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CSABA SULYOK

INOVAÇÃO E ECONOMIA DA GERAÇÃO DISTRIBUÍDA DE ELETRICIDADE FOTOVOLTAICA NO BRASIL

INNOVATION AND ECONOMICS OF DISTRIBUTED PHOTOVOLTAIC ELECTRICITY GENERATION IN BRAZIL

SALVADOR, BA
2019

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“Innovation is seeing what everybody has seen
and thinking what nobody has thought.”

Dr Albert Szent-Györgyi

Hungarian Nobel laureate who discovered Vitamin C

ABSTRACT

Sulyok, Csaba. **INNOVATION AND ECONOMICS OF DISTRIBUTED PHOTOVOLTAIC ELECTRICITY GENERATION IN BRAZIL**. 2019. Thesis (Doctor of Science) – Postgraduate Program in Energy and Environment of the Federal University of Bahia.

In 2014 the Brazilian government made history with its first successful photovoltaic (PV) energy auction. Also, distributed generation (DG) has developed significantly due to the energy compensation system being introduced in 2012. The fast development of distributed PV was motivated by the state tax exemption, significant system cost reduction, increased access to financing, easy access to knowledge about the opportunity and the confidence of the market in the National Agency for Electrical Energy, ANEEL's distributed generation model and in mid 2019 broke the 1 GW capacity record. In order to accelerate the growth of distributed generation, ANEEL has updated the rules of the compensation system in 2016. The normative rule n°687/15 established the dual concept of remote and shared power generation. This opens the way to community solar PV power plants shared between a number of energy consumers. Solar condominiums can be located at high solar radiation locations and apply trackers, increasing power generation by 20% and 25% respectively, compared to rooftops. The cost of installed capacity per watt peak (Wp) is around 30% lower due to economies of scale. Combined, this means that solar energy would cost half the price compared to rooftop installations, making distributed PV generation economically feasible in Brazil. To take advantage of these benefits at the national level and democratize the access to distributed generation for small consumers, an online platform is proposed. The innovation in this work refers to both the new business model os shared and remote generation and the digital technology applied to the transactions between generators and consumers such as IoT meters and blockchain.

Keywords: Solar energy, Distributed Generation, Innovation

RESUMO

Sulyok, Csaba. **INOVAÇÃO E ECONOMIA DA GERAÇÃO DISTRIBUÍDA DE ELETRICIDADE FOTOVOLTAICA NO BRASIL.** 2019. Tese (Doutorado em Ciências) –
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Em 2014 o Governo Brasileiro fez história com seu primeiro leilão de energia solar bem sucedido. A geração distribuída (GD) por fonte solar tenha desenvolvido significativamente, como resultado do sistema de compensação de energia introduzido em 2012. As razões por trás do desenvolvimento rápido da geração distribuída foram a isenção do ICMS, os custos iniciais do sistema mais acessíveis e o acesso ao financiamento, fácil acesso ao conhecimento sobre a oportunidade e da confiança no modelo da ANEEL. A fim de acelerar a geração distribuída a ANEEL publicou uma atualização das regras do sistema de compensação. A nova regra (REN 687/15) estabeleceu conceitos modernos tais como a geração remota e sistemas fotovoltaicos compartilhados. Isso abre o caminho para os condomínios de energia solar, instalações de geração fotovoltaica na escala industrial, compartilhadas entre um grande número de consumidores de energia do menor porte. Os condomínios solares podem ser instalados em locais com altos níveis de radiação solar e ainda rastreando o sol, significando um aumento de 20% e 25% da produção respetivamente. O maior porte até 5 MW oferece uma economia de escala aprimorada que resulta em custos 30% menores por capacidade instalada. Combinado isso significa que a energia solar custa metade do preço em comparação com instalações de telhado, transformando a geração solar distribuída economicamente viável no Brasil. Para poder aproveitar estes benefícios no nível nacional para pequenos consumidores, uma plataforma online foi proposta. A inovação neste trabalho refere-se tanto ao novo modelo de negócios de geração compartilhada e remota quanto à tecnologia digital aplicada às transações entre geradores e consumidores, como os medidores de IoT e blockchain.

Palavras-chaves: Energia solar, Energia renovável, Economia da energia

CONTENTS

LIST OF FIGURES

LIST OF MAPS

LIST OF TABLES

LIST OF CHARTS & GRAPHS

ACRONYMS

AC	Alternating Current
ANEEL	National Agency for Electrical Energy
BTC	Bitcoin
CAPES	Coordination for the Improvement of Higher Education Personnel
CAPEX	Capital Expenditure
CCEE	Electric Energy Trading Chamber
CIGS	Copper Indium Gallium diSelenide
CNPJ	Identification number issued to Brazilian companies
CNPq	The Brazilian National Council for Scientific and Technological Development
CO, CO_2	Carbon monoxide, Carbon dioxide
COFINS	Social Security Funding Contribution
CPF	Brazilian individual taxpayer registry identification
CVM	The Securities and Exchange Commission of Brazil
DC	Direct Current
DSC	Dye-sensitized Solar Cell
CdTe	Cadmium Telluride
EL	Electroluminescence
EPE	Empresa de Pesquisa Energética
EPC	Engineering, Procurement and Construction
EV	Electric Vehicle
DG	Distributed Generation
GHI	Global Horizontal Irradiation
GTM	Greentech Media Research
GHG	Greenhouse Gas (emissions)
GW	Gigawatt (power unit)

ICMS	Imposto Sobre Circulação de Mercadorias e Serviços (Brazilian excise tax)
IEA	International Energy Agency
ILUMINA	Institute of Strategic Development of the Electricity Sector
INMET	National Meteorological Institute of Brazil
IoT	Internet of Things
IRR	Internal Rate of Return
LCOE	Levelized Cost Of Energy
MME	Brazilian Ministry of Mines and Energy
NPV	Net Present Value
NREL	National Renewable Energy Laboratory, USA
O&M	Operation and Maintenance
OPV	Organic Photovoltaics
PID	Potential Induced Degradation
PIS	Profit participation contribution (Brazilian tax)
PRODEEM	Program for Energy Development of States and Municipalities
PROINFA	Alternative Electrical Energy Sources Incentive Program
PPA	Power Purchase Agreement
PV	Photovoltaic (power)
R&D	Research and Development
SAM	System Advisor Model (NREL)
TF	Thin-Film (PV technology)
WACC	Weighted Average Cost of Capital

Measurement

W	Watt	Wp	Watt peak	Wh	Watt hour	x 1
kW	Kilowatt	kWp	Kilowatt peak	kWh	Kilowatt hour	x 1.000
MW	Megawatt	MWp	Megawatt peak	MWh	Megawatt hour	x 10^6
GW	Gigawatt	GWp	Gigawatt peak	GWh	Gigawatt hour	x 10^9

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1 INTRODUCTION

Solar energy is ready for the prime time! During the past four decades, it has completed a successful journey from being a prohibitively expensive experimental technology used in space exploration only, to becoming an affordable and widely used alternative energy source with the highest growth rate among all energy sources. Solar could revolutionize the energy sector in many ways: It will enable distributed, on site generation, forcing large utility companies to rethink their traditional business models. Combined with increasingly affordable battery technology, it could make the now existing electrical grid partially redundant. It could mean a new industrial era with low cost, on site generation of an energy potential that earlier was unthinkable.

In terms of sustainability, photovoltaics (PV) is a game changer: It could single handedly solve our problem of climate change induced by carbon dioxide emissions, as far as power generation is concerned. Solar radiation and silicon is widely available in about every corner of our planet, that could lead to energy abundance due to decreasing costs. The conflict of interest as to the use of the land surface has lessened considering that now, due to the introduction of agrovoltaics, vegetables can be grown underneath the PV structure. PV is also one of the generation technology with the least water use requirement - second only to wind power (Blakers, 2018).

The largely hydropower-based Brazilian electricity mix has to be diversified for both energy security and environmental reasons. As a result of climate change, the North Eastern Brazil experiences droughts that leave water reservoirs at low levels, thus increasing the risk of energy shortages. Solar is therefore a suitable technology to balance the energy mix, as its performance is enhanced by dry conditions (de Jong, 2019).

Silicon is today the most important raw material in photovoltaic manufacturing. Brazil is rich in silica reserves and has a developed silica mining industry. However, in order to develop the national PV industry, a whole new production chain would need to be established; from reduction of sand/quartz, casting Si ingots, slicing it to wafers, and finally assembling them to PV modules and panels.

There are different kinds of PV Technologies. One is a Si-wafer based PV Technology accounting for about 95% of the total production in 2018, while thin-film (TF) technologies add to around 5% (Fraunhofer, 2019). The largest photovoltaic market in 2018 is China with 32%, followed by Europe, with around 28% of global PV installations (Fraunhofer, 2019). However in the market today, the three most important PV technologies are polycrystalline, monocrystalline and TF technology (Fraunhofer ISE, 2019).

The global PV module production capacity in 2019 is approximately 82,7 GW. The industry focus remains on reducing the costs per Watt peak (Wp) by improving the efficiency of all resources, materials and consumables including silicon, as well as by introducing new technologies to increase module output power. The industry's historic learning rate of above 20% is expected to continue. The combination of increased cell and module efficiency related to largely decreased assembling costs will bolster the decrease of expenses associated to the PV installation, and in this way guarantee the intensity of PV power generation in the future (ITRPV, 2018).

At the end of 2014, with the first successful power auction for solar energy, the Brazilian government opened a new chapter in the country's energy history. The contracted 889,7 MW at mean price of R$ 215,12 (~US$ 88) is one of the lowest cost worldwide (EPE, 2015). The annual sum of daily global horizontal irradiation in any Brazilian region (1500–2500 kWh/m^2) is greater than those for the majority of the developed PV markets such as Germany (900–1250 kWh/m^2), Spain (1700 kWh/m^2), California (1800-2400 kWh/m^2) or Japan (1300 kWh/m^2) (SolarGIS, 2015). As the cost of solar energy strongly correlates with the irradiation value, Brazil could enjoy lower photovoltaic electricity costs than markets with lower radiation values. However, despite the lower photovoltaic electricity costs, more than 82% of the Brazilian population lives in vertical cities where tall buildings often shade neighbouring roofs, making rooftop PV installation a challenge (IBGE, 2018). Distributed generation, in its first four years until 2015, only counted 1672 solar installations in Brazil, mainly for the lack of legal security (Energy Research Company, 2018).

As a result of this challenge, three main models of solar energy harnessing, namely, rooftop PV, community solar power plants and utility-scale PV Power station are compared in this thesis to determine which is more advantageous to use. Innovative business models and technical solutions will also be investigated.

In this theses *innovation* is referred to as new practices of business management, digital technology applied to electricity distribution, electricity trading system for distributed generation and internet of things solutions for measurement of electricity consumption. It is not in the scoop of this work to discuss innovation referring to photovoltaic technology, material science, PV chemistry, power plant technology, electrical engineering of PV devices, as this work focuses on economic aspects and digitalization.

1.1 Hypothesis

This work was designed to answer the ultimate research hypothesis, to assess whether:

- Community solar power plants in the 0,5 to 5 MW capacity range sited close to electricity consumers offer any economic, technical or environmental advantages compared to the rooftop PV or utility-scale PV power station models.

The essence of the research hypothesis is to identify the most suitable model for scaling up photovoltaic generation in Brazil by considering the three most important aspects of the decision: economic, technical and environmental.

1.2 General statement of purpose

Shared solar models allocate the electricity of a jointly owned or leased system to offset individual consumers' electricity bills, allowing multiple energy consumers to share the benefits of a single solar array. The economic, environmental, and social benefits of distributed PV will be highlighted via shared generation.

An innovative business model based on the new ANEEL legislation will be introduced and analysed from the viewpoint of its benefits to society and the electric grid.

Innovative technical solutions will be analysed that could enhance such new business model for distributed generation such as blockchain ledger, IoT meters or digital platforms.

The Brazilian PV industry roadmap aims to outline the development of a new energy technology with a potential to supply economically feasible electricity with low environmental impact during the coming decades. First, the state of the art of PV technology and its future development trends are introduced. Second, the rapidly decreasing costs resulting from expanding deployment, and how this could lead to solar becoming the cheapest energy source in the future is explained. Third, how the existing electric power infrastructure in Brazil could integrate the solar source both as a utility and as a distributed generation is analysed. Finally, the economic benefits of early technology adoption and how solar could affect long term energy prices in Brazil is discussed.

1.2.1 Specific statement of purpose

This thesis aims to analyse the following topics in order to to answer the general research question of how the PV source could be best integrated into the Brazilian energy mix:

1. Introducing mature PV technologies and their installed capacity
2. Illustrating the complete PV industrial supply chain
3. Evaluating the global industry of PV components
4. Emerging technological breakthroughs in the solar industry
5. Mapping the solar resource and its potential for PV generation
6. Policy review of distributed power generation
7. Analysis of capital investment and operational costs
8. How to maximise the economic efficiency of solar energy
9. Mapping innovation tendencies in distributed generation
10. Blueprint of a community solar virtual marketplace

1.3 Structure

This work has been structured to first introduce the reader to mature photovoltaic technology in general, in terms of understanding its main components, such as PV cells and panels, inverters, support structure and tackers, and the so-called balance of system.

The cost evolution of these components' impacts on the overall system costs, and how new technologies will influence the PV industry will be examined.

The PV industry has a complex supply chain, beginning from the mining of silicon and rare metals, through to ingot crystallization and the laser cutting of silicon wafers, to cell processing, module assembly and finally the logistics and installation. It will be analysed how new technologies such as thin-film or organic PV could reduce the phases of the supply chain, reducing not only cost but also energy use and environmental impacts.

Once the PV industry and it's trends are analysed, the research focus would shift on the "fuel", the energy source of this technology, solar radiation. Radiation is uneven over the earth due to distance from the equator, elevation and local weather conditions. Equatorial deserts and high altitude deserts offer the best possible landscape for large scale solar installations (Ross, 2019). The installation of solar panels in deserts has different advantages, one of which is the topography: miles of barren land that can be utilized. The construction and maintenance of these solar power plants is advantageous because of high solar radiation and lack of cloud cover. In addition, deserts rarely experience rainfall and they remain dry and sunny for the most part of the year. As well as satellite observations, most Brazilian regions also have ground measured solar radiation data that offers a higher rate of confidence (Smith, 2004). Temperature maps must also be considered, as high temperatures have an adverse effect on PV generation. As such, temperature maps will be highlighted alongside pure radiation in the methodology section, that will help to determine the optimal siting of PV power plants.

1.4 Background information

1.4.1 What is Distributed Generation?

Distributed generation (DG), also referred to as distributed energy, on-site generation (OSG) or district/decentralized energy is the generation of electricity within the proximity of its consumption, performed by a variety of small, grid-connected or distribution system connected devices, referred to as distributed energy resources (DER). DG can lower distribution costs, environmental impacts while increasing the security of supply.

As shown in Table 1. the solar PV industry has different stages with different levels of barriers to entry in terms of technological complexity, job creation, competitive forces and most importantly capital requirements. Drivers of theses industries often depends on the access of raw materials or semi finished goods of earlier processes. Since polysilicon and wafer production has exceptionally high capital requirement, the basis of the industry is limited to those markets capable to apply such high investments in the technology. The lack of early industrial stages could later limit the competitiveness of local PV industries of cell and module production. PV system installation however is an exemption, as the building of power plants inevitably happens locally and requires the highest level of labour in the PV industry.

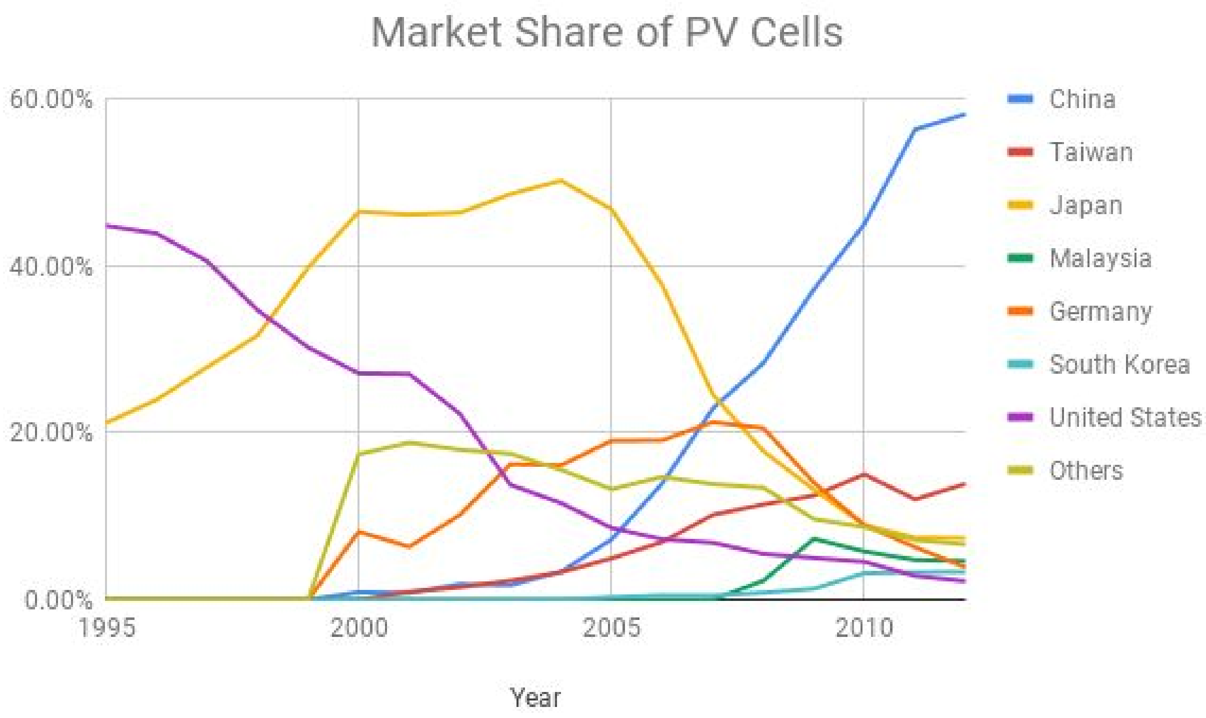
Table 1. Solar PV manufacturing supply chain

	Polysilicon	Wafer	Solar Cell	Solar Module	BOS	Systems
Technology	High	Medium	High	Low	Low	Low
Jobs	Medium	Low	Medium	Medium	Medium	High
Competition	Low	High	High	High	High	High
Capital intensity	Very High	High	Medium	Medium	Low	Low
Drivers	Power Cost Technology Regulatory High volume	Power Cost Access to Poly incentives	Technology Incentives	Labour Cost Market proximity Cell producer relations	Incentives	Location Labour Cost Incentives

Source: CH2M HILL Consulting, 2016

At the beginning of the millennium, the PV industry was centered in Germany, the US and Japan (Hanh, 2014). In 2016, over 85% of the components are produced and processed in China, Taiwan, Malaysia and India (Amin, 2017). These shifts in the production markets to low labour cost regions has had significant cost reduction effects, resulting in a more efficient and integrated mass manufacturing process. As a result, PV cells and panels are now regarded and traded as a commodity on the global market. To illustrate the above stated, Table 1 shows us the supply chain of Solar PV Manufacturing, in terms of technology, jobs, competition, capital intensity and it's main drivers.

Chart 1. – International PV production market trends



Data source: Earth Policy Institute, 2014

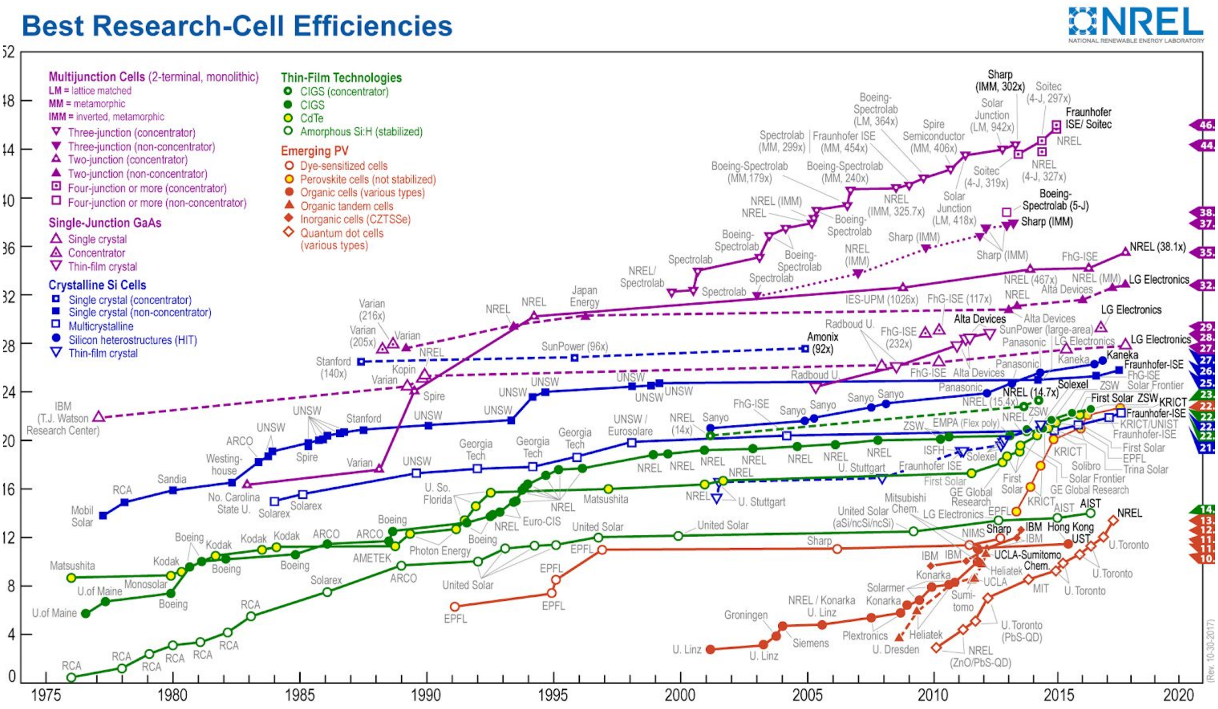
Chart 1 shows the International PV Production trend where mainland China has had continuously increasing PV production from 2000 up to 2013. The other countries (Taiwan, Malaysia, Japan, Germany, South Korea, and United States) are also PV producers, but unlike China, which is continuously making PV market trends.

The PV panel industry is dominated by silicon-based technologies. However, various thin-film technologies are emerging, in spite of their slightly higher costs and lower market experience. A series of new PV technologies are being developed, most notably the perovskite-based so-called "organic photovoltaics". Organic Photovoltaic has the potential to provide lower costs than first and second generation solar technologies, because there are several absorbers which can be used to create colored or transparent OPV devices. The main goal of Organic Photovoltaic (OPV) is to provide an earth-abundant and low-energy production PV solution. There are other benefits of photovoltaics, including low-cost manufacturing, abundant materials, and flexible substrates (Abdulrazzaq, 2013).

These new technologies could result in even more significant cost reduction once the problems of environmental resistance and stability of the material are solved (Abdulrazzaq, 2013). The inverter industry is also changing from central inverters to lighter string inverters due to the more rapid cost reduction curve of the later and easier maintenance (Dogga, 2019).

Micro inverters operate attached to PV panels individually that enable rapid installation and isolation form the impact of shading, dirt or panel failure from other panels of the same installation. Although microinverters can reduce installation labour and wiring costs they have a higher overall capital requirement per Watt installed compared to string or central inverters, therefore they are more adequate for small rooftop installations rather than larger power plants. On the other hand microinverters may have a longer life span compared to string or central inverters that could lead to reduced maintenance costs. (Çelik et al, 2018)

Chart 2. – An overview of PV cell efficiencies and technologies



Source: NREL, 25. April 2018.

Chart 2 was plotted by National Renewable Energy Laboratory demonstrating the highest confirmed conversion efficiencies for research cells for a range of photovoltaic technologies from 1976 to the present. There are 28 different subcategories which are indicated by distinctive colored symbol and there are different families of semiconductors to wit: (1) multijunction cells, (2) single-junction gallium arsenide cells, (3) crystalline silicon cells, (4) thin-film technologies, and (5) emerging photovoltaics. The efficiency results of the different families of semiconductors are best illustrated in Chart 2.

