due to the fact that this generation has very low environmental impacts.

125 Photovoltaic solar energy can be considered a low-risk investment depending heavily on the region  
 126 regulatory framework for the competitive potential of solar energy [15]. Regarding regulatory barriers  
 127 for small-scale generation and the introduction of a new energy compensation system in Brazil,  
 128 ANEEL published Resolução Normativa 482/2012, establishing general conditions access for  
 129 microgeneration and distributed minigeration. Seventeen photovoltaic projects were selected, totaling  
 130 23.6 MW to be installed in several regions of the country [4], with microgeneration and minigeration  
 131 being responsible for the production of electric power from small generating plants connected to the  
 132 distribution network with up to 5 MW of power [16]. By 2015, it reached 34.9 GWh with an installed  
 133 capacity of 16.5MW, with photovoltaic solar energy with 20 GWh of generation and 13.3 MW of  
 134 installed capacity [7].



135  
 136 **Fig. 3. Total energy demand evolution by source until 2050(a); Economic viability estimation of**  
 137 **the photovoltaic systems (b) [8].**  
 138

139 Another incentive to accelerate the implementation of these energy generation systems is the  
 140 incentive program called Programa de Incentivo às Fontes Alternativas de Energia Elétrica (PROINFA),  
 141 responsible for providing the effective use of renewable energy in the country. Funded by the Banco  
 142 Nacional do Desenvolvimento (BNDES), it provides for the diversification of the energy matrix and  
 143 reduction of greenhouse gases, besides the creation of jobs, training and training of labor [6].

144 One of the barriers to the introduction of the most intensive photovoltaic solar energy in Brazil has  
 145 been the investments associated with this technology compared to other technologies installed in the  
 146 country. However, costs are showing significant reductions over the years, increasing the  
 147 competitiveness of photovoltaic [9]. There is a prospect that the tariff parity of photovoltaic generation  
 148 will be reached even in this decade as shown in Fig. 3b [8].

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150 **3.1.3 Photovoltaic solar energy results of implementations in Brazil**

151 A recent study indicates that the implementation of a photovoltaic system at Presidente Prudente's  
 152 college would reduce the local energy consumption and avoid 55 tons of carbon dioxide per year over  
 153 30 years generating a positive environmental impact. It is concluded in his research that the payback  
 154 would be approximately 12 years and 04 months, characterizing itself as economically viable project  
 155 [3].

156 The implementation of grid-connected photovoltaic systems at a residence near São Paulo, for  
157 instance, demonstrated that the return on investment would be 19 years considering the 2014 charge  
158 for the local energy distributor. If the 2013 tariff were considered the return would be 12 years [17].

159 The Green Office of Federal Technological University of do Paraná located in Curitiba was  
160 inaugurated in 2011 and it was Brazil's first "carbon zero" sustainable office [18]. This system has  
161 already produced 11.67MWh in the last five years of uninterrupted operation, which represents an  
162 average monthly generation of approximately 200kWh / month and becoming a zero energy building  
163 (ZEB). In the summer months, as the generation reached 304 kWh / month, it was possible to export  
164 energy to other nearby facilities making a positive energy building [19].

165 In the research conducted by [20], considering the evolution of tariffs based on inflation and without  
166 incentives to distributed generation, there is economic-financial viability of microgeneration in most  
167 Brazilian capitals. In the scenario of increasing energy tariffs above inflation, there is viability in all  
168 Brazilian capitals.

### 169 **3.1.4 Technology negative environmental impacts**

170 Despite generating more energy, hydroelectric plants have large environmental impacts, while solar  
171 energy has reduced impacts [12]. Photovoltaic solar energy implies no greenhouse gas emission  
172 during operation and does not emit other pollutants (such as sulfur and nitrogen oxides); additionally,  
173 it consumes little or no water. As local air pollution and use of fresh water for cooling thermal power  
174 plants are becoming serious concerns in hot or dry regions, these benefits of photovoltaic solar  
175 energy become increasingly important [21].

176 However, a recent study [22] points out that although the negative impacts presented by photovoltaic  
177 systems are very small compared to the positive impacts and advantages of implementation, the  
178 problems that arise are:

179 □ In the physical environment: landscape alteration and/or degradation; solid waste generation  
180 and risks of soil contamination from human activities; dust and gases generation and quality of the air  
181 alteration during the work; generation or intensification of erosive processes and changes in water  
182 behavior and surface hydrological flow; morphological changes and temporary instability of the  
183 surface.

184 □ In the biotic environment: vegetal cover loss; change in the dynamics of local ecosystems;  
185 scaring and escaping local wildlife; reduction of ecological potential (environmental attributes and  
186 biodiversity); accidents risk with animals or caused by animals.