As the PV industry moved to China, the largest companies in the PV industry became Chinese industrial groups such as GCL, Trina, Jinko or JA Solar. The only US company still among the largest players is First Solar, who is the only thin-film company in Chart 3. Hanwha and OCI are South Korean, while Wacker is a German chemical corporation, all with decades of industry experience. The other companies, including Canadian Solar are Chinese solar enterprises. (Moskowitz, 2016)

Chart 3. Top 11 Solar Module Suppliers of 2018

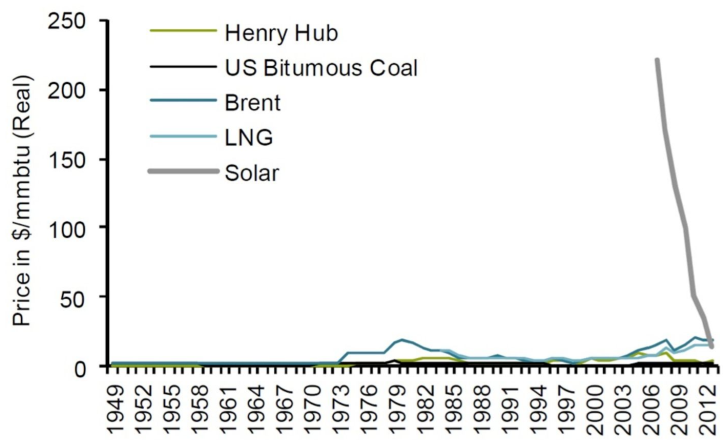
#	Module Supplier	Change vs 2017	2018 Shipments	Market Share, 2018 (%)
1	JinkoSolar	=	11,6	12,8%
2	JA Solar	+1	8,8	9,7%
3	Trina Solar	-1	8,1	8,9%
4	LONGi Green Energy Technology (Lerri)	+3	7,2	7,9%
5	Canadian Solar	-1	6,4	7,0%
6	Hanwha Q-CELLS	-1	5,6	6,2%
7	Risen Energy	+3	4,8	5,3%
8	GCL System Integration Technology	-2	4,1	4,5%
9	Shufeng PV International	+2	3,4	3,7%
10	Talesun	+2	2,9	3,2%
11	First Solar	-2	2,7	3,0%

Source: GlobalData, Power Intelligence Center, 2019

Chart 3 shows the hierarchy of the leaders of the PV industry on which Jinko Solar Energy Holdings Limited ranked as the first PV manufacturer in 2018. They are dedicated to promoting the extensive application of solar panels throughout the world. Chart 3 shows there are several large companies engaged in building photovoltaic devices and all but one are based in China with the only exception of First Solar based in the United States of America.

Although technology and the solar resource are the two fundamental concepts of understanding photovoltaics, without a detailed understanding of local regulations, the technology could hardly be put in praxis. As costs are still higher compared to more traditional energy sources, special government regulation is needed to reduce barriers for the implementation of early stage PV deployment until grid parity is reached, meaning that an alternative energy source can generate power at a levelized cost of electricity (LCOE) that is less than or equal to the price of power from the electricity grid. After gaining insight into the PV industry and its energy source, an economic study will be conducted. After all, this aspect will determine whether solar energy will be applied, and how quickly can it develop into the lowest cost energy source available to humanity. The cost reduction trends of PV technologies are unparalleled in the energy industry, following the Swanson effect observed in the semiconductor industry of computing (The Economist, 2018).

Chart 4. – Bernstein Research comparing the cost for a million British thermal unit (mmbtu) of various liquid fossil fuels and solar



Source: Parker et al, 2014

Chart 4 shows a diagram which plots the cost for one million British thermal units of different petroleum derivatives and sunlight based power. It demonstrates that the cost for sun powered vitality descended significantly in contrast with non-renewable energy sources and has quite recently begun to undermine the cost for a portion of these, for example, oil and condensed petroleum gas (LNG).

2 LITERATURE REVIEW

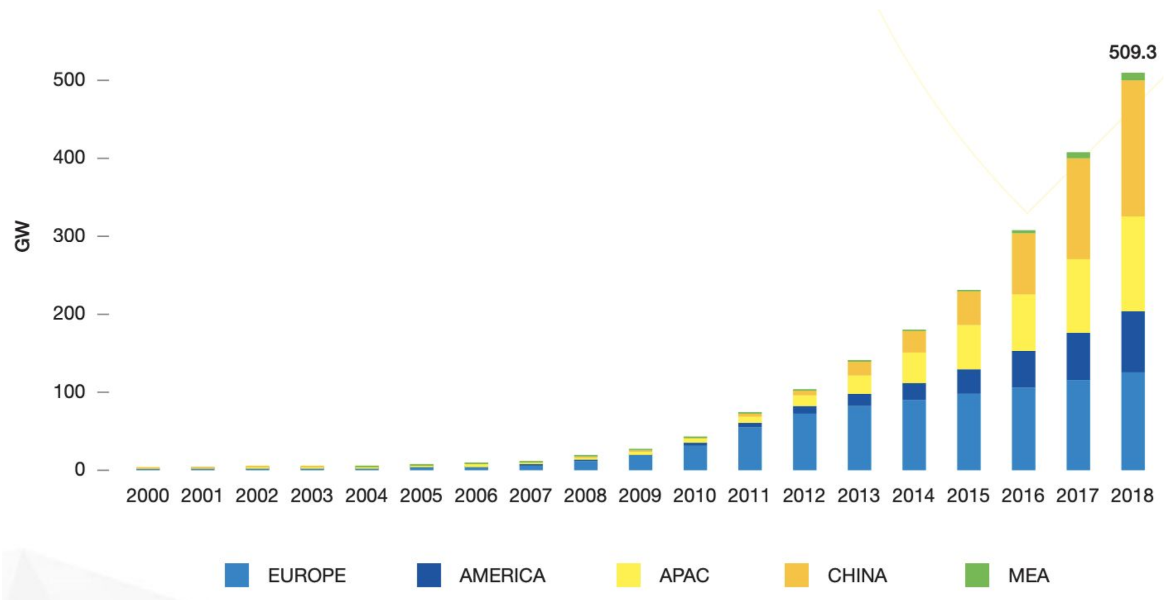
This chapter is a review of the scientific literature surrounding:

a. Photovoltaic technology,
b. Brazilian energy policy related to photovoltaics (PV) in particular (and renewable sources in general),
c. Economic models demonstrating future cost trends of PV modules,
d. Emerging technologies such as blockchain and drone mapping will be researched.
e. Finally, the benefits and challenges of the community solar model will be analysed.

2.1 International Photovoltaic Market Review

In the developed world, grid-connected PV is the fastest-growing segment of the energy market (Fraunhofer, 2015). During the years 2000 to 2015, this industry had a 42% compound annual growth-rate (IEA, 2018). China, Japan and the USA were the three top markets in 2014 following the slowdown in the former leading European market (Research And Markets, 2018). In 2015, solar PV supplied in the countries in Europe such as Italy, Germany and Greece more than 7% of the electricity demanded (IEA, 2016).

Chart 5. – Evolution of Global PV Cumulative Installed Capacity (GW) 2000-2018



Source: International Energy Agency (IEA), Snapshot of Global Photovoltaic Markets, April 2019

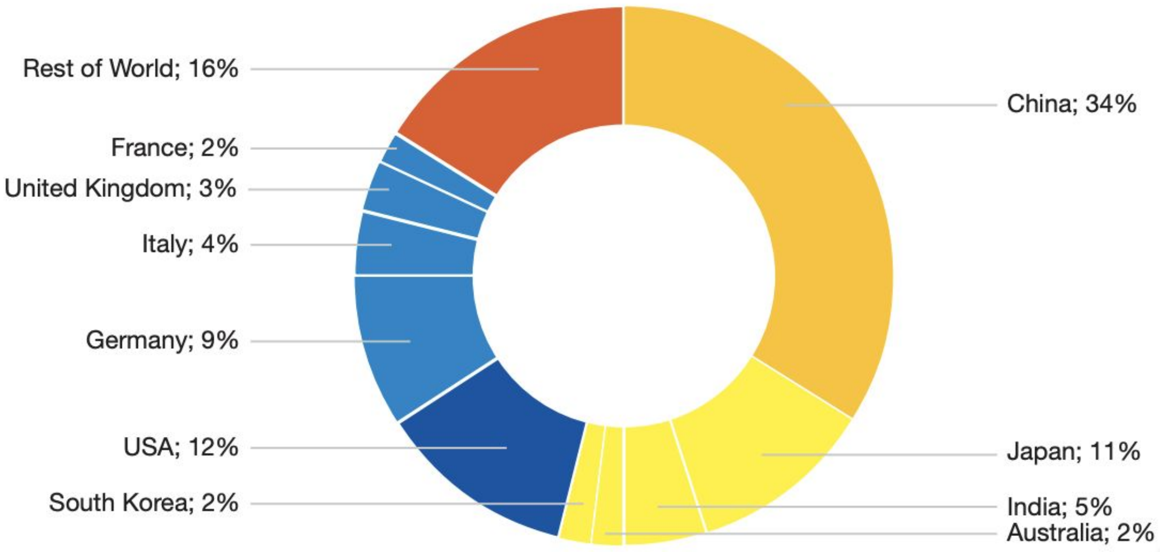
Chart 5 shows the evolution of global solar PV cumulative installed capacity from 2000 to 2018. In 2018, the cumulative solar PV capacity surpassed 500 GW from different contributors, namely: Europe, Asia Pacific (APAC), America, China, Middle East and Africa (MEA) and Rest of the World. This diagram is shown in order to illustrate the rapid development of global solar PV installed capacity.

2.2 Photovoltaic System Cost Trends

PV power prices below 60 US$/MWh have been granted in one project in Dubai (Bellini, 2019). Other projects showed prices between 67 and 80 US$/MWh (ibid.). These prices could be achieved in high radiation regions (above 2500 kWh/m^2/yr) combined with low cost of capital (below 3%) (IEA, 2018).

There is a high variation between estimates of the cost and actual price of solar technologies in the market. The rapidly growing market and sudden changes to PV system pricing in recent years has created a need to clearly differentiate between historical, current, and projected pricing (SunShot, 2015).

Chart 6. – Share of Global PV Installed Capacity in 2018



Source: SolarPower Europe, 2019.

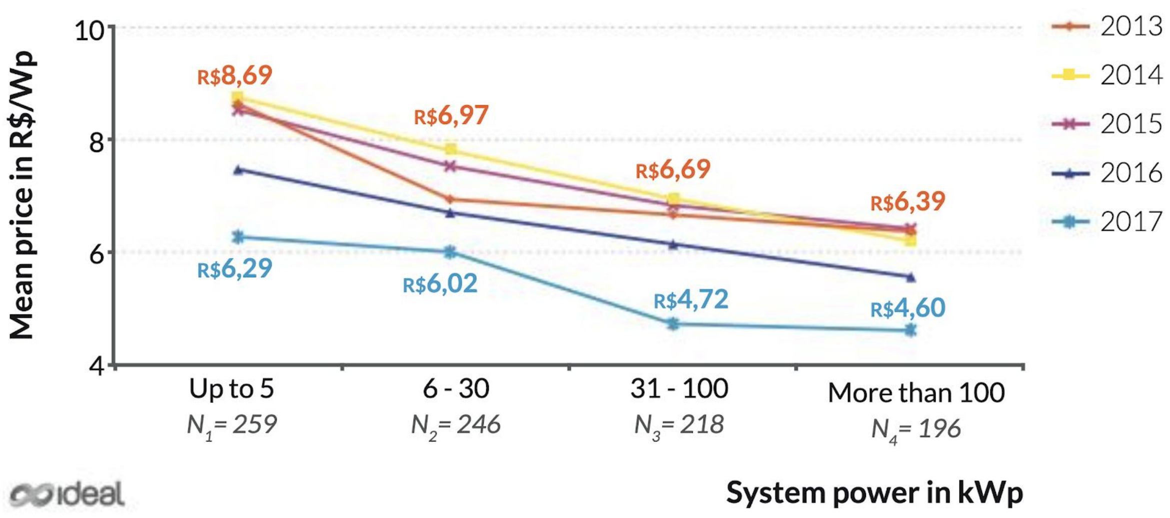
Chart 6 shows the share of Global PV Installation in terms of gigawatts installed capacity and percentage relative to the world total. The leader in terms of PV Installation is mainland China. The graph displays that 85.8% of the installed solar capacity in the world is located in only ten countries. The largest installed capacity in 2017 was in China (131.1

GW), in the United States (51 GW), in Japan (49 GW), in Germany (42.4 GW), and in Italy (19.7 GW).

2.2.1 Rooftop Solar versus Utility-Scale Solar

Utility-scale solar PV systems are more cost effective than residential-scale (rooftop) PV systems in achieving the economic and policy benefits expected from the widespread use of solar energy (Tsuchida et al, 2015). A rooftop solar to utility solar comparison of equal amounts of residential-scale and utility-scale PV solar deployed on an operating utility system was conducted by economists at The Brattle Group (Tsuchida et al, 2015). The following section is a summary of their study.

Chart 7. – Rooftop vs Commercial PV installation prices in Brazil



Source: Ideal, 2018

Economies of scale play a crucial role in the installation cost as demonstrated in Chart 7 that compares installation prices from small 5 kWp rooftop systems to medium sized commercial 100 kWp PV installations in Brazil, where the Wp installation cost difference is almost 50% larger in the case of the small installation size, throughout the past 5 years consistently. Larger PV plants in the 1 to 5 MWp range can be installed even

2.2.2 The Key Findings of the Brattle Group Study

a) The generation cost of energy from 300 MW of utility-scale PV solar is roughly one-half the cost per kWh of the output from an equivalent 300 MW of 5kW residential-scale systems, and utility-scale solar remains more cost effective in all scenarios considered in the study.

b) In that same setting, 300 MW of PV solar deployed in a utility-scale configuration also avoids approximately 50% more carbon emissions than an equivalent amount of residential-scale PV solar.

From the standpoint of cost, equity and environmental benefits, large-scale solar is a crucial resource. As of 2018, the utility-scale PV power costs amounted to US$35,58/MWh (3,5¢/kWh), while residential-scale PV power costs US$62,15/MWh (6,21¢/kWh) (IEA, 2019). These prices are based on historical data, and are not necessarily reflective of current market prices (Tsuchida et al, 2015). In 2018, levelized costs of PV generated electricity in the United States has decreased to 5¢/kWh at utility scale above 2 MW, and 10¢/kWh at residential scale (Fu, 2018).

The study primarily attributes the large difference in per-MWh costs between utility- and residential-scale systems to the economies of scale, and greater solar electric output resulting from optimized panel orientation and tracking assumed for utility-scale systems. The improved orientation and tracking of utility-scale solar also results in a higher capacity factor that causes it to avoid approximately 50% more carbon dioxide emissions than the same capacity of residential-scale solar PV (Tsuchida et al, 2015, p.26).

2.2.3 Non-monetized Benefits of Utility-scale PV Power

a) Water Savings: Utility-scale solar could reduce water externalities by nearly 50% more compared to residential-scale solar, because of the water recycling process of the panel cleaning (Moskowitz, 2016, p. 41);
b) Energy Resilience: In some configurations, distributed generation could be less vulnerable to electric system supply disruptions (Ibn-Mohammed, 2017). However, most residential-scale PV systems installed today are set up so that these PV systems will not generate during outages to avoid potential accidents caused by reverse flows into a downed wire (He, 2016). In addition, in some areas exposed to occasional very strong storms, it is possible that residential-scale PV systems are more vulnerable to storm damage than utility-scale PV systems or central station conventional power (Tsuchida, 2015). In such cases, installing smart inverters or

combining distributed PV systems with storage facilities could potentially increase resiliency, however the exact contribution of the PV system to this benefit cannot be easily calculated, and achieving this resiliency would carry the additional attendant cost of deploying storage and other protection systems on distribution systems (Tsuchida et al, 2015);

c) Greenhouse Gas (GHG) Reductions: PV solar electricity, whether deployed at utility- or residential-scale, produces no GHG emissions from operation. The volume of avoided GHG emissions in either case depends directly on the fuel associated with the avoided resource. Regardless of the fuel type of the GHG Emissions , utility-scale PV solar is anticipated to reduce emissions by nearly 50% more than residential-scale solar (EPA, 2016). This differential is solely a function of the observed variance in generation output of equivalent amounts of installed utility-scale and residential-scale PV (Tsuchida, 2015);

d) Air Pollutants Reductions: Solar electricity is a zero criteria pollutant source from its operation (Feldman, 2015b). Similar to GHG emissions, utility-scale PV systems could avoid more emissions from other energy sources compared to residential-scale solar PV systems;

e) Job Creation: As with all other electric resource additions, PV plants create jobs in both construction and operation. In general, the installation of residential-scale PVs is thought to create more jobs than installing utility-scale PV systems. (Mayer, 2015). However, the respective impact of each PV job type associated with research, development and the production of PV equipment (panels, inverters, etc.), is unchanged (Pyper, 2016).

It is important to recognize the differences between a utility-scale PV system and a residential-scale PV system, particularly if power utilities and their regulators are looking to maximize the benefits of procuring solar capacity at the lowest overall system costs. The options for reducing carbon emissions and the costs of achieving such emission reductions, will have greater importance in the coming years. Simply stated, most of the environmental and social benefits provided by PV systems can be achieved at a much lower total cost at utility-scale than at residential-scale (Tsuchida et al, 2015).

2.2.4 Rooftop PV Advantage

From the above, it seems as though utility-scale PV is clearly preferable, however, the answer may be more complex. As Hagerman (2016) notes, rooftop solar does not require any additional space, nor any additional grid connections or transmission lines, and does not take any additional buffering, or load-following beyond what the local grid already has. Rooftop solar is truly distributed, while utility-scale solar is not.

Another advantage is offered by the shading or rain protection of the PV roof if mounted above a terasse or parking area. With such configuration the energy need for passenger car air conditioning could be reduced compared to unshaded parking areas (Clark, 2018).

Individual rooftop solar users also become more self-sufficient in theory, however without battery storage, they continue to rely on the grid as solar energy is seldom consumed at peak generation hours by residential consumer (Green, 2003).

2.3 Technology Review

Solar PV can be utilized any place where the sun shines and when there is accessible space. The solar radiation hitting the Earth in one hour is adequate to fulfill the world's supply energy needed for a year. As stated above, solar PV contributes a small portion of the world's energy supply, around 1 percent, yet it keeps on improving and developing. There are a few pros and cons in utilizing solar PV (Siegel, 2017):

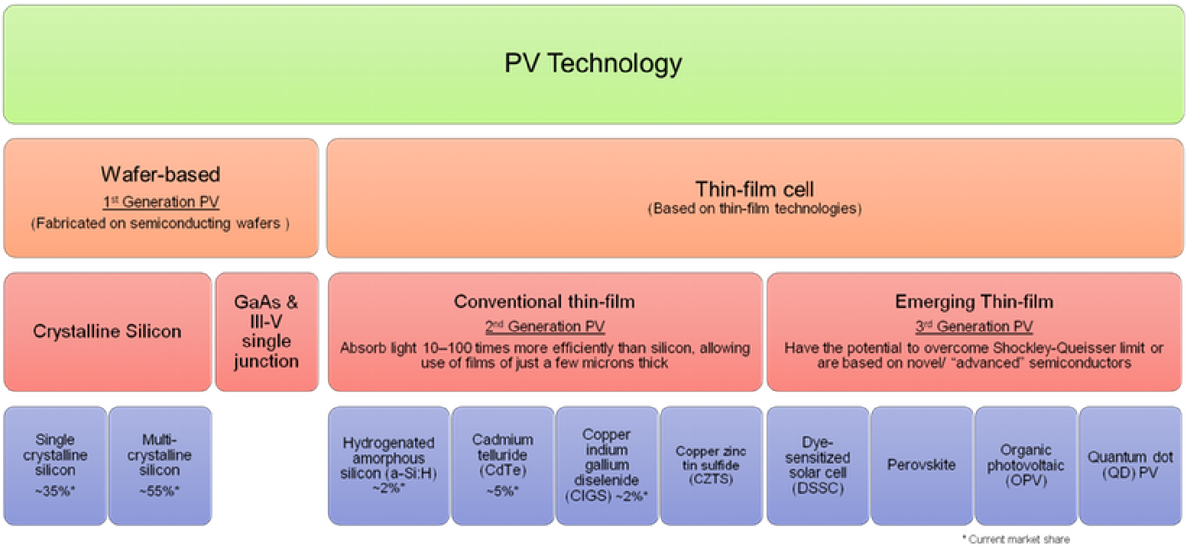
The pros, among others, in utilizing photovoltaics panel are: 1. Solar PV generation is widely accessible given that the area receives sufficient daylight. 2. Installation is a straightforward process on the rooftops or on the ground with relatively little impact. 3. The PV maintenance is low cost and requires little attention (Siegel, 2017).

The cons, among others, in utilizing solar panels are: 1. The unstable weather renders solar photovoltaics less reliable as a base-load source. 2. Although photovoltaic panels have a long lifetime over 30 years, inverters are required to be changed over the lifetime of the PV project, around every 10 years, depending on the model. 3. Utility scale photovoltaics requires significant space for it to be installed (Siegel, 2017).

2.3.1 State of the Art Technology

Currently, the two leading photovoltaic technologies are the poly- and monocrystalline silicon based technologies. However, thin-film cells are a modern technology that could soon take over the PV industry.

Table 2. PV Technology overview



Source: Xiaoxi He et al., 2016

Table 2 - Shows the overview of PV Technology. It is divided into two categories namely: Wafer-based (Also known as 1st Generation PV) and Thin-film cell PV.

2.3.2 Silicon Crystalline Structure

The first generation of PV technology is produced from a crystalline structure by applying silicon (Si) to fabricate the solar cells that are assembled to make PV panels. This method is being continuously enhanced to obtain higher efficiency and lower costs. Mono-crystalline, poly-crystalline, and emitter wrap through (EWT) are collectively referred to as silicon crystalline structures (Chaar et al, 2011).

Wafer-based PV includes Gallium arsenide (GaAs) cells and traditional crystalline silicon. Among different single-junction solar technologies, GaAs cells exhibit the highest efficiency, followed by c-Si cells. The latter dominates the current PV market (Helbig, 2016). Thin-film cells are divided into two parts, namely: Conventional thin-film (also known as 2nd Generation PV) and emerging thin-film. (Also known as 3rd generation PV). PV technologies newer than silicon can be classified into 'generations', as how modern they are. Crystalline silicon PV is classified as the ‘first generation’. Second-generation solar technologies are thin-film based that are already commercially viable, such as cadmium telluride (CdTe), copper indium gallium selenide (CIGS), gallium arsenide (GaAs) and amorphous silicon (a-Si). Third-generation PV is the development stage ‘emerging’ technologies. This refers to organic photovoltaics (OPVs), copper zinc tin sulphide (CZTS), perovskite solar cells, dye-sensitised solar cells (DSSCs), and quantum dot solar cells. (Spooner, 2018)

The difference between wafer-based and thin-film cell are as follows: In wafer-based cells, the efficiency rate amounts to 12% to 24.2%, it is considered to have high stability, is easy to fabricate and has high reliability. It has a high resistance to heat and lower installation costs. Thin-film cell are flexible and easier to handle, and they are less susceptible to damage than wafer-based cells (Ahsan, 2018). The operating temperature of a PV module has a large impact on its energy output. Higher temperatures negatively correlate to the power yield (Virtuani et al, 2010). Thin film technologies however have a better temperature tolerance compared to conventional silicon PV, therefore are more suitable for hot climates such as the Northeast of Brazil. However as overall efficiencies of Si modules are higher than of thin film PV, more support structure and cabling would be required by thin film modules, that would result in higher overall system costs.

2.4 Component Analysis

A photovoltaic system has three main hardware elements: The PV panel or module that captures the solar radiation and transforms to direct current (DC), the inverter that transforms the DC of the panel to alternating current (AC) and the tracker, a mechanical component that enables positioning the panel perpendicular to the solar rays throughout the day. While each component is continuously evolving, the PV panel offers the largest cost reduction opportunity.

2.4.1 Panel

In a traditional solid-state semiconductor, a solar cell is made from two doped crystals: one doped with n-type impurities (n-type semiconductor), which add additional free conduction band electrons, and the other doped with p-type impurities (p-type semiconductor), which adds additional electron holes. In case of Si or GaAs, it is one crystal with two doped regions. When placed in the sun, photons from sunlight excite electrons on the p-type side of the semiconductor, a process known as photoexcitation. In Si cells, generally the crystal is p-doped in the bulk and a thin region is n-doped to form the junction. Finally the light is absorbed in both regions.

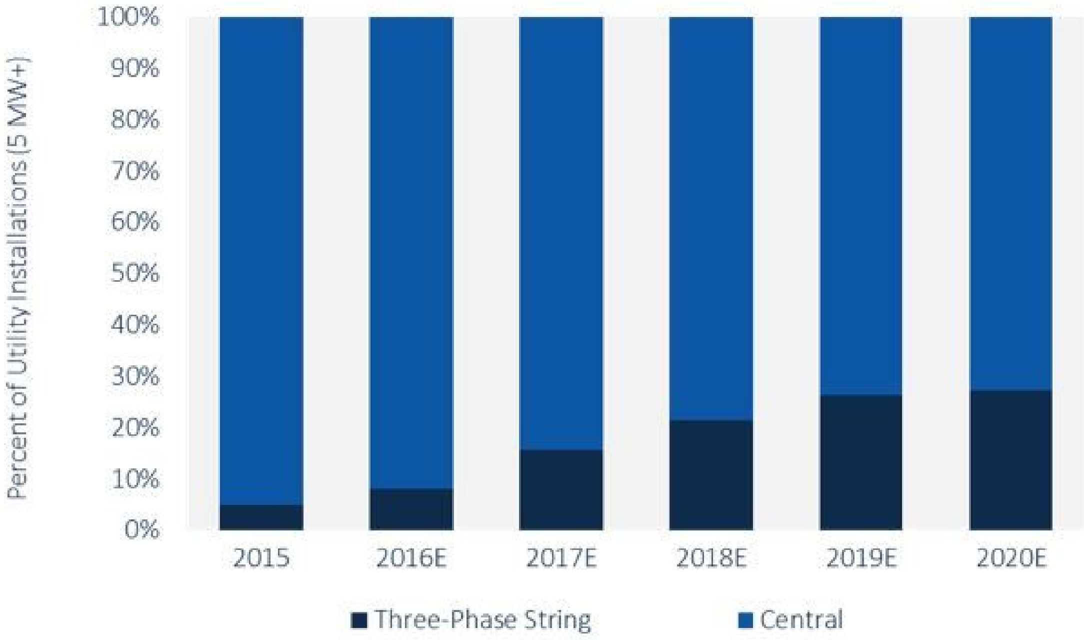
The efficiency of silicon solar cells is currently around 12 -15% for common modules, and up to 25% for the best laboratory cells (The Economist, 2018). By far the biggest problem with the conventional approach is cost. Solar cells require a relatively thick layer of doped silicon in order to have reasonable photon capture rates, and silicon processing is expensive (Dirjish, 2012). On the other hand in thin film panels there are two materials such as CIGS/CdSe, CdTe/ZnO that cause the desired photovoltaic effect.

2.4.2 Inverter

Three-phase string inverters, long the mainstay of commercial solar markets, will account for 37% of all PV inverter shipments globally by 2020 as they become more commonly used in utility-scale systems (Moskovitz, 2016).

Preliminary analysis and anecdotal submissions from leading Engineering, Procurement and Construction (EPC) companies suggests that for 20-megawatt and larger utility projects, overall system pricing for smaller string inverters and large central inverters are relatively close (Moskowitz, 2016). Though the calculations are complicated and entail a number of assumptions, string inverters typically make up some of the upfront premium of 2 cents to 4 cents per watt in their lifetime cost savings, since they require less maintenance (Gaddy, 2016). Additionally, in the event of a failure, availability is minimally affected, and inverters can quickly be swapped out without the need of an electrician (IEA, 2017). However, the complexity of the calculations and the numerous project-specific factors such as slope, land shape, racking type, and interconnection requirements render rules of thumb for string versus central inverter use difficult to come by (Moskowitz, 2016).

Chart 8. – U.S. Solar PV Installations by Inverter Type for Projects Over 5 MW, 2015-2020E

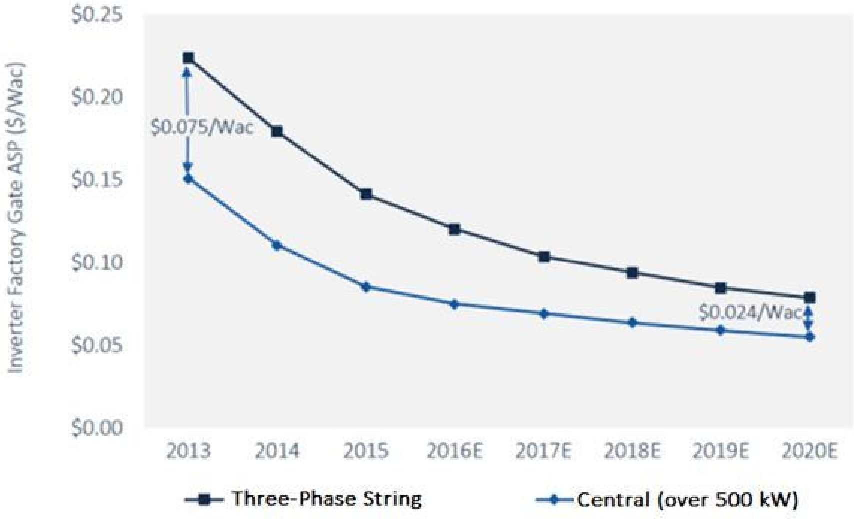


Source: Moskowitz, The Global PV Inverter and MLPE Landscape, 2016

Overall, the share of string inverters will grow as their utility value proposition is proven and new products are introduced. Three-phase string inverters have made giant leaps forward over the past several years; prices have fallen rapidly relative to central inverters, and along with rapid shutdown and arc fault requirements, their use has become standard in larger projects. Over that time period, the threshold for which string inverters making clear financial sense has risen from about 500 kilowatts to around 5 megawatts today (Moskowitz, 2016, p.14).

Chart 9. shows the average sale prices from 2013 until 2020 of PV Inverters produced in the USA at factory-gate ($/Wac). Three-phase string inverters have made giant leaps forward over the past several years. But, prices of central inverters have fallen rapidly and their use has become standard in large projects. However, only 5 percent of U.S. utility installations in 2015 were built only with string inverters (Moskowitz, 2016).

Chart 9. – U.S. Inverter Factory-Gate Average Sale Prices, 2013-2020E ($/Wac)



Source: Moskowitz, The Global PV Inverter and MLPE Landscape, 2016

Huawei, now the world's largest inverter vendor by annual volume shipped (PV Magazine, 2019a), has popularized the use of three-phase string inverters in utility projects in the Chinese market. According to research published by Greentech Media, over 40 percent of installations in China in 2015 were installed with three-phase string inverters. For string inverter use to take off, the broader value proposition must be proven for large-scale projects (Moskowitz, 2016). The following are the major determining factors in the three-phrase string: 1. Price declines are major driver; however, the upfront cost of the inverter is far from the only determining factor. In addition to this, associated balance-of-systems, installation costs, system performance, and lifetime operations and maintenance must also be taken into account. The presence of the major determining factors in three-phrase string would only show that there is no sign in price stability. Current technology trends have not exhausted their cost-reduction potential, and many markets are still extremely fragmented (St. John, 2017).

Different stakeholders are motivated by different metrics. EPC contractors that bid their services on an upfront basis are driven to reach the lowest possible price per watt. Conversely, developers and long-term project owners are typically more concerned with a project's lifetime costs and their effect on project returns (Moskowitz, 2016).

2.4.3 Tracker

Stationary mounts, which hold panels in a fixed position, can have their productivity compromised when the sun passes to a less-than-optimal angle. Solar trackers automatically move to “track” the progress of the sun across the sky, thereby maximizing output. Depending on geographic location, the use of tracker could boost energy production of the same installed panel capacity between 10% to 25% (Katz, 2019). Their capital expenditure is higher compared to fixed ground mounts, but above a certain plant size, around 1 MW, it is more than compensated by the higher energy yield, depending on the latitude. Locations closer to the equator, benefit more from trackers, as opposed to location closer to the artics. (Mertens, 2016).

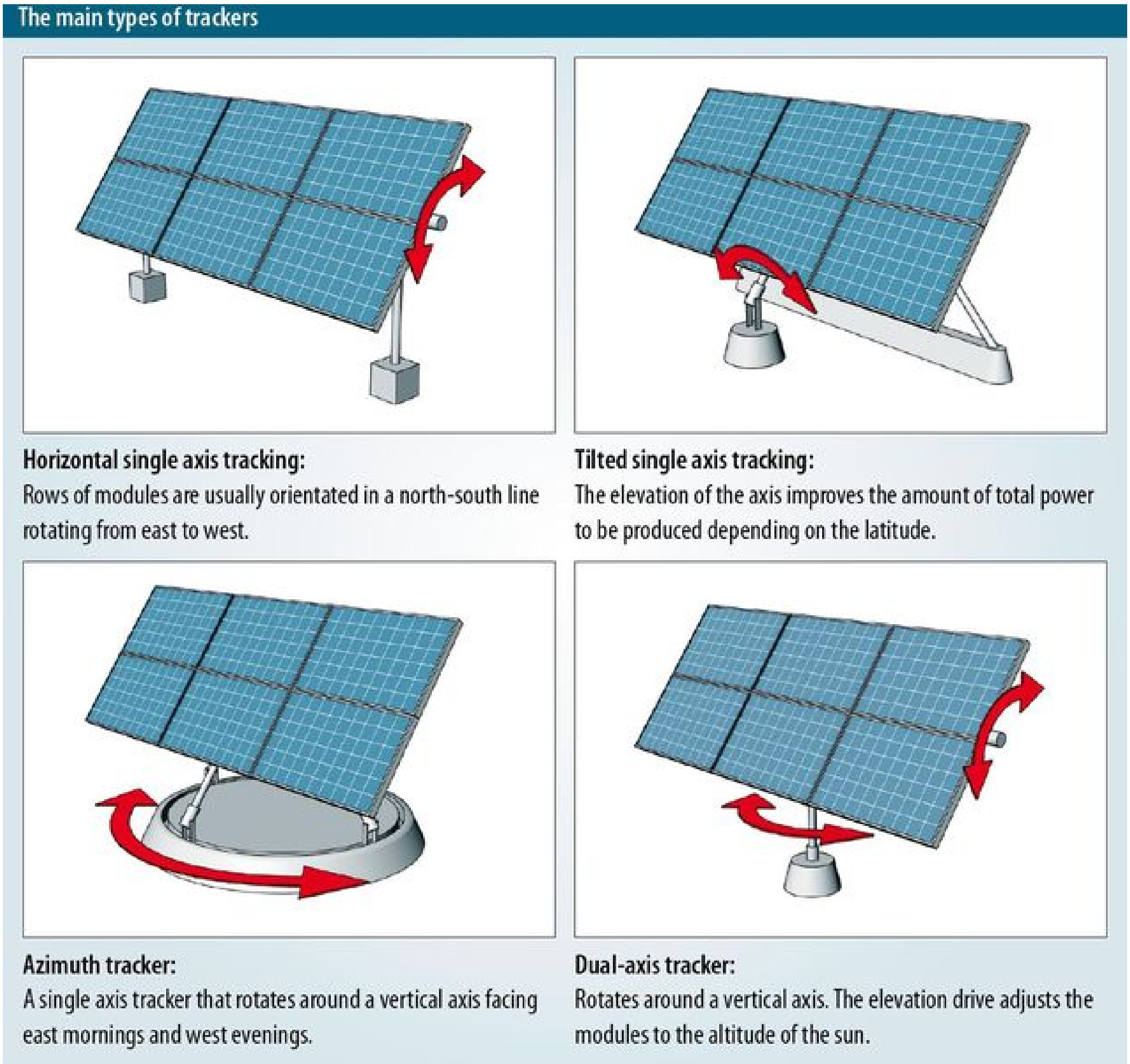
The two main tracking types are:

a) Single axis tracking systems, where hundreds of PV modules are mounted and moved across parallel axis, connected to a single electric motor moving the rows. This is the most cost efficient solution, therefore single axis is the most widely used in large scale PV plants (McCrea, 2017).
b) Dual axis tracking systems, where one motor moves a small set of PV modules in two dimensions. This type of tracker can reach the highest conversion efficiency, but at a significantly higher capital cost. Dual axis tracking also suffers from large shading areas, leading to an increased requirement of land area compared to single axis trackers.

Although trackers assure a higher performance, they also add more technical complexity to the system, potentially driving up operation and maintenance costs. Trackers can also lead to more frequent failures, reducing the plant's overall generation, decreasing its revenue (MIT, 2015).

By the end of 2016, some 23% of ground-mount PV systems globally were using trackers, with that number expected to grow to 49% by 2021 (PVMagazine, 2016). In 2021, annual tracker installations will value $4.9 billion (PVMagazine, 2016). Falling costs and improving technology will contribute to growth in the tracker market.

Figure 1. - PV Tracker types



Source: PV Magazine, 2013

Figure 1. shows the different PV Tracker Types. PV Tracker Types includes: Horizontal Single Axis Tracking, Tilted single axis tracking, Azimuth tracker and Dual-Axis Tracker. The most commonly used tracker type is the horizontal single axis tracker, as this provides the best cost benefit ratio besides the least amount of shading and land requirement. The single axis tracker is also the design with the least amount of maintenance cost.

Single Axis Horizontal Tracking is more adequate for low latitude land. Area layouts applying single axis horizontal trackers are easy to adjust. A long horizontal girder is spans on bearings mounted upon columns or pillars. Single Axis Tilted Trackers feature rotation axes both horizontal and vertical. The tilt angles are usually restricted to reduce the wind resistance and decrease the height of the higher end of the axis.

An azimuth–altitude (or alt-azimuth) dual axis tracker (AADAT) has its primary axis (the azimuth axis) vertical to the ground. This arrangement is preferred as the weight of the array is divided over a part of the ring, in contrast to just one suspension point of the pole.

Dual Axis Trackers operate with two degrees of freedom, acting as rotation axes. Dual axis trackers maximize the yield of PV energy resulting from their capability to track the Sun both vertically and horizontally. Independent from the Sun's position relative to the PV panels, the dual axis trackers can point the solar panels exactly perpendicular to the Sun. (Afanasyeva, 2018)

Table 3. Global market of the tracker industry

Vendor Category	Dual-Axis Designs	Centralized Tracker Designs		Decentralized Tracker Designs	
Vertically Integrated Firms w/ Trackers		SUNPOWER			First Solar, SUNPOWER
Diversified Manufacturers		Schletter, Krinner		Krinner	Magna, Solar FlexRack
Mounting Structures Firms w/ Trackers	PARU, Sun Action Trackers	Clavijo, STI norland, Scorpius Trackers, Powerway, Sunlink, PARU, Sun Action Trackers, Arctech Solar, shoals, Versol Solar		Sunlink, GameChange Solar	Ideematec, Optimum Tracker, STI norland, Clavijo
Pure-Play Tracker Vendors	allEarth		exosun, Array Technologies	NEXTracker	Convert, sunfolding, Soltec
Tracker Sub-Type	Dual-Axis Trackers	Centralized Trackers: Push-Pull	Centralized Trackers: Rotary Drive Line	Decentralized Trackers: Self-Powered w/ Auxiliary Module	Decentralized Trackers: Parasitically Powered

Source: Moskowitz, 2016

Table 3 Shows the Global Market of the Tracker Industry. It delivers the market measure data and market trends together with different factors and parameters such as single or dual axes, centralized or decentralized PV plants. California-based NEXTracker held its lead over the PV tracker industry in 2018, claiming 30% of the global market in terms of shipments. New Mexico-headquartered Array Technologies also maintained its second-place position last year, accounting for roughly 12% of global deliveries. Two

Spanish companies, PV Hardware, its rival Soltec and China's Arctech Solar all claim about 9% of the global market for solar trackers (PV Magazine, 2019).

2.5 Innovation in PV Technologies

Although some 90% of the PV market today is still based on the first generation silicon technology of the 1950s, the development trend is expected to be towards second and third generation technologies (Rao et al, 2016). The high cost of traditional silicon solar cells and their complex production process generated interest in alternative technologies (ibid.). A thin-film solar cell is a second generation solar cell that is made by depositing one or more thin layers, or a thin film, of photovoltaic material on a substrate, such as glass, plastic or metal (ibid.). Thin-film solar cells are commercially used in several technologies, including cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous thin-film silicon (a-Si, TF-Si) (ibid.). The major drawback of thin-film technologies is that it uses rare elements such as ruthenium, gallium, indium, which makes them difficult to scale (Hook, 2015). Emerging or third generation PV cells include organic, dye-sensitized, and polymer solar cells, as well as quantum dot, copper zinc tin sulfide, nanocrystal, micromorph, and perovskite solar cells. The third generation approaches to photovoltaics aim to achieve high-efficiency devices, but at a reduced material requirement of the thin-film technology. Also, the energy requirements of thin-film technology is lower, as there is no heat used in the process for melting the silicon to form ingots. The concept is to do this with only a small increase in real costs and hence, to reduce the cost per Watt peak. Thus, these third generation technologies will be compatible with large-scale implementation of PV.

2.5.1 Organic Solar Cells

An organic or plastic solar cell is a type of PV technology that uses conductive organic polymers or small organic molecules for light absorption and charge transport to produce electricity from sunlight (Koh, 2014). The molecules used in organic solar cells are cheap, resulting in low production costs to fabricate large volumes. Compared to silicon-based devices, polymer solar cells are lightweight and potentially have less adverse environmental impacts (Helgesen, 2012). The main disadvantages associated with organic photovoltaic cells are low efficiency, low stability and low strength compared to inorganic PV cells such as silicon solar cells (Kaur, 2014).

2.5.2 Dye-sensitized Solar Cell

A dye-sensitized solar cell (DSC) is a low-cost solar cell belonging to the group of thin-film solar cells. Michael Grätzel was awarded the 2010 Millennium Technology Prize for this invention (Renewable Energy Focus, 2010). The report of his findings, published in 1991 in the journal *Nature*, was the catalyst that spawned a whole new industry and a novel way of looking at harvesting electrical power from sunlight (O'regan et al., 1991). In a DSC, solar radiation impacts the the dye layer of the translucent electrode. In the process it induces electrons that then are channeled to the titanium dioxide. The electrons stream to the translucent electrode, resulting in a load that can produce power. Once the electrons leave the outside circuit, they are directed to the electrode on the back of the PV cell, until reaching the electrolyte. The electrons are finally delivered back to the dye molecules by the electrolyte (Swami, 2012). Dyesol is a solar energy company innovating in the field of solid-state Dye Solar Cell (DSC) technology, known as Perovskite dye solar cells, lead by Professor Grätzel.

2.5.3 Perovskite Solar Cell

Perovskites are hybrid organic-inorganic lead or halogen based material, bonded to organic molecules made mostly of carbon and hydrogen atoms in a crystal structure (Chen, et al. 2015). Perovskite PV cells can be made at much lower temperatures, hence requiring only fraction of the energy input compared to traditional silicon (Ibn-Mohammed, et al. 2017). This not only means a lower cost of manufacturing, but also a lower level of emissions from the electric furnace. Perovskite solutions can be deposited directly to light thin-film materials, like a simple printing process. In 2016, perovskite solar-cell efficiencies grew above 20%, a tenfold growth within a decade (Hicks, 2018). The technology continues to develop. The major difficulty with perovskite technology is its low environmental resistance and rapid degradation (Ibn-Mohammed et. al, 2017).

Oxford PV™[1] is a company developing and commercializing thin-film perovskite solar cells, paring them to existing silicon and thin-film modules, thus increasing efficiency.

2.5.4 Graphene and Solar Panels

Graphene is a monolayer of carbon atoms arranged in a honeycomb pattern. It is incredibly light, flexible, exponentially stronger than steel, and capable of conducting electricity even better than copper (Graphene, 2019). It is almost entirely transparent and is made of abundant carbon, a relatively inexpensive material. Graphene has a seemingly endless potential for improving existing products (Graphene Solar, 2019).

Solar cells require materials that are conductive and allow light to pass through them. Thus, graphene's superb conductivity and transparency could greatly benefit existing PV technologies. Graphene is indeed a great conductor, but it is not very good at collecting the electrical current produced inside the solar cell (Graphene, 2019). Hence, researchers are looking for appropriate ways to modify graphene for this purpose (ibid.). Graphene Oxide (GO), for example, is less conductive but more transparent, and a better charge collector, which can be useful for solar panels. According to Grioni et al, a photovoltaic device using doped graphene could show significant efficiency in converting light to electricity.

The conductive Indium Tin Oxide (ITO) is used with a non-conductive glass layer as the transparent electrodes in most organic solar panels (Helgesen, 2012). However, ITO is rare, brittle and makes solar panels expensive (Papageorgiou, N.D.). There is the potential to use graphene as a replacement for ITO in transparent electrodes of organic photovoltaics (OPVs) (Koh, 2014). Others search for ways of utilizing graphene to improve the overall performance of photovoltaic devices, mainly OPVs, as well as in electrodes, active layers, interfacial layers and electron acceptors (Mertens et. al, 2016).

2.5.5 Multi-junction Solar Cell

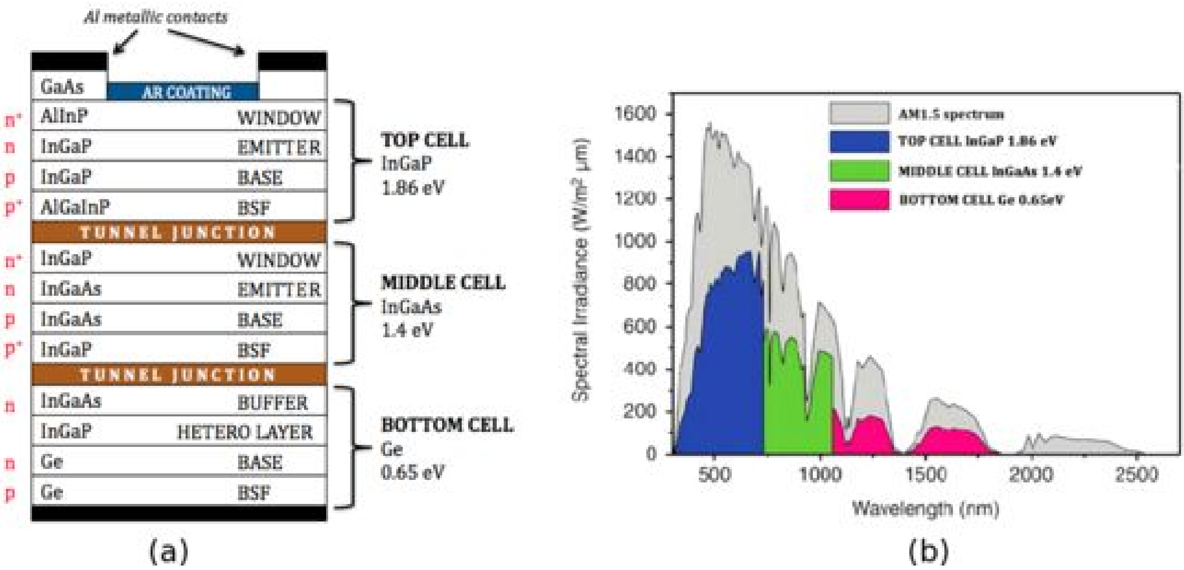
Multi-junction (MJ) photovoltaic cells feature various p-n intersections made of different semiconductor materials. Every material's p-n junction will create electric current

[1] https://www.oxfordpv.com/

because of the various wavelengths of light. A p-n is a two-terminal or two-electrode semiconductor device, which allows the electric current to flow in only one direction while blocking the electric current in opposite or reverse direction. It allows the electric current to flow if the diode is forward biased. Otherwise, it blocks the current electric flow (Pradesh, 2015). The utilization of various semiconducting materials permits the absorbance of a more extensive scope of wavelengths, enhancing the cell's daylight to electrical power transformation effectiveness (Stam, 2018).

Conventional single-junction PV cells have a maximum hypothetical effectiveness of 33.16% (Ruhle et al, 2016). In theory, an interminable number of intersections would have a constraining productivity of 86.8% under exceptionally focused sunlight (Green et al., 2003). Tandem manufacture procedures could enhance the efficiency of existing PV materials. This method can be utilized to make thin-film based PV cells more economically efficient by using amorphous silicon instead of regular crystalline silicon to create PV material with around 10% conversion efficiency that is lighter and more adaptive (Solar-Era, 2018). At present, however, such materials are only applied as special roofing products (Berdahl et al., 2008).

Graph 3 - The structure of an Multi-Junction solar cell



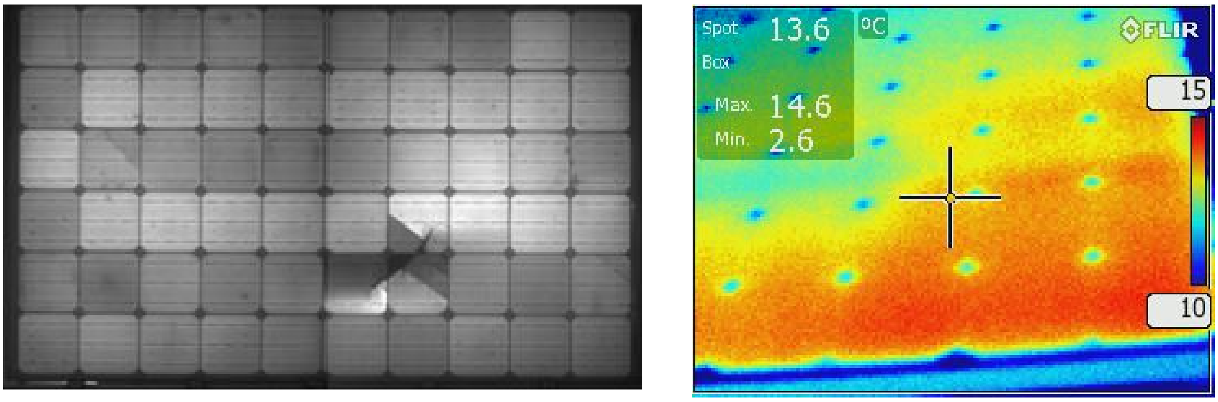
Source: N.V.Yastrebova, High-efficiency multi-junction solar cells: current status and future potential, (2007) Presently, the best lab cases of conventional crystalline silicon PV cells have efficiencies somewhere in the range of 20% and 25%, while lab cases of MJ cells have exhibited efficiencies more than 46% under concentrated sunlight (Fraunhofer, 2017). There are many commercially available PV products featuring 30% efficiency under one-sun illumination, which can be enhanced to around 40% under concentrated daylight (Askari, 2015). Unfortunately, such gains are being achieved at the cost of expanded production and assembling cost (Duffy, 2001). To date, their higher cost has restricted their utilization to certain applications, such as aviation, where their high capacity-to-weight relationship is attractive (ibid.). In earthbound applications, these PV cells are gaining importance in concentrated photovoltaics (CPV), suitable in areas with high direct irradiance (clear skies) as opposed to diffuse sunshine (clouds) (Solargis, 2015).