187 □ In the socioeconomic environment: employment and income generation; local economy  
188 growth and increase in tax collection; flow of vehicles increase; materials consumption; work  
189 accidents risks; equipment efficiency increase; energy source use; security improvement, electricity  
190 reliability and supply.

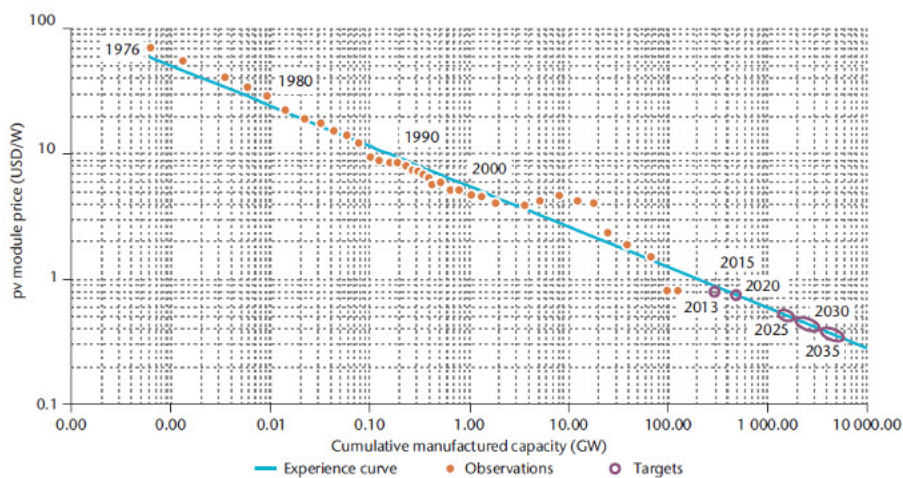
191 During its operation, the photovoltaic system does not emit pollutants and is a sustainable energy  
192 alternative. The most significant environmental impacts are caused during manufacturing, system  
193 assembly and implantation. However, most of the implantation phase negative impacts are temporary.  
194 While most of the positive impacts are consolidated in the operation phase, environmental control and  
195 monitoring are needed to minimize possible system degradation resulting from the Photovoltaic Solar  
196 Power Plant [22].

### 197 **3.1.5 Impediments and technology future prospects in Brazil**

198 The study related to future prospects, concludes that the market of micro and minigeration in Brazil  
199 are in an early stage of development and may be considered below their potential [23]. The possible  
200 barriers identified in the study include regulation, incentives, technological capacity and professional  
201 qualification, currently composing a non-development scenario required for the sector to prosper. It  
202 was pointed out that most Brazilians still do not know the about this topic. However, when presenting  
203 information on the subject, they proved to be in favor of renewable generation demonstrating the  
204 consolidation potential of these initiatives.

205 Large size centralized generation clearly is not competitive at the moment in Brazil. The economic  
 206 viability for distributed generation is closer to happen [4]. The expansion of these systems is driven by  
 207 self-consumption - the use of electricity directly in the same place where it is generated - being able to  
 208 carry small amounts of negotiated energy [21]. The possibility of using already built areas to fix  
 209 panels, reducing investments in transmission and distribution lines, contributing to the diversification  
 210 of the Brazilian energy matrix [5]. Nevertheless, the main disadvantages are the high cost of solar  
 211 cells, variation of the amount of energy produced according to the climatic situation and forms of  
 212 storage still not very efficient. However, they point out that there is no type of energy that only brings  
 213 advantages and the appropriate choice will depend on the priority aspect (cost, risk, short-term or  
 214 long-term environmental impact, space, resources, among others) [1].

215 In terms of the photovoltaic systems costs, 60% are from solar panels, 10% from the inverter and the  
 216 rest from support structures, auxiliary electrical equipment, as well as installation and assembly [4].  
 217 After analyzing photovoltaic systems in Brazil historical data, the total cost of implementing a  
 218 complete system shows a downward trend, mainly due to the trend of reducing the modules value  
 219 [24], as shown in Fig. 4. According to Solar Power Europe, the outlook is promising as the  
 220 photovoltaic system price has dropped by 75% over the last 10 years [15].



221

222 **Fig. 4. Photovoltaic modules old prices and 2035 projection [21].**

223

224 Another reduction that can occur is in the solar panels themselves. In October of 2016, an United  
 225 States company announced the production of solar roofs with renewable energy which promises to  
 226 accelerate the solar energy use with this new technology. This new type of roof promises to be more  
 227 economical than the normal roof combined with the energy savings the new system offers [25]. This  
 228 new market could further accelerate the use of solar energy over the next few years and create a new  
 229 scenario for the future in terms of system cost.