2.6 Potential Induced Degradation (PID)

During the normal operation of a PV module, weather impacts such as changes in temperature and humidity cause foreseeable degradation to the module. When this degradation goes further than expected, developers face a problem. Among the factors that can cause such abnormal accelerated degradation of the PV module, the most important is the potential induced degradation, or the PID effect (Fraunhofer, 2016). The PID effect is degradation due to a mix of different factors: weather conditions (temperature and humidity), array design (system voltage, topology and module position within the string), PV module design, and materials used (Hoffman, 2014). Such degradation is characterized by a loss of generation capacity that could amount to 30% (ibid.).

The PID effect provokes an electrical leakage current to flow from the frame to the cells in an order of magnitude of nanoamps, accumulating positive charge over the cell surface (Luo et al., 2017). This affects the cells electrically, and in the long term, physically. For modules based on P-type wafers, this effect will occur in the modules installed in the most negative part of the string, and among other factors, will depend on the drop voltage between the cells and the frame (the bigger the difference, the higher the risk) and the dielectric quality of the materials used in the PV module (González, 2017). There are different ways to detect the PID effect: through thermal or electroluminescence (EL) pictures or obtaining the I/V curve of the module. EL is an optical and electrical phenomenon in which a material emits light in response to the passage of an electric current or to a strong electric field (Electronicstutorials, 2019) while The I-V Characteristic Curves, which is short for Current-Voltage Characteristic Curves or simply I-V curves of an electrical device or component, are a set of graphical curves which are used to define its operation within an electrical circuit (Technopedia, 2019).

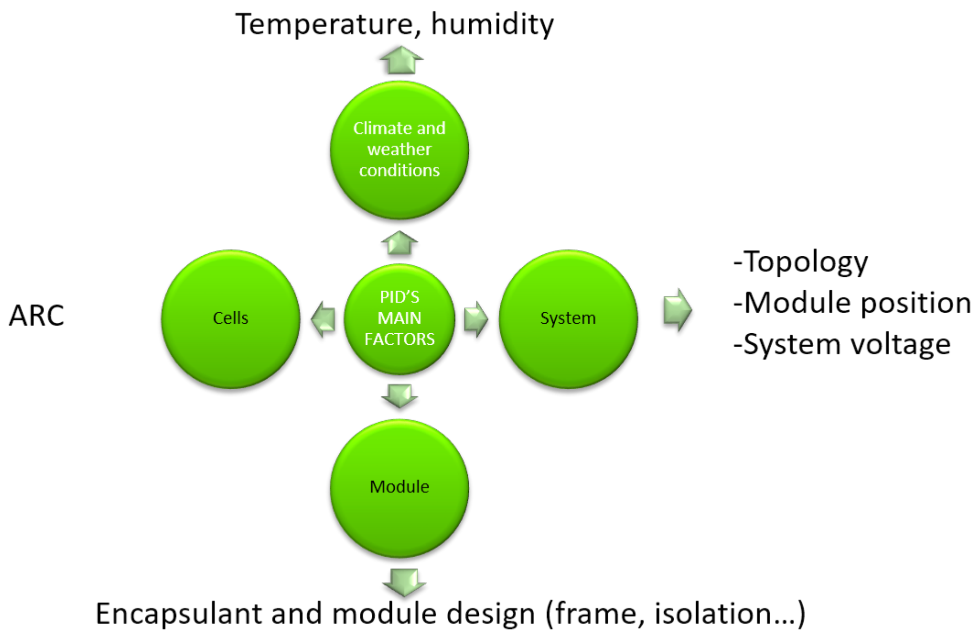
Figure 2. – PID detection by Electroluminescence test and Infrared image-forming



Source: www.ilumen.be

Taking into account that the climate conditions has unavoidable effects, PID ought to be lessen at the establishment level (Gonzáles, 2017).

Figure 3. – Main reasons causing PID



Source: González, 2017

Connecting one pole to the ground is one of the solutions which is adopted when the installation has already been complete, or the module is not fitted with a grounding hook. To illustrate, let us consider a string of 23 PV modules with identical dielectric or isolation level for each module in a system with a voltage of 800V. If we could measure the voltage between the cells of each PV module in this string, on the PV module with the most negative charge in the string, we would see a voltage of 400V. As long as we go through the string towards the pole with the most positive charge, the voltage will be proportionally approaching 0V. This would be the focal point of the string, a.k.a central PV module in the string. From this point onwards, the voltage would be positive until it comes to +400V in the best module of the string. According to this, in p-type wafers the current can potentially flow from the frame to the cells and therefore degrade the PV modules located in the negative part of the string. PV modules with a positive voltage compared to the ground will never be affected by the PID issue. Therefore, in order to avoid the leakage of the current flowing from the frame to the cells, a connection of the negative pole of the string to the ground should be made. For cells based on n-type wafers, the positive pole should be grounded. There is a potential risk of electric shock in the case of one string being separated from another one since there would be a circuit flowing to the ground. For this case, a fuse is installed between the negative pole and the ground, securing the circuit. Another factor to be examined in this type of configuration is the inverter. When there is an existing pole connected to the ground, transformerless inverters are unsuitable and it is advisable to refer to the inverter manufacturer’s guidelines (González, 2017).

2.7 Policy Review

In 1994 the Brazilian national program PRODEEM (Program for Energy Development of States and Municipalities) was created, focusing on the promotion of energy services to communities which had no access to the conventional grid, mostly in the north and northeast regions of Brazil. Later, in 2003, a national program called PROINFA (Alternative Electrical Energy Sources Incentive Program) was put in place to encourage the use of alternative energy sources to produce electricity (Jannuzzi et al, 2013).

The Normative rule n° 482/2012 of the Brazilian Electricity Regulatory Agency (in Portuguese, *Agência Nacional de Energia Elétrica*, ANEEL), approved in 2012, was the first to establish incentives to grid-connected distributed generation by small producers, and to introduce a net metering system. This regulation is a significant step towards the establishment of the domestic PV market, however it falls short of creating sufficient incentives to kick start the solar market (Faria, 2017). Until the end of 2015, during its first 4 years of existence only about 1620 grid connected PV systems were inaugurated nationwide (ibid.).

2.7.1 ANEEL Distributed Generation Regulation n°482/2012

The purpose of the normative rule n°482/2012 is to establish the conditions for distributed micro- and minigeneration as an energy compensation scheme. It defines microgeneration as a grid connected electricity generation unit equal or below 100 kW using renewable sources such as hydro, wind, solar, biomass or qualified cogeneration (Jimeno, 2019). The same definition is applied to minigeneration, since it has a potential higher than 75 kW but lower or equal to 1 MW (Freitas, 2015).

In the compensation system, the participating residential, commercial or industrial electricity consumer injects its generated energy as a credit to the grid and receives an equivalent compensation from its energy consumption, as long as the generator unit and the consumer shares the same company register (CNPJ) or personal ID number (CPF) (RES 482, 2012; Gucciardi, 2017). One has to take into consideration that the minimum tariff of the so called grid availability corresponding to 30, 50 or 100 kWh a month for single, double or triple phase connection respectively, can not be compensated and must be payed independent from the energy credits compensated.

There is no need to sign a separate contract between the micro- or mini-generator and the power distribution company. It is sufficient to close an operational relationship agreement between the parties. The generation system must be limited to the installed capacity in case of a low tension electricity consumer or the contracted demand in case of high tension energy consumer. In case the client is willing to install a larger generation capacity, they have to request an increase of its contracted demand or installed capacity at their own cost.

That normative rule n°482/2012 is a hallmark for the actual implementation of PV systems in Brazil, and it included the general procedures for connection into the grid of micro- and minigenerators. It also regulated the issue around “net metering” (power compensation regime), through which the system’s owner is not required to consume all the energy produced at the time of generation, since it may be sent to the Power Distribution company’s grid in their region. During the following months, consumers receive credits in the form of kWh in their electricity bills, related to that amount of generated, but not consumed, power (Gucciardi, 2017). Those credits may be utilized during the months with lower insolation, or they may be used to abate rates from the electricity bill of another property owned by the same legal or natural person (and even the same Taxpayers’ Registry number) in the same concession area (ANEEL, 2012).

2.7.2 ANEEL's Normative Regulation n°687/15

As the distributed generation market did not develop in a significant measure between 2012 and the end of 2015, ANEEL has updated its net metering rules. The new normative regulation is based on the previous rules, but includes significant updates. The most important novelty is the inclusion of the concept of shared generation and remote self consumption. Shared generation means a renewable energy facility of any size that is either financed by many interested parties, or is used by multiple consumers to generate their own electricity (Gucciardi, 2017). This can be as simple as installing a PV system on the roof of a residential condominium with the investment benefiting various residents.

In addition to that, the new rules of 687/2015 have established several significant improvements for the country’s micro- and minigeneration model, thus placing Brazil in the forefront in terms of policies to stimulate the development of distributed generation among the general population (Faria, 2017). Among the main improvements, the following introduced Brazil to the world in terms of micro- and minigeneration models as a new player in the solar industry:

a. Establishment of the remote self-consumption and shared generation modalities;

b. Possibility of compensating energy credits between the branches of business groups;

c. Community distributed generation systems (natural and legal entities);

d. Extension of the maximum capacity of minigeneration from 1 MW to 5 MW;

e. Extension of the duration of the electric power credits from 36 months to 60 months;

f. Reduction in the bureaucracy involving distributors;

g. Standardization of the request forms to have access to all the national territory;

h. Submission and follow-up of new requests through the internet starting in 2017. (Faria, 2017)

2.7.3 Tax Policy of the Distributed Generation

The ICMS Tax treaty nº 16 of April 22, 2015, which authorizes to tax exemption in internal operations related to electric energy flow, subject to billing under the Electric Power Compensation System mentioned in Normative Resolution nº 482 of 2012 by ANEEL, already counts on the adhesion of 23 of the 27 Brazilian States. The State of Minas Gerais also grants ICMS Tax exemption as applicable to the energy supplied by the distributor to a consumer unit, according to a state law (Cavalcanti, 2014). That covenant is extremely important, because it stimulates electric energy consumers to invest in a PV solar power micro-and minigeneration system, since the financial return on their investment will come faster with such ICMS Tax exemption.

For the above reason, the actual article states:

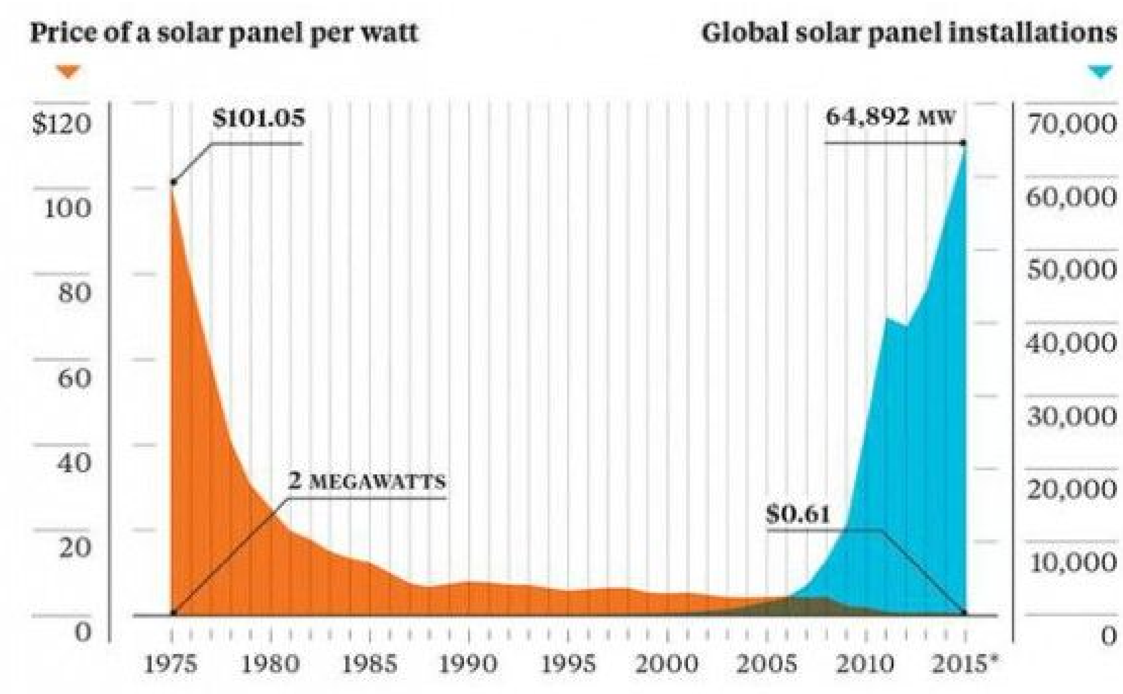
> Law nº 13.169 of October 06, 2015 : Art. 8th The aliquots of the PIS/Pasep Contribution and of the Social Security Funding Contribution - COFINS befalling the active electric energy supplied by the distributor to a consumer unit are reduced to zero, at an amount corresponding to the total sum of the active electric energy entered into the distribution grid by the same consumer unit with the active energy credits generated by the very consumer unit in a same month, in the previous months or in other consumer units owned by the same person, according to the terms of the Electric Power Compensation System for distributed micro and minigeneration, according to the National Electric Energy Agency – ANEEL’s regulations. (LEI Nº 13.169, Art. 8, DE 6 DE OUTUBRO DE 2015.)

The main difference between the nation-wide ICMS tax exemption based on the CONFAZ 16 as opposed to the State decree of Minas Gerais (State Decree Nº 47.231, of 4 of August, 2017) is that the later included the new models of shared generation to the tax exemption criteria while the general rule of CONFAZ limits to exemption to where the generation and consumption units are registered for the same entity eg. household or company. This means that large companies with a number of consumer units in a distribution area enjoy full tax exemption on their distributed generation resources, while a group of individual small companies or households would be taxed for the same distributed generation resource. In the opinion of the author this causes negative discrimination and competitive disadvantage to small and medium sized companies compared to their larger competitors who enjoy such tax benefits. Therefore the author suggests to follow the example of Minas Gerais on the national level by updating the CONFAZ 16 tax ruling.

2.8 PV Cost Evolution

Until recently, PV electricity generation was prohibitively expensive compared to hydroelectricity or thermal power (Kavlak et al, 2018). Technological developments and steadily increasing market demand helped to reduce the costs, and as a result PV has become competitive in various markets (Kavlak et al, 2018). The two main factors influencing PV generation prices are the solar radiation levels and the cost of capital. In markets enjoying high insolation (above 2000 kWh/year) and government backed low interest rates, financing solar is readily competitive today without subsidies (Hesary et al, 2018).

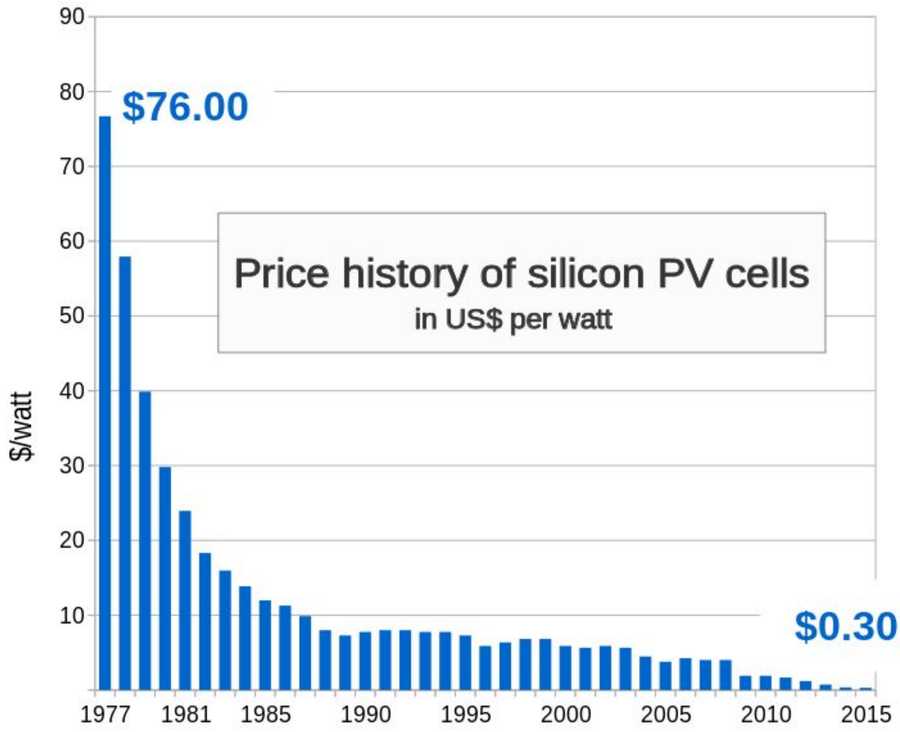
Chart 10. – PV price vs capacity evolution



Source: Earth Policy Institute/Bloomberg, 2015

Chart 10 shows the installed PV capacity that has been installed in the world (blue). To illustrate, the price of solar panels (in orange) hit a tipping point and installation exploded (in blue). This demonstrates the reasons behind the exponential growth of PV.

Chart 11. – PV cell cost evolution in US$ / W



Source: Bloomberg, 2016

Chart 11 illustrates the price history of silicon PV Cells in US$ Per watt, as opposed to the PV modules' price in Chart 9. This shows the emerging development and price decline of PV. It shows the price per watt, starting in 1977 at over $76/watt all the way down to $0.30/watt in 2015. While it's already very competitive with conventional sources of power in large parts of the world, in a few years solar will simply be too cheap to ignore, even without a price on carbon emissions.

2.8.1 Hardware Components

2.8.1.1 Photovoltaic modules

PV panels or modules convert solar radiation to electricity by the photoelectric mechanism. PV modules consists of photovoltaic cells and are manufactured by doping silicon molecules, a glass sheet, EVA back sheet, aluminium framing and conductive wires. The size of a PV panel depends on the rated peak power expressed as Watt-peak (Wp). Solar modules can be formed in PV arrays on a support structure or tracker. PV panels produce direct current (DC) electricity and need an inverter in order to yield alternating current (AC) used in most appliances.

2.8.1.2 Solar inverters

As PV modules produce DC electricity a solar inverter is needed to transform it to alternating current (AS) used by consumer appliances and the distribution grid. Inverters can be either grid-connected and standalone units. According to their size one can differentiate between micro-, string- and central inverters. Micro inverters are directly mounted on the solar module hence are unaffected of the performance of other modules in the array. String inverters can attend an array of solar modules, are mounted as a separate box on the building wall or support structure and are both employed to connect rooftop PV installations and commercial size PV plants. Central inverters attend megawatt size, utility scale PV power plants and are the most efficient in converting AC to DC electricity. Due to their large size however, central inverters are more difficult to transport, install and maintain compared to string inverters. This explains the latest trend of employing string inverters in MW scale PV installations instead of the central inverters. Inverters may be connected to batteries, that permit for back-up power throughout outages or to be stored for peak demand.

2.8.1.3 Solar panel or PV module mounting systems

PV systems may have different architecture in terms of racking structure and mounting types. As PV systems have considerable space requirement and the installation conditions could be different in each case. Mounting solutions range form rooftop rails to ground mounting structures and solar trackers, according to the size of the installation. Most mounting systems apply non corrosive metal alloy structures founded in concrete, that can guarantee the longevity of the PV installation for its 25 years lifetime.

Ground Mount structures allows arrays of multiple rows of modules to be installed on the ground. Roof Mount does not require roof penetration especially when the roof is flat. Ballasted roof mount is one of the most used mounting structure for solar modules installed on flat roofs. It utilizes the weight of concrete or sand to ensure the system stays still to stand all kinds of external forces such as pullout wind forces (Hagerty, 2015).

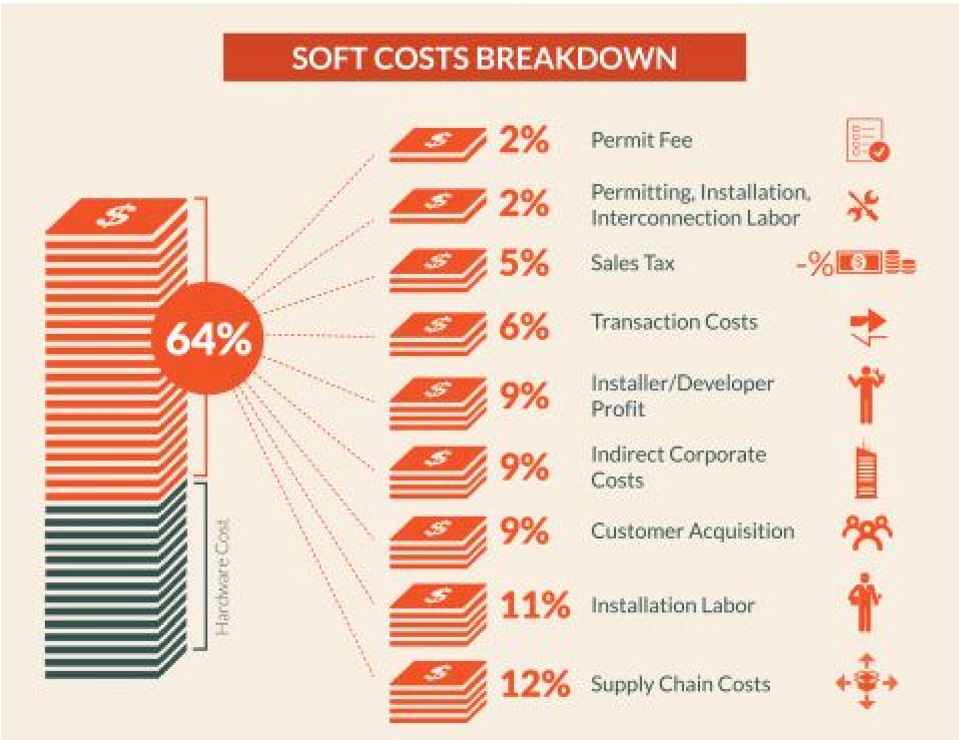
2.8.1.4 Batteries for solar electric systems

Batteries chemically store electrical power in sustainable power source frameworks. They come in a number voltages, yet the most well-known assortments are 6 Volt and 12 Volts. Fixed batteries tend not to keep charge insofar as flow batteries. All maintained flooded lead-acid (FLA) batteries can operate up to ten years, with sealed batteries having a life span of five years. Other factors to remember are that a portion of these batteries weigh more than 200 pounds and, depending on limit, can cost somewhere in the range of $20 to $1200 each. (Cormican, 2015)

2.8.2 Soft costs

The soft or "plug-in" costs of PV accounts for as much as 64% of the total cost of a new solar system (APSystem, 2016). These barriers are often the result of a lack of information needed to make a purchase decision. These information gaps can slow market growth or prevent market access (SunShot, 2015).

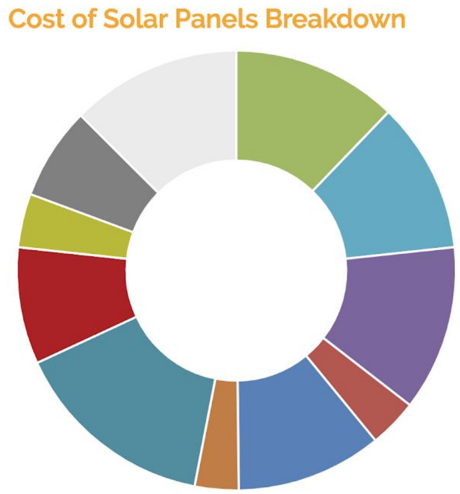
Chart 12. Soft cost breakdown of photovoltaic systems



Source: Sun Shot, 2016

Chart 12 shows the soft costs breakdown of photovoltaic installations in the United States of America. Specific cost breakdowns of solar panel systems for homes vary according to numerous factors, including the size of the installation, the region in which the installation takes place, any government incentives available, the manufacturer and installer chosen, periphery technology like sun tracking, the permit process in a particular community, and many more.

Chart 13. – US Photovoltaic System Cost Benchmark, 2017



Itemized List

Item	Cost per watt	Legend
Profit	$0.34	
Overhead	$0.31	
Customer acquisition (Sales & Marketing)	$0.34	
Permitting, Inspection, Interconnection	$0.10	
Installation labor	$0.30	
Sales tax on equipment	$0.09	
Supply chain cost	$0.42	
Electrical BOS	$0.24	
Structural BOS	$0.11	
Inverter	$0.19	
Module	$0.35	
Total	$2.80	

Data Source: National Renewable Energy Laboratory, U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017 Benchmark

Chart 13 illustrates the cost breakdown of photovoltaic installations in the United States of America in terms of US$ as of 2017. Hardware costs amount to less than 40% of the total costs. Supply chain and client acquisition costs are more significant than the cost of key components such as PV panels or inverters. BoS refers to the balance of system costs, that are hardware equipment outside of the PV system such as transformers, cables and electrical components.

2.9 Electricity Tariff Analysis

The amount of money charged by the power utility for the supply of electrical energy to various types of consumers is known as an electricity tariff. In other words, the tariff is the methods of charging a consumer for consuming electric power (CircuitGlobe, 2017). Electricity tariffs are billed according to the classification of the energy consumer. There are two distinct groups (ANEEL REN Nº 414, 2010):

a. Group A, connected to medium and high tension
b. Group B, connected to low voltage grid

Group A, known as an industrial energy consumer, is charged a fixed sum for the use of the grid called Contracted Demand (Demanda Contratada - em Português), and a variable cost depending on the actual energy consumption measured in kWh per billing cycle. This group consequently pays a lower kWh variable cost as the fixed costs cover some of the distribution charges (ANEEL REN Nº 414, 2010).

On the other hand, Group B is only billed based on its actual kWh energy consumption, not having a fixed cost apart from the disponibility fee that corresponds to a minimum charge of 50, 75 or 100 kWh per month for mono-, bi- or tri-phase connections. Therefore, Group B is charged a much higher unit cost per kWh of energy consumed as it does not cover distribution charges in any other way (ANEEL, 2010).

Since the compensation system of ANEEL only provides kWh credits for the excess power injection, the real market value of these credits is significantly higher in the case of Group B, having a higher kWh price. This also means that in its present form, ANEEL's compensation system for distributed power generation is much more economically viable for the Group B consumers (ibid.).

2.9.1 Cost Structure

There are two main cost components for Group A, industrial energy consumers:

a. Power infrastructure component: Contracted demand, fixed cost
b. Energy component, kWh consumption, variable cost

Meanwhile, there are five components for the Group B, low voltage consumers, typically residential and commercial sectors:

a. Energy component on a kWh basis, around 30% of the bill
b. Distribution fee (TUSD), around 30% of the bill
c. State tax (ICMS), around 30% of the bill

d. Other taxes (federal and local), 5%
e. Public lighting, 5% (Fugimoto, 2010)

2.10 Environmental Impacts

PV energy generation is one of the cleanest sources with low environmental impacts. (UCSUSA, 2015). Unlike thermoelectric generation based on fossil sources, solar PV does not directly emit greenhouse gases. Water consumption is also the lowest among all sources since it does not require significant cooling or vapor generation like thermal or nuclear power sources (IEA, 2017). Even its land use impact can be considered medium as solar PV requires less land than hydroelectric reservoirs and silicon mining has a lower impact compared to coal mines (EWG, 2000).

The monocrystalline silicon (mon-Si) solar based PV cell creation life cycle evaluation demonstrates that the issues, for example, human poisonous quality, marine ecotoxicity and metal exhaustion realize the ecological weight in view of the nearness of silver (Ag) glue, power, and glass utilization. Accordingly, greenhouse gas discharge is created which ranges from 0.42 to 0.91 years and 5.60-12.07 g CO2 eq/kWh individually (Chen et al., 2016).

One of the most significant environmental impact occurs during the reduction process of sand / quartz to the polysilicon ingot. As this process is highly intensive in heat at high temperature the source of such heat is a determining factor of the environmental impact in terms of greenhouse gas emissions. (IEA, 2016)

2.11 Brazilian PV Market Overview

Even with the rapid increase of the number of solar PV projects of various types, the share of solar PV electricity generation in Brazil is still very low, not reaching even 1% in any region (ANEEL,2010). At present, distributed generation of electricity is still showing a negligible impact on the Brazilian energy mix and on business models of power companies.

ANEEL has regulated the electricity compensation mechanism of distributed generation, through Resolution nº482/2012, updated by resolution nº687/2015 in

August 2012, and March 2016 respectively. This new model allows customers to install power generating systems of any renewable power source (solar, wind, hydro or biomass), at installed capacity up to 5 MW. The energy surplus generated and injected into the distribution network benefits consumers through an equivalent discount from their electricity bills. This system is called the "Energy Compensation" giving the right to receive energy credits (kWh) in proportion to the surplus of power injected into the utility network from the distributed generation unit.

In the past year growth has accelerated: in the first half of 2018, the distributed generation sector has installed 38% more new capacity than in the whole of 2017 (Hahn, 2018) . The previous years were already showing rapid growth, but the year 2019 is expected to have even better results.

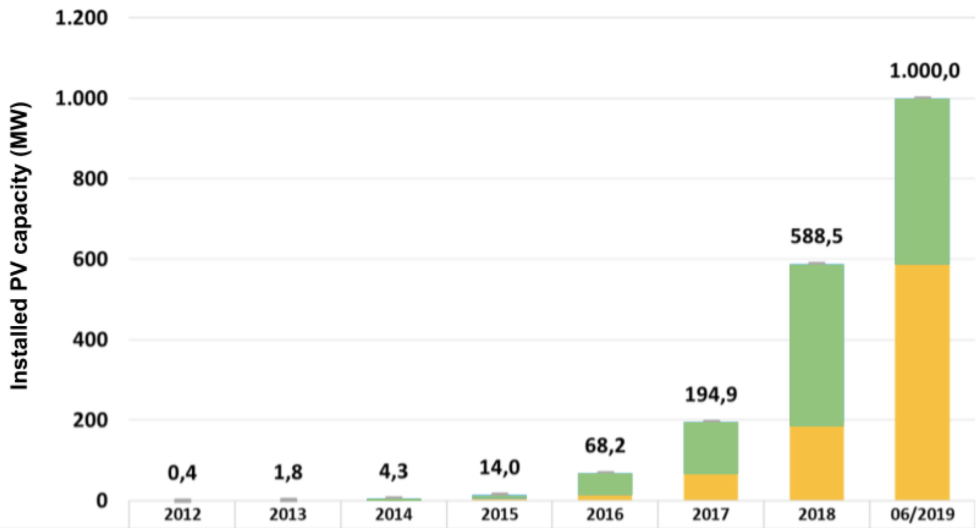
Brazil especially holds potential for advancing its level of solar energy through distributed generation, which generates power on-site at the point of consumption, i.e., in a decentralized way, and has a small but established market in parts of the country. By moving away from large, centralized plants, the country could reduce the costs, complexity, interdependencies, and inefficiencies associated with transportation.

In spite of great natural resources and favourable legislation, the distributed generation sector is still very small part of the Brazilian electricity sector. The evolution of distributed generation in Brazil will be presented, introducing case studies of the PV industry based on their technical characteristics and impacts on the distribution grid. The main technical and economic difficulties faced by distributed generation and its growth also will be discussed. Through this analysis, we can identify and suggest technical and regulatory changes so that distributed generation can achieve higher levels of penetration and can contribute to the diversification of the Brazilian energy matrix.

Although the average price of PV equipments has increased in 2018 due to the increase of the dollar value compared to the Real, the final consumer had a lower price for their solar energy installations, meaning that integrators are willing to secure projects, in order to establish a track record, and gain market share, even at the cost of putting up with lower margins.

According to the Monthly Bulletin on the Monitoring of the Electric System from the Brazilian Ministry of Energy and Mines (MEM), Brazil had 2501 MW of grid-connected solar power (MEM, 2019). This capacity is represented by 2007 MW of large-scale PV projects selected in auctions held by the Brazilian government, and 496 MW of distributed generation solar power generators (up to 5 MW) (MEM, 2019).

Chart 14. - Evolution of installed capacity of distributed PV in Brazil 2012 - 2019



	2012	2013	2014	2015	2016	2017	2018	06/2019
Newly installed capacity (MW)	0,4	1,4	2,5	9,7	54,2	126,7	393,6	411,4
Accumulated capacity (MW)	0,0	0,4	1,8	4,3	14,0	68,2	194,9	588,5
Total installed capacity (MW)	0,4	1,8	4,3	14,0	68,2	194,9	588,5	1.000,0

Utility-scale solar reached a share of just 145 MW, while distributed generation installations totalized 92 MW. (PV Magazine, 2019b) This means that, over the past 12 months, a total of 1.36 GW were connected to the country’s grid, and that growth was stronger than ever in both segments (Bellini, 2019).

In Appendix III a table with all PV power plants above 100 kW are listed, with valid grid connection as of mid 2019. The data is retrieved from the Generation Information Database (BIG) of ANEEL, consulted on the 10th of August 2019.

Table 4 shows the operational PV Plants in Brazil. Brazil had a total of 39 operational PV Plants in 2016. This significant number shows that the PV keeps on increasing and would dominate in the future.

Table 4. - Operational PV plants in Brazil

STATES	Operational Installed PV Capacity		
	Total Number of Photovoltaic Installations	PV Power Capacity in Operation (MW)	(%)
PE	2	10.00	37.10%
CE	1	5.00	18.55%
SC	3	4.00	14.84%
BA	2	2.51	9.30%
MG	3	2.08	7.72%
RN	2	1.11	4.10%
SP	6	1.10	4.08%
MT	1	0.90	3.34%
AM	13	0.17	0.61%
MA	2	0.05	0.19%
RO	1	0.02	0.08%
PR	2	0.02	0.07%
MS	1	0.00	0.01%
BRASIL =	39	26.952	100.00%

Source: ANEEL, 2016

As of 2019, the the Brazilian government through EPE has contracted 2505.6 MW of PV capacity, of which 1935.3 MW is represented by large-scale solar plants, and 564.3 MW by distributed generation PV power generators (up to 5 MW). Most of these will be concentrated in Bahia and Minas Gerais states (Bellini, 2019).

Table 5 shows the number of contracted PV Plants in Brazil, showing that there are 66 plants which were grid contracted by 2016. The number stated above shows the significance of the PV sector in Brazil which has a positive effect because there is an increasing trend.

Table 5. - Contracted PV plants in Brazil

STATES	Contracted PV Capacity		
	Total Number of Photovoltaic Installations	Contracted PV Power Capacity (MW)	(%)
BA	26	724.46	39.02%
MG	11	330.00	17.77%
PI	9	270.00	14.54%
SP	8	240.00	12.93%
PE	3	73.32	3.95%
PB	3	84.00	4.52%
CE	2	60.00	3.23%
GO	2	40.00	2.15%
RN	1	30.00	1.62%
TO	1	5.00	0.27%
BRASIL =	66	1856.777	100.00%

Source ANEEL, 2016.

Table 6 shows the number of auctions which the Brazilian government has offered. There were thirty three projects that contracted by the Brazilian government.

Table 6. - Auction winning PV plants in Brazil

STATES	Auctioned PV Capacity		
	Total Number of Photovoltaic Installations	Auctioned PV in (MW)	(%)
MG	8	240.00	25.64%
BA	6	169.34	18.09%
RN	5	140.00	14.96%
CE	4	120.00	12.82%
PE	4	105.00	11.22%
TO	3	90.00	9.61%
PB	2	66.75	7.13%
SP	1	5.00	0.53%
BRASIL =	33	936.090	100.00%

Source: ANEEL, 2016.

2.11.1 Market Actors

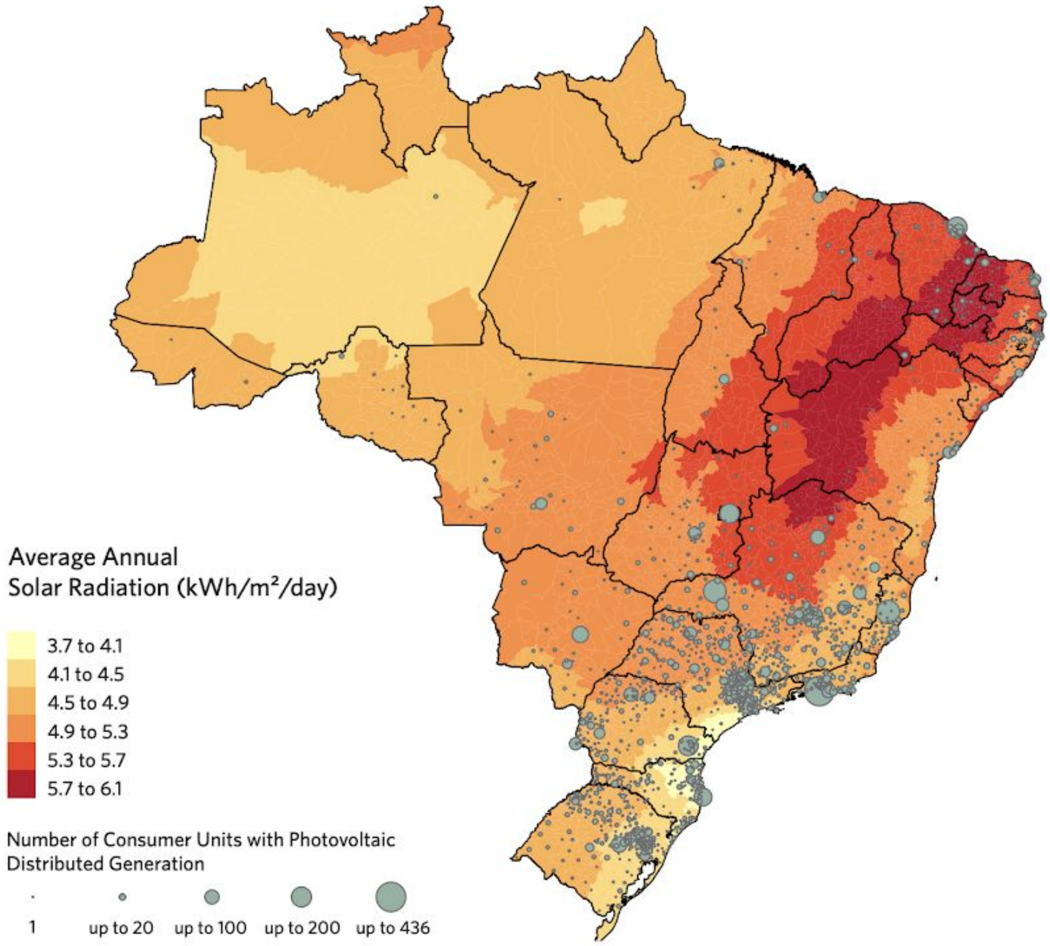
Among the companies acting in the distributed generation segment, the highest number, some 2500 active companies, are the so called PV integrators, their services focusing on small scale rooftop installations (ANEEL, 2016). The majority of these companies were recently founded between 2014 and 2018 and many only have installed a couple of systems so far (ANEEL, 2016). Competition has increased significantly in the integrator segment as the number of companies has tripled in just two years (ANEEL, 2016). As a result of the high competition, only some 10% of the integrators have reached financial break even with an annual revenue above R$1.000.000,00. The large majority of the players only install about one system per month (ANEEL, 2016).

2.11.2 Geographical Differences

The most developed states in terms of number of installations and installed capacity are Minas Gerais and São Paulo, this last one also boosting the highest population density and economic activity among any Brazilian state (ANEEL, 2016). As the Northern and Northeastern regions are less developed, only one quarter of the integrator companies operate there (ANEEL, 2016).

As Map 1 illustrates, the areas with the highest numbers of consumer PV generation units are not actually those with the highest levels of solar resource. On the contrary, the map shows that PV units are mainly concentrated in the Southeast and South. These areas have minor solar potential when compared to the Center and Northeast regions. The data shows that in Brazil, areas with higher levels of sunlight have lower numbers of consumer units with photovoltaic generation (ANEEL, 2017). Factors like Gross Domestic Product (GDP), population size, and electricity tariffs are more accurate predictors of where distributed generation is installed in Brazil. As the south of Brazil is a more economically developed region compared to the north of the country, unfortunately, PV installations are not optimally located to benefit form the highest solar radiation values in the country.

Map 1. – Average Annual Solar Radiation and Consumer Units with Photovoltaic Distributed Generation per Municipality in Brazil



Source: ANEEL, LABREN, CCST and INPE, 2017

2.11.3 Target Group Profiling

Residential and commercial markets are the main contributors to PV installed capacity. By the end of 2016 both contributed with more than 78% of the total installed power in the country in distributed photovoltaic generation (41.99% residential and 36.02% commercial in 2016) (ANEEL, 2017). According to ANEEL data, in April 2018, 78% of the 24247 PV installations in Brazil are residential, followed by commercial installations (16%). (ANEEL, 2018)

New modalities were introduced with the update of REN n°482/2012 in REN n°687/2015, such as remote and shared generation, allowing different entities to organize into a consortium or a cooperative and install a micro- or minigenerator plant to reduce their power bills. These new ANEEL rules also allow residential condominiums to share among residents the power generated by a single power plant, according to percentages the participating consumers define.

In the case of residential consumers (CPF), the legal firm is the cooperative, while in case of commercial consumers (CNPJ) the recommended legal entity to be created is the consortia. In both cases, the leader of the cooperative or consortia has to define the percentages of each member and inform the utility company, so the utility could credit the corresponding values of the energy credits of a shared power plant to each of its members.

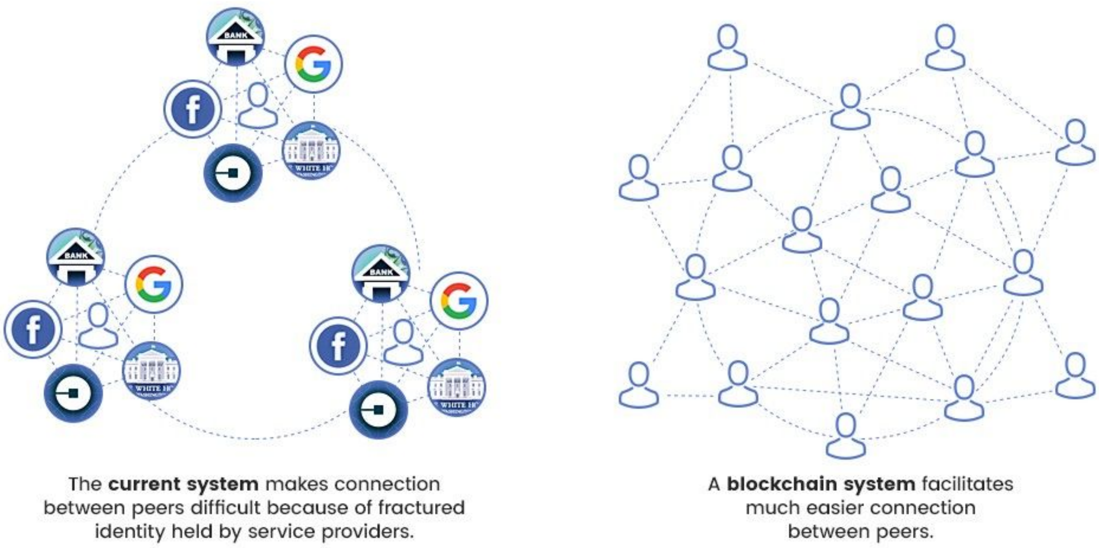
To help the administration of the percentage distribution of energy credits among the members of the consortia or cooperative, the distributed generation startup COSOL[2] with support from SENAI has developed an online marketplace. The digital platform identifies the most adequate percentages within the consortia, based on the historic data of electricity consumption of each member and readjusts the percentage distribution in function of the actual energy consumption of each member.

2.12 Blockchain technology

One of the innovative technologies this work examines is the distributed ledger technology, also referred to as blockchain since the database is organized in a series of blocks. A blockchain is a decentralized system that empowers trade of data and services, such as electricity, between parties without the need of an outsider (think banks or insurance organizations). The blockchain is a reliable advanced record of monetary exchanges that can be modified to record money related exchanges as well as for all intents and purposes that is having worth (Tapscott, 2016). Each exchange or collaboration is straightforwardly recorded and shapes a chain of history that can't be adjusted later on. Trust is therefore moved from concentrated specialist organizations, for example, banks and tech organizations, to the peers themselves, enabling individuals to fabricate their own record keeping. In this way the transaction costs could be eliminated without the need of a verifying outsider.

[2] See Appendix I.

Figure 4. – Comparing traditional and blockchain systems



Source: Lacey, 2016

These smart contracts can be verified by anyone with internet access, ensuring the distribution of trust.

Blockchain is traditionally famous as the public ledger created to track the cryptocurrency Bitcoin. It records and connects every transaction made across the network with a timestamp, turning Bitcoin more secure and keeping the authentication process decentralized. Blockchain technology has enabled cryptocurrencies such as Bitcoin and those transactions applying such technology are secured (Lacey, 2016).

The idea of blockchain is not constrained just to Bitcoin. Blockchains can be utilized to follow the stream of electrons on an appropriated grid. Transactions in the blockchain are recorded and anything which requires any advanced connection which it is intended to be verified, straightforward, exceedingly impervious to blackouts, capable of being verified and more productive. However, the application of blockchain increases the likelihood of rendering a whole sector of intermediaries obsolete, for example, money related administrators, changing business practices, for example, company evaluation and bookkeeping, and empowering new forms of transaction (Lacey, 2016).

2.12.1 The Benefits of Blockchain Technology

The following are the main features of blockchain technology:

a. It is reliable and available

The blockchain innovation has no single possibility of error due to its expansive member network share a single ledger and, it is intended to be flexible even with system breakdown or hacking. The system's nodes are particular and separate from one another in this manner, an error of one node won't turn the remaining nodes worthless. Different nodes unaffected will continue to function, guaranteeing the data's accessibility and trustworthiness.

b. Straightforward

Members of the blockchain can see the exchanges and thus there is an expansion in the trust and certainty of each member.

c. Permanent

Exchanges in the blockchain are irreversible. Making changes in the blockchain is unattainable as it has no location, thus there is an expansion of trust in the data it conveys and consequently, misrepresentation is additionally decreased.

d. Advanced

The use of blockchain innovation, still in its infancy, would imply that energy resources and consumers could automatically transact, machine to machine, and their transaction records be kept independent and decentralized.

These key ideas and qualities of blockchain innovation offer chances to disintermediating outsiders from the exchange process, which provides lower exchange costs, and expands the likelihood of improvement in each industry segment (Andoni et al, 2019).

2.12.2 Marketplace for Renewable Energy on a Blockchain Network

Blockchain is a cryptographically secured database of exchanges which also supports the bitcoin currency. No central authority is in charge and each individual can screen every other exchange so as to avoid extortion. The rundown of exchanges are recorded on each PC in the network and it is ceaselessly refreshed as the exchange is being concluded. Such an exchange database is fabricated utilizing a blockchain program called

Ethereum which manages purchasing and selling electrons produced by PV systems (Lacey, 2016).

In the following sub chapters we will introduce the leading projects applying blockchain technology to electricity distribution accounting.

2.12.3 TransActive Grid by LO3

Ethereum blockchain is supporting the TransActive Grid. It is utilized to record every individuals' segment of solar PV based power generation in a network. Blockchain utilizes smart contracts, creating an understanding between members, who participate on TransActive Grid. Blockchain is overall a record keeping system that all individuals from the network can trust to consult whenever needed. The unused power credits can be exchanged into blockchain tokens by these specific smart contracts where the network members can buy and sell the tokens. This is the first project in the blockchain space of a new kind of energy market which is managed by consumers. It could create a novel approach how we generate and consume electricity (LO3, 2016).

Currently, for managing electricity, there is a need to work with a central power utility organization like COELBA in Bahia or Light in Rio de Janeiro. With the utilization of blockchain innovation, energy transactions can be settled peer to peer between consumers and producers. Transactive Grid can avoid the central authority on the grounds that its power exchange is based on decentralized yet dependable technology. Transactive Grid plans to empower individuals to purchase and offer a sustainable power source to their neighbors. (Rutkin, 2016)

2.12.4 Grid Singularity

Grid Singularity develops a web based, decentralized power information and trading platform that is based on blockchain technology. A group of experienced power experts founded the organization joining forces with the blockchain innovation designers from Ethcore. Ethereum is developed by Ethcore. Grid Singularity assumes a major challenge in the field of electricity business, serving the interest of various actors from authorities to administrators, speculators, dealers and end consumers. The digital solution would anticipate tasks related to network management, help capital allocation in new assets, would trace the source of electricity and even help with the commercialization of green bonds. (Grid Singularity website, 2017)

The continuous tracing of important energy information from any power source (generation facility) on the blockchain diminishes the hazard of data loss or security breach and ensures that the information can never be altered. While the decentralized nature of the system guarantees that the information is solely accessible by the power asset holder. Authorities of the electricity sector could make sure that the saved information is approved and could provide mediation in case of a dispute. The digital solution is outstanding in its capacity to be utilized at much lower costs to manage the infrastructure as opposed to standard grid management systems that require a completely unique agreement for every power transaction. As an additional benefit, the information is highly secure as it is always recorded directly by the source of power generation. This blockchain-based system allows for easier entry to electricity markets as it does not require the participant to have a complex authorisation process with a third party approval mechanism. The cost advantage and the multifaceted nature of the platform makes it increasingly productive and successful. Therefore it will draw in more individuals and would modernize the power market to be more open and democratic (Breteau, 2018).