230 At present, there are few research and development institutions in the area of solar panels in Brazil as  
 231 well as excess solar panels with low cost being produced in other countries [4]. It would be necessary  
 232 to present improvements and adaptations in the facilities available in Brazil both to develop materials  
 233 for production of photovoltaic cells with thin film and also to include the production of silicon for solar  
 234 use and complete modules assembly [26].

235 Photovoltaic solar energy stands out given its potential and the wide range of applications possibilities  
 236 from technological innovations in various sizes and scales. Despite the barrier to cost and efficiency  
 237 limits of systems, the use of this technology is fully feasible with the government incentive programs  
 238 creation, changing the way to generate, distribute and consume energy, in addition to the rapid  
 239 diffusion of existing technologies [27]. In this scenario, the government role is preponderant to spread  
 240 to expand the use of this technology [4, 27].



241 Capital targeting decisions for the energy sector are increasingly shaped by government policy  
242 measures and incentives, rather than signals from competitive markets. Private sector participation is  
243 essential to meet the full energy investment needs, but the private mobilization and capital investors  
244 will require a concerted effort to reduce political and regulatory uncertainties [28].

245 Satisfactory incentive laws such as some mechanisms observed in Europe, establishing a tariff that  
246 the electricity distribution concessionaire pays for each kWh of energy produced, is capable of  
247 encouraging large photovoltaic energy markets at a cost that ends up being distributed among all  
248 electricity consumption, allowing production costs to fall due to an increase in the scale of production  
249 [27].

250 Among the incentive options, contracting models, financing models, tax incentives or even premium-  
251 rate offers can be reported [4]. About contracting models, there are two main strands in the area of  
252 incentive to solar generation: feed-in tariff and net metering. The first is the tariff payment generally  
253 higher than the local concessionaire's energy tariff and the cost can be assumed by the national  
254 treasury or prorated by the energy consumers (this incentive form predominates in Europe mainly  
255 Germany and is also adopted by Japan). The second consists of the credits accumulation in  
256 concessionaires when solar energy exceeds local consumption. This model predominates in the  
257 United States. It should be highlighted that the net metering instituted by ANEEL in Brazil has an  
258 ICMS tax incidence in some states, which makes it impossible to apply this model in the country and  
259 making it difficult to evolve in this sector [29].

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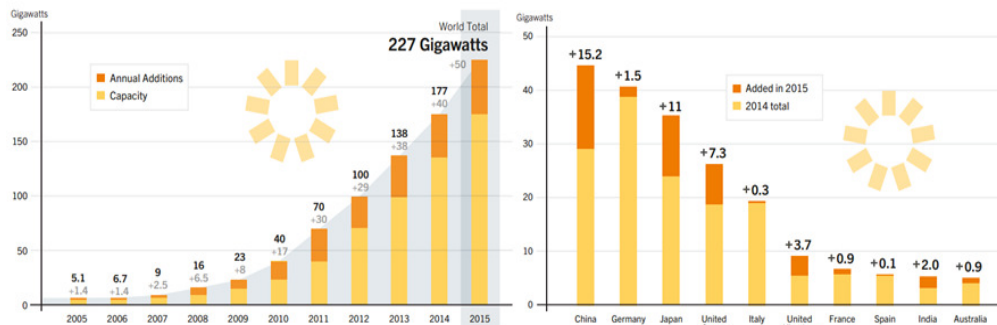
#### 261 **4. FUTURE GOALS AND PROSPECTS FOR PHOTOVOLTAIC SOLAR ENERGY IN THE** 262 **WORLD**

263

264 Despite the increase in energy consumption over the years, for the first time in four decades the  
265 carbon dioxide global emission associated with energy consumption stabilized in 2014 as the  
266 economy grew. This stabilization was attributed to the renewable energy introduction and  
267 improvements in energy efficiency. Globally, there is increasing concern that has impacted the  
268 implantation of these critical systems to reduce global warming, creating new economic opportunities  
269 and providing energy for billions of people. This type of energy is an extremely important element for  
270 global climate adaptation [30].

271 The year 2015 was extraordinary for renewable energies with the largest additions of global capacity  
272 till now although the challenges remain. The year has had several developments that have an impact  
273 on renewable energy, including a dramatic decline in global fossil fuel prices; a series of  
274 announcements on the lowest prices of all long-term renewable energy contracts; a significant  
275 increase in attention to energy storage; and a historic climate agreement in Paris that brought  
276 together the global community. Rapid growth was driven by a number of factors, including improved  
277 cost of renewable technologies, policy initiatives, improved access to finance, energy security and  
278 environmental concerns, increasing energy demand for developing and emerging economies and the  
279 need for access to modern energy. Consequently, new markets for both centralized and distributed  
280 renewable energy are emerging in all regions [31].