2.12.5 Bankymoon

Bankymoon assembled the first ever blockchain smart metering system in South Africa for a novel power network. Smart meters applied by Bankymoon have their unique bitcoin addresses. As a Bankymoon Internet of Things (IoT) meter receives a bitcoin transfer, it automatically computes the value of energy and charges the energy meter accordingly. The incorporation of bitcoin transactions into Bankymoon's IoT metering process enables clients to send power credits to anyone from any place, by charging their IoT electricity meters. With this development, Bankymoon's settles power transactions without needing banks and payment cards that many people do not have, and by applying the IoT approach, third parties need not be involved (Prisco, 2015).

2.13 Solar Drone Mapping

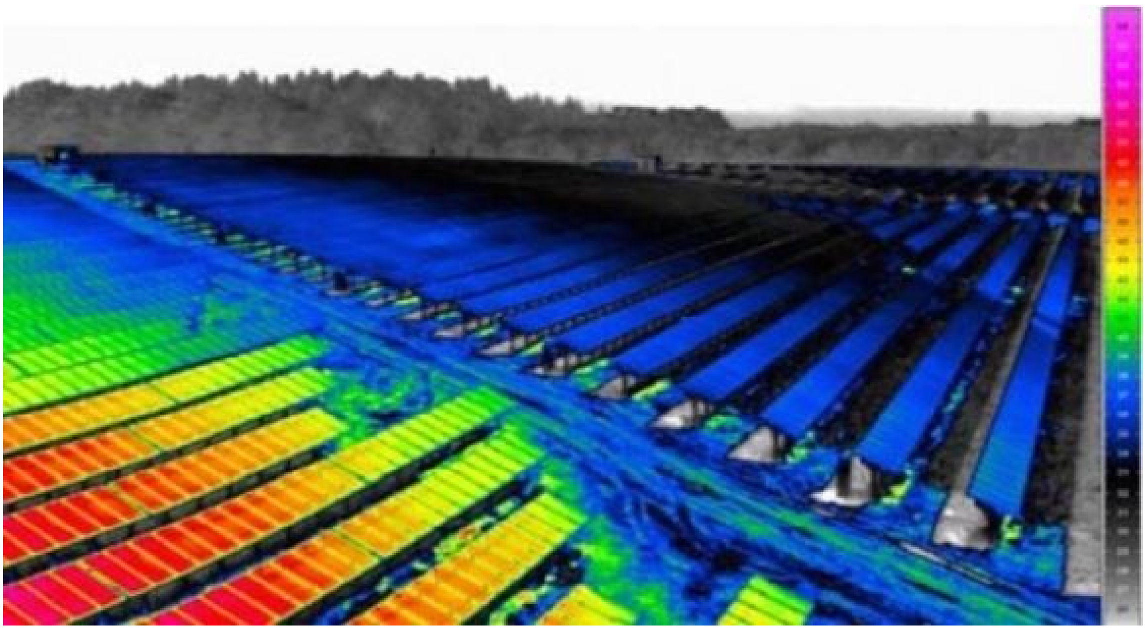
Drones are unmanned aerial vehicles that could someday serve multi-megawatt solar farms. They could do plant monitoring much more cheaply than people in trucks or helicopters. Drones could theoretically support an entirely new, data-driven approach to preventative maintenance and enhanced operations on PV plants.

The following are the benefits of drone monitoring:

1. It limits the safety hazard. The utilization of drones is simple and protective as it negates the requirement for laborers to be physically present in antagonistic situations. It gives the client of the drone an effective way to get to the hard to reach places.
2. Accumulation of top-to-bottom, higher detailed information. Drones have the capacity to maintain a strategic distance from dangers or risk and can catch high detail information. Automatons have a high-resolution cameras to catch all relevant details.
3. Quick Deployment or Launch. Drones are quick and fit for finishing the examination in 5-20 minutes (UASVision, 2018).

Conventional preventative maintenance approaches, which entail periodic inspections to proactively prevent major breakdowns, tend to be both tedious and costly, making frequent and comprehensive inspections of large systems infeasible (EPRI report, 2015).

Figure 5. – Drone recorded heat map of a PV park helps detect failures



Source: Droneland, 2016

Drone technology can reduce utility-scale PV plant measurement times from days to minutes (Vadhavkar, 2018). In addition, on-board thermal imagery can help to ensure that equipment is in the optimal position for maximum production (Pyper, 2016). Drones could assess how much dust has collected on any particular panel, or identify areas where fast-growing trees and grasses have begun to cast shade over certain strings. They could also investigate a problem the control room has found, but can not explain.

DroneDeploy[3], a cloud software platform provider for commercial drones, and DJI[4], a leading maker of drones and camera technology, announced a partnership that is expected to dramatically increase the efficiency of solar panel installation and inspection using drone-based thermal imagery capture and analytics (DroneDeploy, 2019). Solar installers can automatically fly the drone and collect data that is sent to DroneDeploy's cloud-based infrastructure.

Drone technology reduces the amount of time workers spend on site, reduces the potential for measurement errors, and simplifies the maintenance of existing systems - all of which should help drive down the maintenance cost for utility solar. Infrared cameras mounted on drones can help detect malfunctions in solar panels and enable faster repairs. Currently, utility PV workers conduct inspections by walking through a solar farm. The faster flaws can be found and repaired, the more renewable electrons will be produced (Pyper, 2016).

2.14 Community Solar

As the solar energy market rapidly expands, more people are exploring the possibility of going solar. While not everyone is able to install panels on their roofs due to unsuitable roof space, living in a large condo building, or renting a living space, alternative business models like community solar and shared solar are gaining popularity and increasing access to clean solar energy (DOE, 2016).

Community solar business models increase deployment of solar technology in communities, making it possible for people to invest in solar together. Shared solar falls under the community solar umbrella, allowing multiple participants to benefit directly from

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[3] https://www.dronedeploy.com/

[4] https://www.dji.com/

the energy produced by one solar array. Shared solar participants typically benefit by owning or leasing a portion of a system, or by purchasing kilowatt-hour blocks of renewable energy generation (SunShot, 2016).

Figure 6. – Distributed generation models by type

Source: Office of the Energy Efficiency and Renewable Energy[5]

Figure 6. shows the distributed generation model by type. The upper left drawing shows that the rooftop PV installation was collectively contracted by a neighbourhood and distributed to the households. The upper right image presents the offsite shared solar model, where a remote mini solar power plant built on the ground supplies energy to the households via transmission grid. The lower right image illustrates the community driven financial model, a.k.a PV crowdfunding, where a group of outside investments or donations are collected to finance the PV plant. It implies that PV can be adopted to different scenarios.

The National Renewable Energy Laboratory (NREL) finds that 49% of US households and 48% of businesses are unable to host PV solar systems because they rent their spaces or have a lack of suitable owned roof space (NREL, 2016). For this customer

[5] https://www.energy.gov/eere/solar/community-and-shared-solar

base, shared solar opportunities give them the chance to purchase solar energy (Meehan, 2016). By the year 2020, shared solar could account for up to half of the overall distributed solar market in the United States (NREL, 2016).

Community solar is typically sized between 0.5 and 5 megawatts (MW) of installed capacity and can inject electricity directly into local distribution networks, offering communities and utilities the benefits of renewable power generation sited near the load. (Ptak et al, 2018). It is very cost-effective as it provides the benefits of the economies of scale compared to residential solar, and avoids the need of costly transmission incurred by utility-scale solar (Coleman, 2017).

2.14.1 Benefits

By conglomerating client requests, shared PV projects can decrease the monetary and technical boundaries in adopting solar. Rather than acting alone to acquire PV panels and contracting experts to finish individual site assessments, shared solar powered projects divide the expenses among the individuals who take part. This additionally makes it simpler for members to purchase a model that effectively works best for their financial plans. Investments are even safe for the individuals who can't remain in one spot for a long period of time. On the occasion a client moves its home or office, its PV asset can be transferred to another home inside a similar power utility administration domain, or sold to another person.

Utilities also enjoy the benefits of community solar projects. They can guarantee that PV clusters are deliberately sited for most enhanced power benefits. It also makes the process easier; having larger, shared arrays connected to the grid allows utilities to operate in a more streamlined manner compared to maintaining many smaller, diffuse solar systems (DOE, 2016).

Community solar plants can viably lower expenses of up to 50% of distributed solar market rates, even approaching utility-scale prices in some areas, as above 5 MW, the economies of scale effect diminishes (Rogers, 2018). Such low rates are made possible by the economies of scale, choosing optimal sites that enjoy higher radiation, and by employing tracker devices. These results in a lower-cost, progressively adaptable, and economically viable approach to adapt solar PV. This model is especially useful in markets where housing is located in vertical model of high rise cities, rather than the horizontal deployment of low rise buildings where rooftops are more accessible and shading is less of an obstacle.

2.14.2 Challenges

The Securities and Exchange Commission of Brazil (CVM; in Portuguese: Comissão de Valores Mobiliários) requires the registration and disclosure of shared solar projects, which could create a serious challenge. If a shared solar program is classified by the CVM as financial investment, meaning the application of capital with the objective of capital gain or interest, it could significantly impact how the program operates and subject it to more government scrutiny, potentially affecting the financial benefits of participating. The issues regarding the solar program depends on the marketing, as shared solar offerings that are marketed and structured as reducing customers' electricity bills are less likely to be treated as financial investment than those marketed as profit-generating programs (NREL, 2016).

2.14.3 Financing Community-scale Solar

The Rocky Mountain Institute published an insightful brief about financing community scale solar (CSS) written by Coleman et al. (2017) that not only lists all the benefits of the CSS model, but also sheds light on the various financing structures critical to turn CSS economically feasible in developing markets. The following is a brief summary:

Unlike residential solar, if customers default on payments, the plant owner can easily substitute the effected contract to a new consumer instead of having to remove PV panels from the rooftop of the defaulting customer. By creating waiting lists and rules for such mechanisms to easily transfer customer obligations mitigates the credit risk of the PV plant as well as any individual customer. This model also allows energy consumers that lack the credit rating to enter into conventional financing models – frequently the case in developing nations – to take advantage of solar energy generation. Additionally, this model addresses the desire in some communities for local or shared ownership and helps capitalize smaller projects that may not otherwise attract third-party financing. A possible drawback is that it can be accessed only by those community members with sufficient means to make the upfront investment and utilize the tax attributes of clean-energy investments (Coleman, et al., 2017). As a result, efficiently financing and developing CSS projects can help pick up the slack and accelerate solar market growth. But the huge market opportunity created by CSS will not be realized without listening to the "community" in whatever form it takes (Coleman, et al., 2017).

2.15 Venture Capital Funding For Cleantech

Funding for cleantech[6] innovation is essential to enable the ongoing development of new materials, emerging technologies and business models required to turn renewable energy sources a cost effective, efficient and economically viable option for humanity. Therefore, it is important to understand the factors influencing investment decision makers, their concerns about risks, expected returns, and how to create incentive mechanisms that increase such fundings. Naturally, investors fund sectors where they can expect high profits with lower risk, so comparing cleantech to competing sectors such as software or biomedical innovation can help us better understand the behaviour and decision making process of investors (Gaddy, et al, 2016).

According to Gaddy et al, venture capitalists experienced considerable losses in the cleantech sector and consequently developed a preference for sectors with higher returns and lower risk. Their paper entitled *Venture Capital and Cleantech: The wrong model for energy innovation* analyses hundreds of cleantech investments to calculate the risk and return profile, and to compare the results with those of medical and software technology investments. Poor performance of cleantech portfolios are due to long development time for materials and chemicals. The paper concludes that among cleantech ventures, "profound innovation" speculations — in organizations producing new equipment, materials, sciences, or assembling processes — required the most capital and yielded the least returns. On the other hand, investments in cleantech software has returned capital to early investors. Gaddy et al's data indicates that venture capital investors responded to the performance of their cleantech investments by lowering the capital allocated to the sector, and by shifting investments from hardware and materials to cleantech software.

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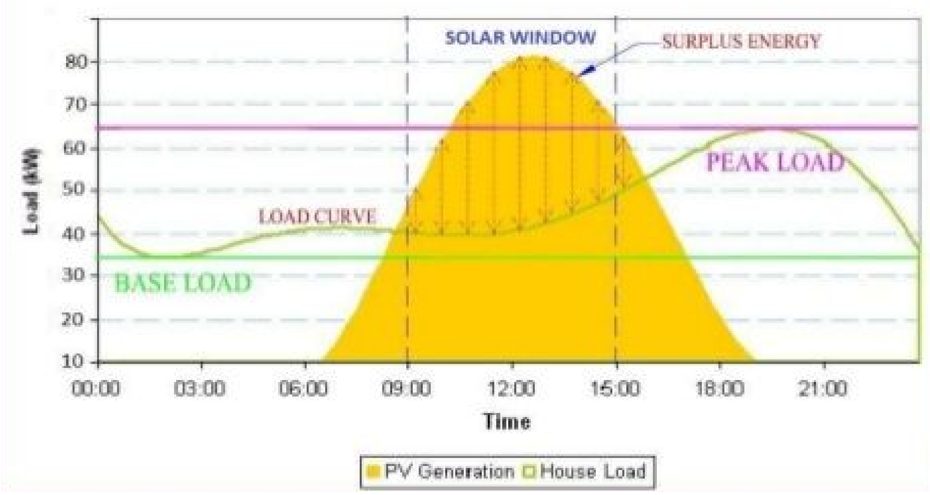
[6]Cleantech is term generally used to define a set of technologies that either reduces or optimises the use of natural resources, whilst at the same time reducing the negative effect that technology has on the planet and its ecosystems. (https://www.azocleantech.com/article.aspx?ArticleID=532)

5.16 Load curve and storage

Photovoltaic generation correlates with solar radiation peaking around noon that has to be matched to the consumption load curve peaking the evening hours from 18:00 to 21:00 o´clock. As figure 7 illustrates PV generates surplus energy in the peak solar radiation hours that must be stored for 4 to 7 hours so it can supply energy at peak consumption hours.

Figure 7 – Photovoltaic load curve vs consumption load curve



Plug in electric vehicles, pumped hydro storage or redox flow batteries could in the future offer the most cost effective storage mechanism to match PV generation load to consumption load. The widespread inclusion of PV generation to the energy mix will also enable low cost air conditioning in the hot Brazilian climate. On a longer horizon hydrogen production from water electrolysis could also be an economically feasible option to store the midday surplus energy generated by PV installations. Hydrogen than could fuel vehicles equipped with hydrogen fuel cells or grid level fuel cells generating electricity at peak electricity demand as batteries.

Electricity storage currently requires high upfront investments however given the vast Brazilian hydroelectric generation infrastructure this cost could be mitigated by applying pumped hydro technology. On the other hand the rapid evolution of plug in electric vehicles significantly lower battery costs that, given well designed incentives, could also offer low cost PV peak shifting by charging them around noon and injecting power in the evening hours.

3 METHODOLOGY

This work is aimed at optimizing the economic efficiency of solar photovoltaic power generation with the objective of reaching grid parity with traditional energy sources like hydropower or thermoelectric generation. The main factors influencing the economic efficiency of a PV installation will be analyzed. First, the effects of economies of scale will be considered. The per-Watt installed capacity cost of larger plants are lower due to a more efficient supply chain, reduced engineering costs, more efficient logistics, automated deployment, and more cost effective use of centralized components. Second, solar radiation values of different locations will be examined and how it could affect the levelized cost of power generation. The increase in energy production of the same PV System is the result of a location boosting higher solar radiation, therefore reducing the cost of the energy produced. Third, the various mature PV technologies, such as mono-, polycrystalline and thin-film panels, and the effects of the PV tracking device will be compared. Our hypothesis is that at the higher temperatures characteristic of Northeastern Brazil, thin-film panels could perform significantly better. Also, the use of solar trackers would significantly increase energy production. The use of such technologies that could impact the overall levelized cost of energy will be determined. The modeling and simulation tools that facilitate energy yield calculations in different locations and apply different technology and installation sizes will be evaluated. The principal financial indicators of a PV project and energy price trends will be examined. The benefit of various market segments from solar energy and what the necessary size of an area is to increase PV generation to be a significant factor in the energy mix will be determined. The local conditions in European and Latin-American PV markets resulting from different city structures will be compared. The environmental impact of PV generation will be investigated. Finally, the best model for implementing solar PV with the best economics and lowest environmental impacts considering local conditions too will be proposed.

3.1 Economic research methodology

3.1.1 Economies of scale

In order to determine the ideal size of a PV installation, a multi criteria analysis is applied. Three scenarios are considered: residential (2 to 5 kWp), commercial and industrial (50 to 500 kWp) and utility-scale (above 1 MW) PV installation. Each scenario has to be evaluated by the following criteria:

a. Levelized cost of energy (LCOE)
b. Operation and maintenance
c. Land requirement and impact
d. Impact on the transmission network
e. Self consumption vs grid injection
f. Module costs
g. Balance of system costs
h. Engineering, procurement and construction costs (EPC)

3.1.2 Financial Evaluation Methods

From the investor's point of view there are indicators that determine whether to engage in a generation technology or not. This section shows the different calculation methods that are used and demonstrates their use:

Profit Margin (%)

Net Income Total Revenue × 100

EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization) margin (%)

EBIT (Earnings Before Interest and Taxes) *Total Revenue* × 100

Net Present Value (NPV)

∑ *Ct* (1 + *r*) *t* − *C*0 *t t*−1 Where: *Ct*= net cash inflow during the period *C*0= initial investment r = discount rate t = number of time periods.

Free Cash Flow

Operating Cash Flow − Capital Expenditures

Discounted Cash Flow

DCF = *CF*1 (1 + *r*) 1 + *CF*2 (1 + *r*) 2 + ⋯ + *CFn* (1 + *r*) *n* Where: CF = cash flow for the period r = discount rate (Chen, 2014)

Return on Investment (ROI)

Cumulative Cash Flow − Initial Investment Initial Investment × 100

Internal Rate of Return (IRR)

[∑ *Ct* (1 + *IRR*) *t* − *C*0 *t t*−1] = 0

The rate at which NPV is zero, where: *Ct*= net cash inflow during the period *C*0= initial investment IRR = internal rate of return t = number of time periods

Debt-service coverage ratio (DSCR)

Net Operating Income Total Debt Service

Cash flow from operations

EBIT + *Depreciation − Tax Payments*

Real Interest Rate (%)

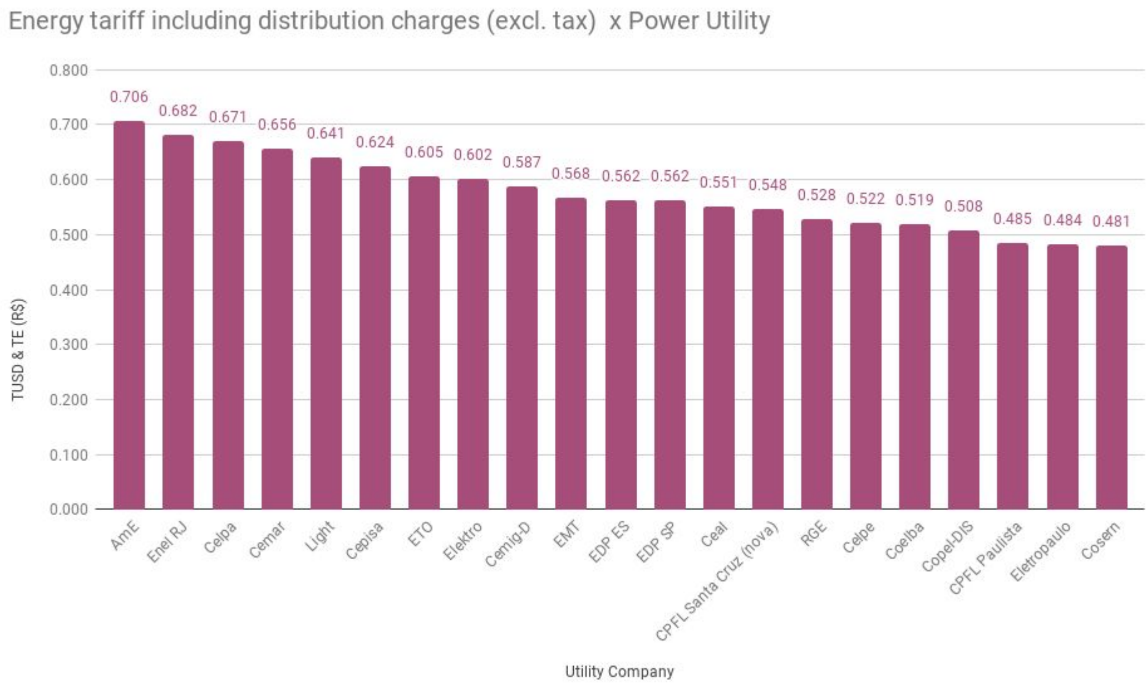
Nominal Interest rate − Inflation rate

(Investopedia, Financial dictionary 2014)

3.1.3 Energy price trends

Analysing past energy price cost evolution and comparing it to inflation rates could indicate a market trend in the Brazilian energy sector (EPE, 2017). The tariff trends in our return of investment model for the sake of financial modeling will be extrapolated. As Chart 16 illustrates, during the past 20 years, energy tariffs have increased significantly more than the average inflation rate. Unless energy demand was rising more slowly than energy supply in Brazil, this trend would hardly change, meaning ever increasing returns to investors. The different factors that could contribute to this trend will be examined.

Chart 15. - Price of electricity excl. tax. for low voltage consumers (B3) of major Brazilian power utilities



Data source: ANEEL, 2019

3.1.4 Market analysis

The Brazilian electricity market is divided into various segments, based on the size of the consumption and nature of the consumer (World Energy Resources, 2016). The two main groups to differentiate are the so called low tension (Group B) and high tension (Group A) markets (ANEEL, 2013). The basic difference between these two segments is how energy is billed (ANEEL, 2013). While the low tension segment is charged on a kWh consumption basis, the high tension A group is billed a fixed sum called contracted demand and a variable fee based on the actual kWh consumption (McCrea, 2017). The compensation system of ANEEL only offers energy credits for the kWh consumed, leaving the fixed cost of the contracted demand of the Group A uneffected. Therefore the high tension segment has a much lower economic incentive to join a compensation scheme.

As demonstrated in Chart 16, from 1995 to 2012, the tariff expanded in linear terms, and considerably increased around 2005, when there was a modified regulation (D'Araujo, 2018).

The decrease in state hydroelectric power plants under a market that had been diminished by roughly 15% has become the motivator. Clearly, in a somewhat "blocked" way, a motivator has been embedded to the movement to the free market. The growth of the free market is illustrated by the fact that in 2002 there were less than twelve consumers on the free market. In 2008, this number increased to more than 700 (D'Araujo, 2018).

Today, around half of Brazilian industry and part of the commercial sector are in the free market. As CCEE[7] (Electric Energy Trading Chamber) does not reveal normal costs, we can say that, today, Brazil does not know the tariff strategy for the free market. ILUMINA[8] (Institute of Strategic Development of the Electricity Sector) comprehends the idea of the exercises of free customers, yet attracts regard for the way that at least straightforwardness would be the revelation of normal costs by division (D'Araujo, 2018).

There is no uncertainty that the model embraced since 1995 did not convey the guaranteed price decrease. Exactly the opposite, there is a constant increase of energy costs. In fact, the guarantee of tariff decrease was unfeasible (D'Araujo, 2018).

A frequent misconception in the general public is that PV technology has such a low conversion efficiency that vast land areas would be necessary if we wanted to supply any considerable part of our energy needs from solar (Dias et al, 2019). Solar PV is orders of magnitude more efficient than biofuels in terms of converting sunlight to useful energy, especially considering the efficiency differences of internal combustion engines (20%) and electric motors (95%), as shown in Section 2.3 of the technology review (Holmberg, 2019).

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[7] https://www.ccee.org.br
[8] http://www.ilumina.org.br

Chart 16. - Residential and Industrial energy tariff evolution 1995 - 2012.

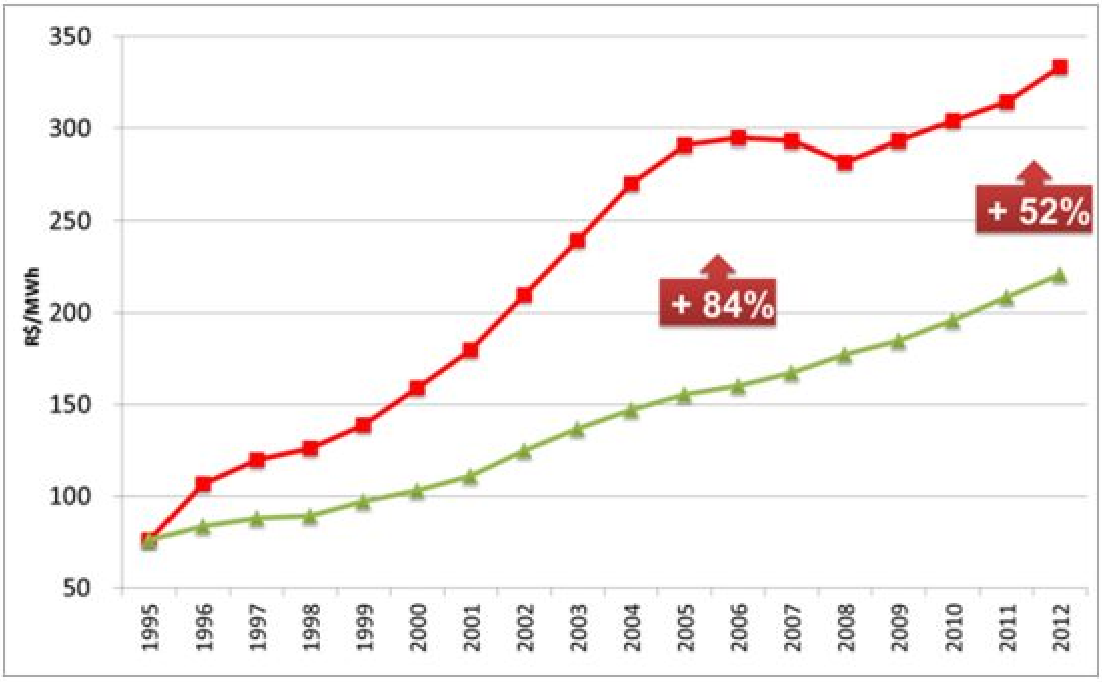
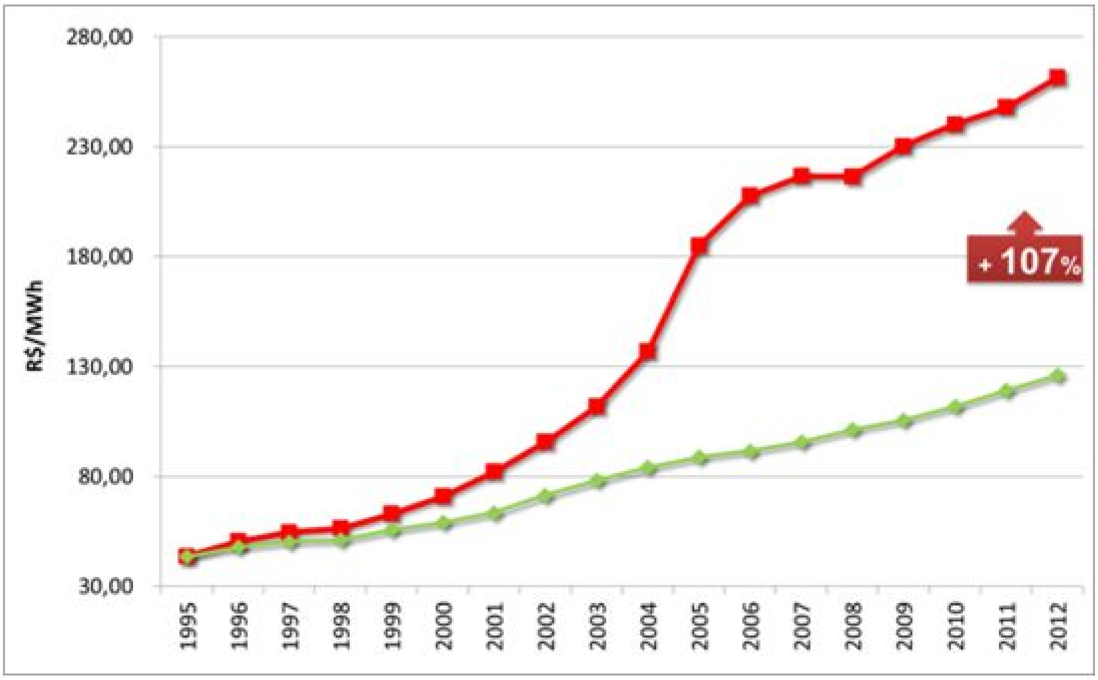


Gráfico 30 – Evolução da tarifa residencial 1995 – 2012



Source: ILUMINA ORG, 2013

In order to determine the land area needed to power all of Brazil's electric energy needs with exclusively solar PV, we must first determine how much land is needed to construct 1 MW of PV capacity. Secondly, there is a need to compute (considering average radiation values and the use of current PV technology and trackers) how much useful electric power 1 MW of installed PV capacity could generate. Third, the total electric energy consumption of Brazil must be considered. Then, the total electricity consumption by the figure that 1 MW of PV capacity would generate must be divided, so the result will tell us how many MW of PV capacity would be needed to be installed. Once we know the capacity needed, we can multiply that figure by the land area needed per MW of installed PV capacity. A 10.000 km^2 area in Bahia state would be sufficient to supply all the electricity Brazil consumed in 2015 based on the preliminary calculations in our hypothesis.

In a second land area calculation, other types of energy consumption, such as liquid fuels for vehicles should be considered. In this case, first a conversion would be necessary between the liquid fuels energy content (Joule) to electric power (Watts). Once the energy equivalent is calculated, we could easily adapt the above method to estimate the land area needed to power all vehicles, considering the expected electrification of transport.

3.1.5 Business model innovation

Distributed generation rules enable new business models, especially in the shared and remote self consumption model. There are measurable economic benefits of this new business model and this work will analyse these advantages in terms of lower levelized cost of electricity due to the economies of scale of mid size 5 MW plants, the cost benefits of lower need of transmission as the generators and consumers are closer, or the reduced cost of intermediaries such as competing digital marketplaces able to operate at a higher economic efficiency compared to monopolistic, centralized power accounting systems such as traditional utility companies.

3.2. Photovoltaic research methodology

3.2.1 Location Analysis

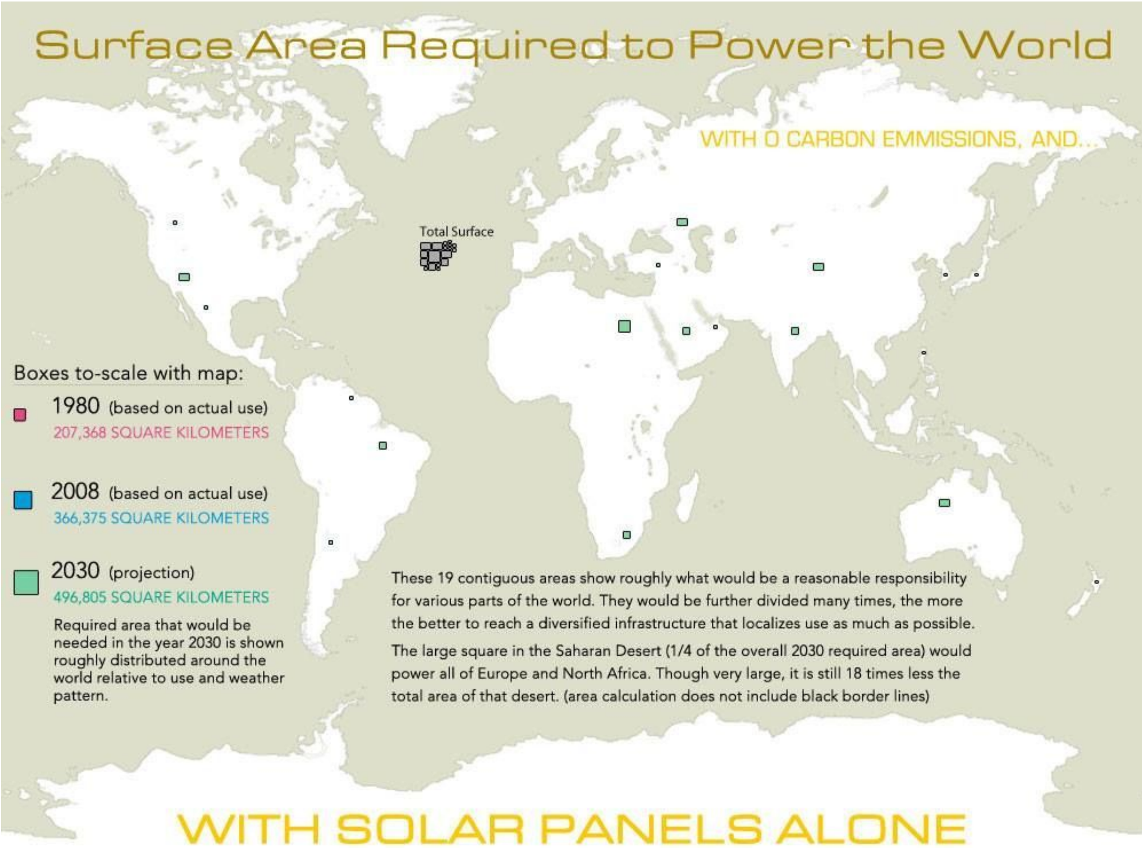
Finding an ideal geographic location for a PV plant has to consider the following items:

a. Global horizontal solar radiation values
b. Land costs
c. Topography
d. Electricity grid infrastructure, eg. ease of access to a substation with sufficient capacity
e. Access to a water resource for operation and maintenance
f. Road access for supply logistics

3.2.2 Solar Radiation Maps

As a foundation of the implementation of PV technology, we need to investigate various mapping tools. In order to maximise energy output and minimise the LCOE we need to determine locations with the best possible solar resource. For PV, we need to consider the global horizontal irradiation (GHI) values. There are existing GHI maps developed using radiation data taken from satellite observation (Sengupta et al, 2018). One of the best known such satellite based solar resource map is offered by the company SolarGIS (Sengupta et al, 2018). The first global solar maps used satellite measurements based on reflection, such as the SWERA program of National Laboratory of Renewable Energy (NREL/US) (Sengupta et al, 2018). Such maps offer a great overview of our planet's solar resource differences, highlighting the areas receiving the best solar radiation, such as the Sahara (2500 kWh/m^2), the Gobi desert (2600 kWh/m^2), north-west Australia (2800 kWh/m^2) and the Atacama (3000 kWh/m^2) (Martins et al, 2007). From the satellite map, the locations receiving the most GHI values in Brazil are the semi arid Northeastern regions, most notably western Paraíba (2180 kWh/m^2) and the São Francisco river basin in Bahia state (2150 kWh/m^2) (Martins et al, 2007). The regions offering the lowest radiation are around the Paraná capital Curitiba and Santa Catarina states Florianópolis (SolarGis, Map 2, 2015).

Map 2. – Surface area required to power the World by PV plants

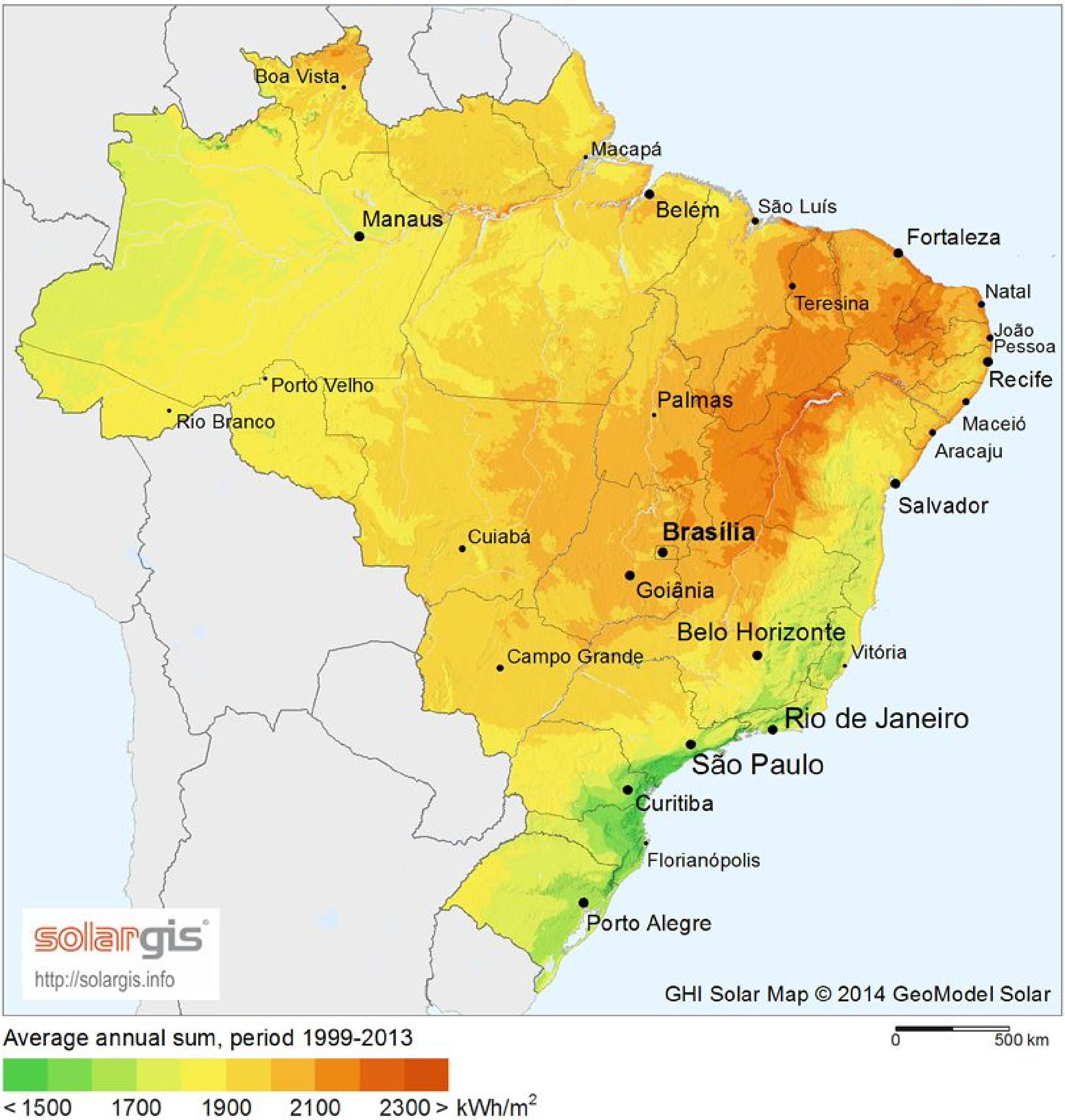


Source: Landartgenerator.org

Map 2. Shows the surface area covered by PV panels to generate the equivalent amount of the world consumption of energy in all of its forms like barrels of petroleum, cubic meters of natural gas, watts of hydro power, etc. It is projected to reach 678 quadrillion Btu (or 715 exajoules) by 2030 – a 44% increase over 2008 levels (levels for 1980 were 283 quadrillion Btu and we stand at around 500 quadrillion Btu today). (SolarGis, 2015).

Although satellite radiation maps offer a good general guideline, they are not entirely reliable and do not offer highly precise solar radiation data (Caballero, 2017). For a more sophisticated methodology on radiation analysis, we must research terrestrial measurement data with at least ten years of data collection, so the yearly variations could also be taken into account. The National Meteorology Institute of Brazil (INMET) has some 300 meteorological stations measuring solar radiations (INMET, 2017). For our methodology to be more accurate, data from two meteorological stations in each Brazilian State and comparison to the data to the satellite maps of SolarGIS must be considered.

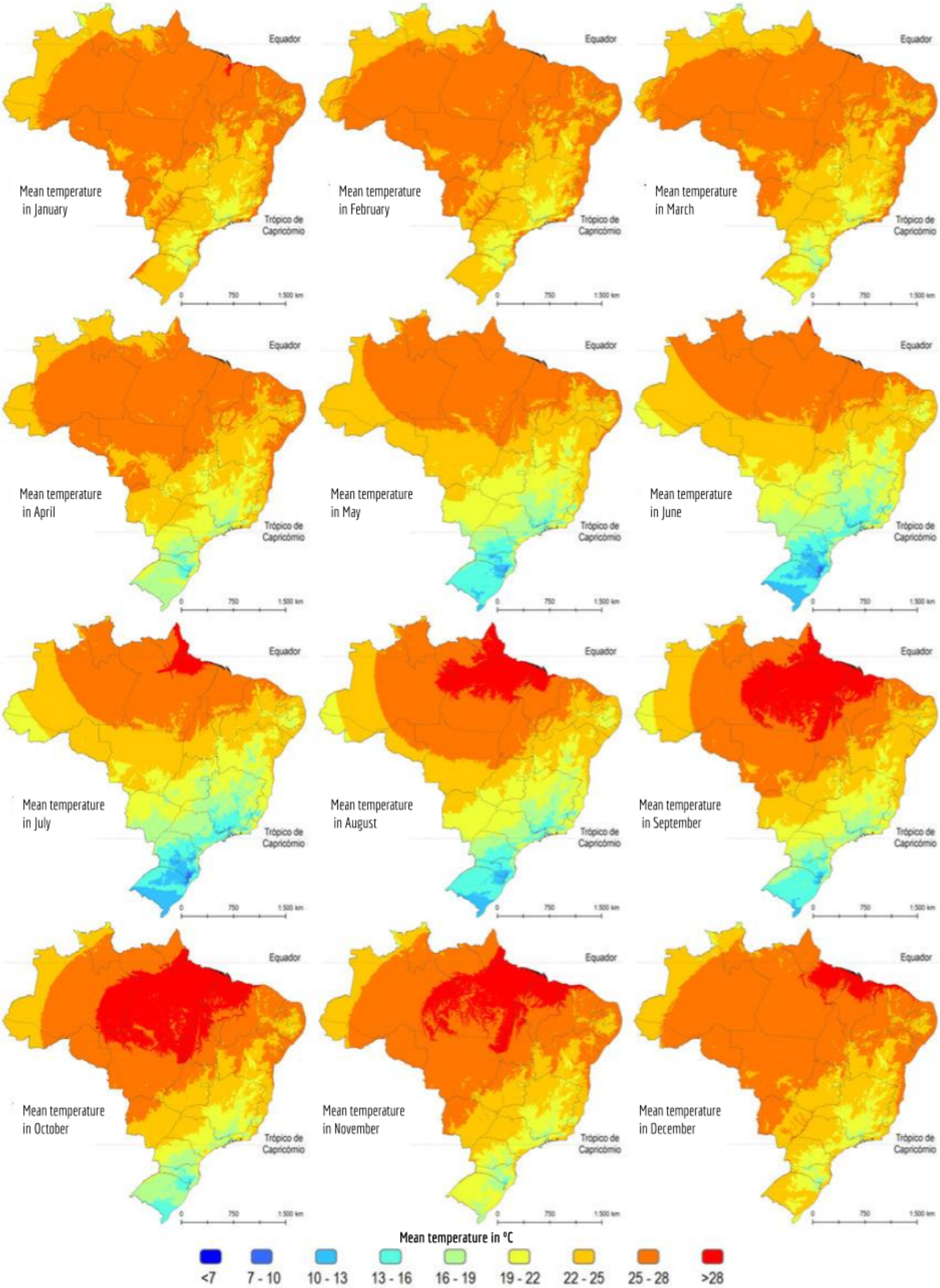
Map 3. – Brazilian map of global horizontal radiation (GHI)



Source: SolarGis, 2014

Map 3. Shows the Brazilian map of global horizontal solar radiation (GHI). This map provides average annual period of daily total photovoltaic solar resource averaged over 1500 to 2300 kWh/m^2. The locations enjoying the highest radiation values are in the semi-arid region of the north-east of Brazil (dark orange region). The areas with the lowest radion values are the coastal regions of the southernmost States, as a result of high equatorial distance and intense cloud cover formed by ocean evaporation. (SolarGis, 2014).

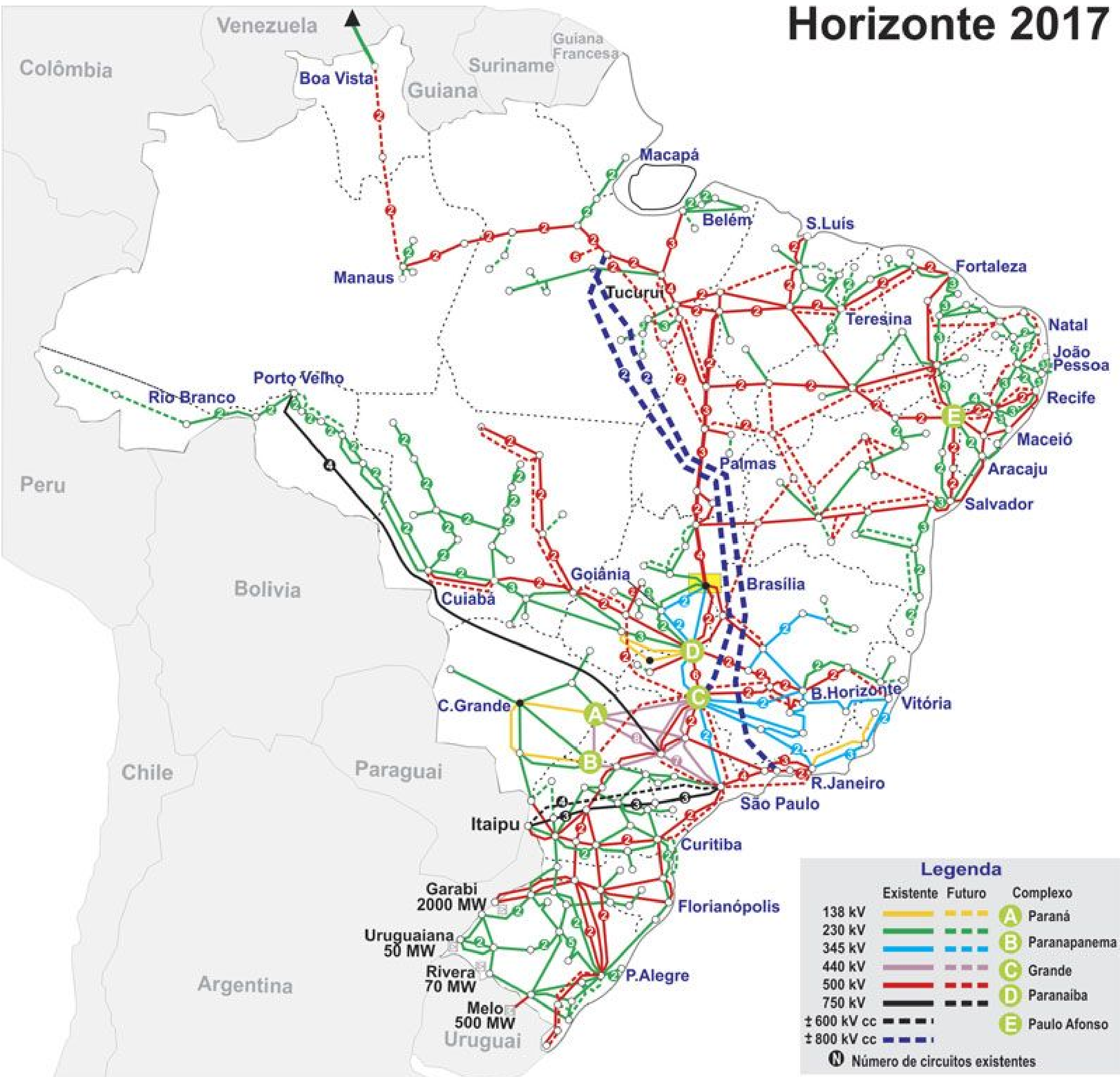
Map 4. – Monthly average air temperature maps in Brazil



Source: Alvares et al., 2017

Map 4. demonstrates the Brazilian average air temperatures that has to be taken into consideration when choosing the optimal siting location for PV installations. High air temperatures have an adverse effect on PV conversion efficiency, therefore locations with lower temperature should be preferred. As high solar radiation strongly correlates with high air temperatures, tradeoffs must be carefully considered. Arguably, the best locations based only by the combined effects of these two criteria of high solar radiation and low relative air temperature, are to be found in the higher elevations of northern Minas Gerais and central Bahia (Alvares et al., 2017).