281 Since 2010, worldwide, there has been an increase in the photovoltaic systems capacity greater than  
282 had occurred in the last four decades. New systems were installed in 2013 at a rate of 100 MW of  
283 capacity per day led initially by Germany and Italy [21]. In 2014, 40 GW of capacity was added,  
284 reaching a total of 177 GW of global capacity [30]. By 2015, it has reached 227GW of global capacity.  
285 The countries that invested most in these systems were China, Japan and the United States, followed  
286 by Germany and the United Kingdom [31], as shown in Fig. 5a and 5b. Depending on the evolution of  
287 the solar energy markets in the coming years, the total capacity installed in 2019 could reach between  
288 396 and 540 GW with the most likely scenario around 450 GW [15].



289

290 **Fig. 5. Global Capacity of Photovoltaic Systems (a); Capacity and Additions in 2015 (b) [31].**

291

292 With regard to global warming, the International Energy Agency (IEA) proposes to increase energy  
 293 efficiency in industry, buildings and transport; to progressively reduce the use of less efficient coal-  
 294 fired power plants and to prohibit their construction; increase investment in renewable energies;  
 295 reduce subsidies for fossil fuel consumption and methane emissions from oil and gas production [32].

296 The road map established by the IEA [21] foresees the photovoltaic systems participation by 16% by  
 297 2050, a significant increase in the 2010 roadmap target of 11%. China is expected to continue to lead  
 298 the global market, accounting for about 37% of global capacity by 2050. This forecast would imply  
 299 4,600 GW of installed capacity, avoiding 4 gigatons of CO<sub>2</sub> emissions annually, contributing to market  
 300 development with a cost reduction of 25% by 2020, 45% by 2030 and 65% by 2050, leading to a  
 301 range of \$ 40 to 160 / MWh, assuming a cost of capital of 8%.

302 The investment path outlined by the IEA [28] is far short of achieving climate stabilization goals, as  
 303 today's policies and market signals are not strong enough to shift investment to low carbon sources  
 304 and energy efficiency in the scale and speed required. It is estimated that \$ 53 trillion in cumulative  
 305 energy supply and energy efficiency investment are required in the period up to 2035 (Scenario 450)  
 306 to make the world follow an energy path compatible with the limiting global temperature increase to  
 307 2°C goal, limiting the greenhouse gases concentration in the atmosphere by about 450 parts per  
 308 million of CO<sub>2</sub>.

### 309 5. CONCLUSION

310

311 There is scientific evidence that the Earth's temperature is warming and that recent changes in the  
 312 climate are most likely due to an increase in greenhouse gases produced by human activities. The  
 313 renewable energy use is one of the solutions to adapt to climate change, improving the resilience of  
 314 conventional energy systems and contributing to a more diversified and distributed energy matrix [30].

315 The growing global concern about climate change due to the greenhouse gases increase on the  
 316 planet has caused Brazil to commit itself to the Paris Agreement at the United Nations Climate  
 317 Conference to avoid global warming above 1.5°C [13]. In order to comply with this agreement, the  
 318 country should increase the share of renewable energies in the energy matrix so that the technologies  
 319 combination balances supply and demand and the country uses its natural resources better.

320 Based on the study presented, photovoltaic solar energy is a renewable energy option to complement  
 321 the envisaged energy demand for the coming years, besides that it gives importance to the  
 322 conservation of non-renewable resources and reduction of the gases emission from the greenhouse  
 323 effect. The most environmentally sustainable policy proposals for Brazil have the scientific and  
 324 technological challenge of developing and / or adapting the most eco-efficient solutions. When valuing  
 325 natural resources, the green economy inserts a new way of using the territory and the natural  
 326 patrimony contained in it [33].

327 Despite the energy sources in Brazil enormous diversity and all the photovoltaic solar energy benefits,  
 328 the Brazilian energy policy has not yet created the necessary incentives to implement photovoltaic  
 329 solar energy on a large scale and its potential is not used. It is evident that the government needs



330 projects and incentives for massive implementation, removing regulatory barriers, increasing  
331 incentives, investing in technological capacity and professional training for the technology  
332 development. With more aggressive incentive programs, there will be rapid diffusion and  
333 implementation, contributing both to the supply and to the preservation of the planet and its  
334 ecosystems.

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