Map 5. – Interconnected Transmission System - SIN



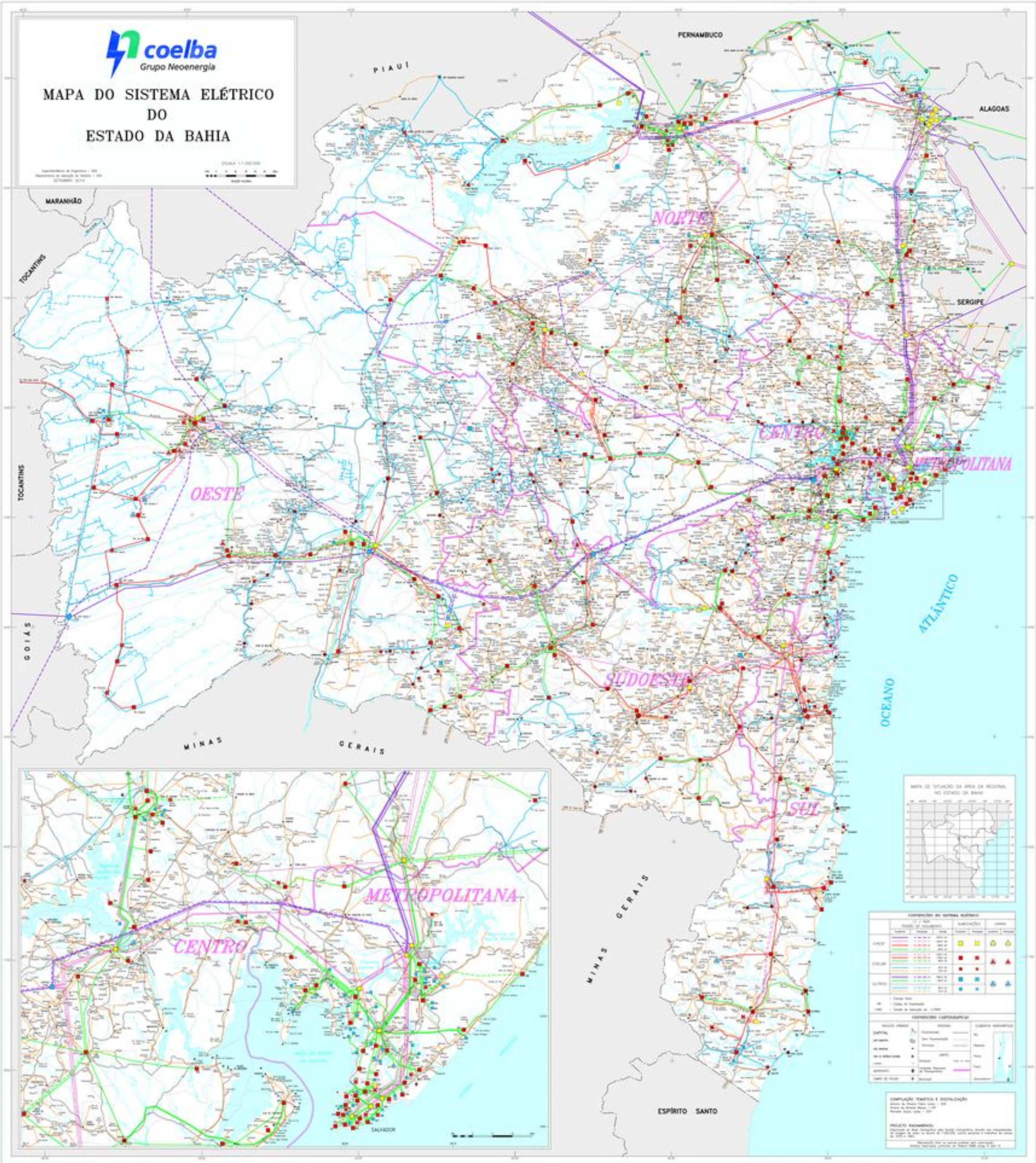
Source: ONS, 2018

Map 5 shows the Interconnected National Transmission System - SIN. It was created with the objective of maximizing Brazilian energy use. It is an electricity transmission system, supplied by around 70% from hydroelectric plants (Nogueira, 2015).

As of today, the Interconnected National Transmission System connects the South, Southeast, Midwest, Northeast and part of the Brazilian Northern region. With an installed capacity of 165.879 megawatts (MW) (ANEEL, 2019), the interconnection enables the exchange of energy between regions, thus allowing us to obtain the benefits of the rivers' regional diversity from different Brazilian basins. The coordinated operation seeks to minimize the overall costs of electricity production and increase the reliability of the service (Hollanda, 2016).

In order to accomodate a large scale insertion of PV generation to the Brazilian SIN, new high voltage transmission lines in northern Minas Gerais should be installed and the existing transmission infrastructure in central Bahia should be upgraded and extended, as these two regions would be most suitable for utility scale PV generation. As the construction of new transmission lines is costly, an even better alternative could be placing the new PV infrastructure near to energy consumers in a distributed generation model.

Map 6. – Map of the electricity transmission and distribution system of Bahia state



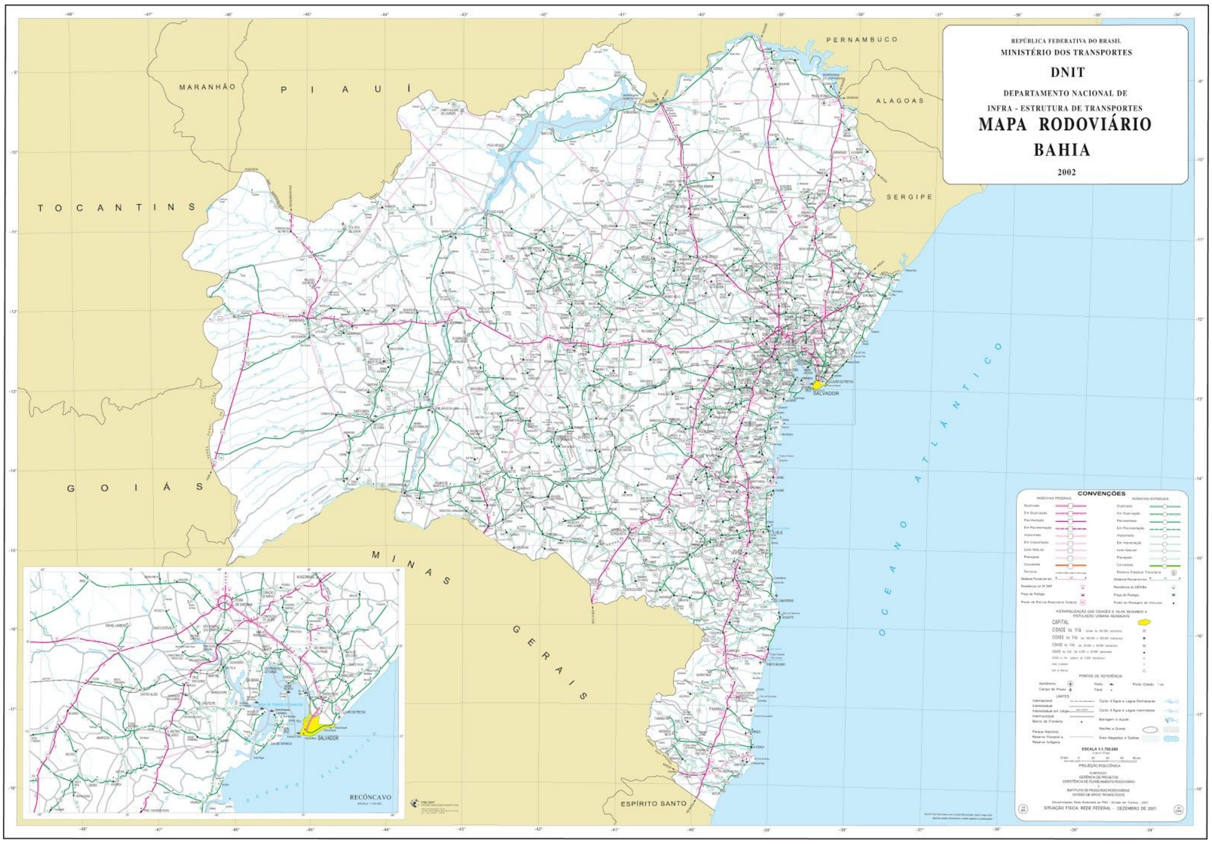
Source: COELBA, 2015

Map 6 shows the map of the electricity transmission and distribution system of Bahia state. It is a complex hydro-thermal system that is connected by a long transmission grid. It connects the south, southeast, mid-west, the northeast and part of north of Brazil (COELBA, 2015).

Approximately twenty million Brazilians living in remote communities do not have access to reliable electric power. The bulk of those underserved reside in Brazil's

Northeast, the rest dwell everywhere the country, even within the well-developed states of the South and Southeast regions. These communities utilize tiny diesel generators to produce power for basic public services like water pumping, communications, lighting for facilities, and immunogen storage for health clinics, and small businesses (Geni, 2016).

Map 7. – Road network of Bahia State



Source: Ministry of Transport (DNIT), 2002

Map 7 shows the road network of Bahia. The evaluation of the road infrastructure is important in the case study as it facilitates the logistics of the PV plants in Bahia as one of the major players in solar energy.

When comparing PV cell technologies, it is important not to confuse physical conversion efficiency (that is, how effective is the PV cell converting solar radiation to electricity on a square meter basis) with economic efficiency (meaning at what cost a PV cell could generate one unit of useful electric power). Although, in some circumstances (such as limited rooftop space, installation on vehicles with limited surface area or small mobile devices) the physical efficiency is more important. Generally speaking, for conventional large scale energy generation, the most important factor to consider is the economic efficiency. This is the reason why a thin-film panel or organic solar cell with much lower physical efficiency than silicon could be more cost effective.

The average physical and economic efficiencies of the Silicon PV cell technologies in a matrix of different environmental conditions must be compared. One such condition is ambient temperature to illustrate which technology performs better in the hot, semi-arid regions, characteristic of North-eastern Brazil.

3.2.3 PV Modeling and Simulation Tools

Although it would be possible to create a custom model for multi-criteria analysis that would consider solar radiation values from a number of terrestrial observation stations, the installation costs for both rooftop and utility-scale, the impact of the use of various PV technologies and trackers, and local electricity prices, there are already simulation tools such as the more complex System Advisory Model (SAM) advisory model or the online platform PVWatts, both developed by the US National Renewable Energy Laboratory, that can perform these functions (IFC, 2015). For the sake of simplicity, our methodology will apply the PVWatts calculator that features terrestrial solarimetric measurement data for a number of Brazilian locations (Briggs, 2011). The PVWatts tool also offers the choice of commercially available technologies to choose from. We can adjust for the use of trackers or the angle of fixed installations and model conversion losses. The PVWatts tool also accepts a value for local energy prices, so it calculates not only the monthly energy generation, but also its current value.

As well as the PVWatts calculator, the radiation data obtained from the Brazilian Meteorological Institute, INMET, will be validated. Important to remember that the INMET and PVWatts data are not always sufficiently accurate as they are not always ground measurement but satellite observed data, prone to a higher factor of deviation.

3.2.4 Local Conditions for PV Development

The first markets that adopted distributed PV power generation on a significant scale were in the countries of Germany and Italy, followed by Japan in the late twentieth century (Cherp et al, 2017). These markets have certain characteristics that provided ideal conditions for rooftop PV installation. First, the urban structures of these developed European markets are horizontal cities, with strong urban regulations on the height of the buildings (Zambon et al, 2019). Horizontal city means the development in this type of cities are horizontal. It focuses on accommodating small population on a large piece of land. Buildings that have approximately the same height provide ideal conditions for rooftop installations. Rooftop access is less difficult, and shading is rarely an issue where roofs are approximately the same height across the city (Johnston, 2018). Second, these developed countries enjoy a higher level of public safety, therefore there is a comparatively lower risk of PV panels being stolen during their 30 year lifetime (ibid). Third, urban areas have a truly distributed nature, there are a large number of medium size cities with just a few metropoles (ibid). Such distribution of the population and housing enables truly distributed rooftop PV generation across the country, meaning real benefits in terms of lowering the load on the distribution and transmission networks.

Applying PV generation to Brazilian conditions needs to consider a fundamentally different methodology in line with the urban environment. Brazilian cities are highly concentrated, not only in terms of population density, but also in city structure. They are mostly modern high rise buildings in vertical arrangements for the richer part of the population who could afford the high investments needed for PV installations. There is limited rooftop space per inhabitant, and they frequently suffer from shading from adjacent buildings. Additionally, over 6% of the Brazilian population (11.425.644 inhabitants) lives in low cost shantytowns (IBGE, 2010). Even though these low rise dwellings would enable rooftop access, there are serious security issues besides the obvious difficulties of the low income population’s ability to finance or receive loans for high investment PV systems. Brazilian cities are also very concentrated and vertical compared to the horizontal cities of Europe. According to the Brazilian Institute of Geography and Statistics, IBGE, there are some 5570 cities in Brazil, but half of the population of 202 millions live in only 200 large cities (IBGE, 2016). While out of 3 gigawatts in projects awarded, most in Brazil’s arid northeast, only 19 of 111 solar parks started construction. According to an inspection report by electricity regulator ANEEL, 24 of the approved plants face difficulties in the project’s economic viability. (ANEEL,2016) A quarter of all Brazilians, some 50 million people, live in the 20 largest cities, each with a population above or close to 1 million. This means that cities are not as evenly distributed as in Europe, hence rooftop PV installations do not provide the same distributed characteristics in the Brazilian market.

The Brazilian PV development plans have to be adapted to the local conditions that largely differ from the most developed European markets and Japan. As rooftop access is difficult or insecure, and cities are highly concentrated, an alternative PV strategy is needed to be able to solve the challenges presented by the local environment. One such solution is already offered by the Brazilian distributed generation rules of ANEEL: by allowing remote and shared generation, enabling small, 5 MW PV plants to be shared between thousands of residential and small commercial consumers (Bellini, 2019).

3.2.5 Environmental Impacts of Photovoltaics

One of the main motivations behind adapting to photovoltaics from more mature and lower cost large hydro- and thermoelectric power generation plants mostly present in Brazil is to considerably reduce the environmental impacts in terms of greenhouse gas emissions, water consumption, land and river impact and long term sustainability. Our methodology must therefore quantify these impacts by comparing PV generation life cycle impacts with current power generation methods.

Not all PV technologies are equal in terms of their environmental impact. This section highlights the differences of various PV technologies in terms of their energy use during manufacturing, and the challenges and possibilities of recycling after their useful lifetime. The thin film technology offers lower environmental impacts than traditional silicon based technologies. This is achieved in particular, by avoiding the need to melt raw materials in high temperature furnaces and instead, depositing the material at lower temperatures by printing will be offered by the thin-film PV technologies.

As this work analyses PV implementation on various scales, comparing small rooftop, mid-size commercial and large utility-scale PV parks, should address the environmental impact of each. It is tempting to believe at first sight that rooftop installations have a lower environmental footprint since they do not occupy extra space or land. However, it is hypothesized by the author that the most important environmental impacts in terms of energy generation are greenhouse gas emission (GHG) per kWh generated and water use in liters per kWh generated. As the total surface area needed to supply the world's energy need exclusively from PV is only 400.000 km^2 (Map 1), meaning a less than 0,1% of the total surface area of 510.100.000 km² of the Earth, land footprint is not a considerable environmental issue. Even less so, when PV plants are located in desert areas where vegetation is scarce and agriculture is unfeasible, except maybe countries like Israel that employ high technology to irrigate deserts for agriculture. As PV parks can be located in higher radiation areas and can benefit from tracker technology, they would generate significantly more energy using the same physical and material investment in the installed capacity. PV generation's main GHG emissions occur during the melting of the silica and crystallizing to ingots (Ludin et al, 2018). If a given PV panel could generate 50% more energy during its lifetime in a large PV park than the same PV panel would generate on a rooftop, then the rooftop installed panel's GHG emissions per kWh are 50% higher than the panel's installed in a large PV park. In the same way, we suggest that water usage in a controlled PV park (where cleaning is done with recycled water) could be lower compared to rooftop PV, however water use also depends on rainfall and dust levels so this aspect needs more careful case by case inspection.

3.2.6 Optimal PV Model

A number of aspects should be considered before creating an optimal PV strategy for the Brazilian market. Economic aspects, especially economies of scale, influence the cost of installed capacity, potentially reducing cost up to 50% by constructing larger installations compared to small rooftop projects. Choosing the most suitable PV technology for the local climate requires selecting the one most resistant to heat, as well as the one that presents the largest future cost reduction capacity. Our hypothesis is that the new, second generation thin-film PV technologies would be better suited for the Brazilian environment as their heat loss coefficient is lower (Spooner, 2018). Another technology choice to be addressed is the use of trackers that add complexity, capital and maintenance costs, but effectively increase production by up to 25% compared to fixed installations (Appleyard, 2009). Installing PV capacity in the locations enjoying the highest radiation values could further increase energy productivity by 20% compared to local installation at the place of consumption (Bertrand et al, 2018). This increase more than compensates for the 3% transmission losses (Costa-Campi et al, 2018).

3.3 Innovation research methodology

The third and final focus of the current research is how modern innovation in terms of business model disruption, technology developments or structural improvements transform the electric power sector from a centralized to a distributed, decentralized model.

It is challenging to apply conventional research methods to innovation research, as the most up-to-date and therefore interesting information is largely not yet published as peer reviewed scientific literature, and difficult to identify among relevant patents. To overcome this difficulty we have conducted a patent research form the EPO and Google patent database and have analysed patents relevant to energy innovation.

3.3.1 Patents

National and international patent offices maintain useful and easily accessible databases on the latest technology patents that could be consulted for the purpose of innovation research. However, the number of patents during the last two or three decades is so immense that finding the relevant technologies would be outside the scope of this research. Also, while patents describe in great detail their innovation, this does not mean that these technologies would be economically feasible or have real world applications. Finally, there are a number of technological areas impacting electric sector innovation, posing a further challenge on how to filter down the scope of patents to consider. Is quantum computing impacting energy transaction data security? Certainly it could, but the technology is both immature, complex and currently economically infeasible, so it is unclear whether or not to include as relevant technology in the power sector. Therefore, we only conduct limited patent research in this work linked to energy management, trading platforms, blockchain technology, and IoT technologies applied to the electric sector.

3.3.2 Scientific Papers on Electricity Innovation

A literature search was conducted using Science Direct, BASE and Google Scholar scientific search engines on topics related to innovation in the electricity sector.[9] Keywords included: digitalization, Internet of Things, electricity platforms, electricity blockchain, distributed generation, battery storage, photovoltaic materials.

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[9] www.sciencedirect.com, https://www.base-search.net, https://scholar.google.com/

3.3.3 Social media

Although it is unconventional, one of the best source of discoverning cutting edge energy related innovation trends is the news feed of LinkedIn, the professional social network (Elsebakhi, 2015). Thousands of innovators in the energy space share their ideas in form of articles or short posts on LinkedIn. An extensive worldwide social network with prominent innovators was developed and their publications followed on a daily basis, sometimes even participating in the related discussion. Without a doubt, social media is a very diverse and large source of research material related to the latest technology trends. Many professionals who are not necessarily academics publish exclusively on LinkedIn. These thoughts and articles are not found in the peer reviewed scientific literature, nor in the databases of patent offices.

Besides LinkedIn, YouTube is an increasingly interesting source of innovation research, where innovative minds publish short videos about their ideas or developments (Mention et al, 2019). In spite their informality, a modern innovation researcher can not ignore them, as these materials are often unpublished in the scientific literature. There are already lots of science related projects including electricity blockchain projects which are already published in YouTube. The challenge is the correct filtering, confirmation and integration of these informal sources. However, we should acknowledge the drawbacks of using social media posts as sources, largely, because they are not peer reviewed (ibid).

3.3.4 Open Innovation Programmes

During the research period of this thesis, most major innovation competitions and acceleration programmes in the Brazilian electricity sector were applied to. By the end of 2015, during the second year of research, a startup company was idealized and founded in order to test the research hypothesis regarding the distributed generation marketplace model. About a year later, this startup was officially registered as a limited company under the name COSOL CONDOMINIO SOLAR Ltda, with reference to the community solar model as the objective of the startup experiment.

COSOL applied for, and was successfully selected by the national startup innovation accelerator programmes of large energy corporations such as AES, EDP, ENGIE and the largest beverage producer "Americas' Beverage Company" (AmBev). The author spent weeks at each programme, having gained first hand experience about the innovation methodology of the leading multinational energy corporations. Besides these acceleration programmes COSOL has also been selected for pitching in front of the board of directors of CPFL, ENEL and the telecom corporation Algar.

The experience during these startup innovation programmes enabled a unique research methodology perspective, not only by gathering information on the programmes themselves, but also by having the opportunity to become familiar with most of the leading Brazilian energy startups, their technologies and methods to transform the electricity sector. The most successful startups selected by large energy companies were the ones focused at reducing operation and maintenance costs by applying remote monitoring and automation. Applying IoT devices to monitor, analyse or influence the consumption or generation side, proved to be exciting for power utilities. Other startups applied artificial intelligence algorithms to PV plant design or energy commerce. Hardware solutions to increase consumption or generation efficiencies were also awarded. However, business model innovations that could have fundamentally changed the commercial relations in the energy sector were observed closely but never founded.

Such a research objective could have been the purpose of many at these programmes on the methodology of the multinational energy corporations and on fellow startups. Most of the programmes were quite clearly designed so that it was easy to acquire a deep understanding of the most innovative enterprises and inventors for the upper management of the multinational energy corporations. As most of the major power utilities run such startup acceleration programmes, there is no need to name them individually. This was achieved by an attractive call, offering eventual cooperation, investment opportunity or a significant monetary price for the “winner” of the innovation contest. These open innovation programmes provided this research with invaluable insights to ideas that will form the future of the sector.

3.4 Research Startup Methodology

Being a practical researcher, and given the very nature of economic and innovation research areas that are inherent in real life applications, the decision was made early on in this research to apply alternative methodologies to test the hypothesis. The above described startup methodology was applied. The startup was meant to create and test a new economic model based on the updated rules of distributed generation that ANEEL first introduced at the end of 2015. Directly after reading the updated ANEEL regulations, a new model connecting energy consumers has been envisioned, community solar plants and their investors through a virtual marketplace, easily accessible to all players throughout the Brazilian market. The startup idea was partly inspired by the successful digital marketplace model of AirBnB and it evoked curiosity whether this model could be applied to the electricity sector. The detailed business plan and explanation of the marketplace platform technology is to be found as Appendix I.

Combining the new economic model created by the updated rules of distributed generation and the digital marketplace model of AirBnB, I was curious whether a digital marketplace could become a catalyst of the dissemination of PV technology by enabling efficient transactions between PV developers, landowners, investors and energy consumers.

4 RESULTS AND DISCUSSION

In this chapter, first it will be illustrated how the economics of rooftop PV and community solar plants compare. As in both cases the electricity must be injected to the grid, community solar power plants in the range of 1 to 5 MW produce nearly the double of electricity with the same investment, as a result of economies of scale, the use of tracker, and siting the plant in higher radiation areas. Second, the comparison of conversion efficiency of the internal combustion engine powered by bioethanol to the electric motor powered by PV electricity will be calculated. Electric vehicles powered by PV electricity are found to be around 9 times more efficient compared to bio-ethanol powered vehicles. Third, we illustrate use cases of PV technology from tiny watches to gigawatt sized utility power plant megastructures. PV plant size influences the LCOE in an exponentially decaying fashion. There are significant economic gains between a small rooftop installation and a megawatt sized PV plant, however the benefit is gradually diminishing with the size increase to massive GW size plants. On the other hand, extremely large centralized PV requires costly electricity transportation (Green, 2004) and may also causes higher environmental impacts. The middle of the road approach of MW sized community solar installation is found to offer the best cost benefit ratio between economic advantages, transportation needs and environmental impacts.

Once the economics of PV generation are explained, the focus will shift on understanding the financing mechanisms of PV plants. This part will be introduced by concepts of financial indicators such as return on investment and contractual issues arising from the lack of a state guaranteed feed in tariff (FIT). A case study of the research startup COSOL CONDOMINIO SOLAR Ltda. will help to walk through various financing models from bank loan that require real guarantees, through crowdfunding that requires special licencing or high fees, to investment funds that are only interested in large deals with proven models and rock solid power purchase agreements.

Next, a short review of specific elements of the legal framework will be analysed that impact the legality of the renal model of community PV plants. By the end of this chapter, the concept of the role of startup companies as the engine of innovation will be introduced. The cost reduction potential and efficiency gains from novel business models and technologies will be examined. Finally, a brief overview of environmental impacts and storage options of PV electricity will be described.

4.1 Maximising Economic Efficiency

The purpose of this section is to compare the costs and financial returns of rooftop and on site solar PV systems to community solar plants. Such community PV plants offer PV allotments in an up to 5 MW shared PV power plant, where energy consumers can generate their own electricity remotely. As the community solar plant is close to the consumers, the need to transport electricity is similar to the rooftop generation that is also not consumed directly by the household but injected to the public grid.

Table 7. Rooftop vs PV allotment comparison table considering R$20.000 investment

Scale	Radiation kWh/m²/yr. (1)	Tracker (2)	Cost /kWp (3)	System size (Invest/Cost)	Generation /kWp/yr.	System's output
Rooftop PV	1800 Salvador	Without	R$6000	3,75 kWp	1428 kWh	5 355 kwh
PV allotment in a shared Power Plant	2200 Bom Jesus Lapa	With tracker	R$4000	5,00 kWp	2014 kWh	10 069 kWh
Difference	22%	25%	33%	33%	42%	88%

Sources: 1: PVWatts simulation, NREL, 2018; 2: Bazyari et al, 2014; 3: Ideal, 2017;

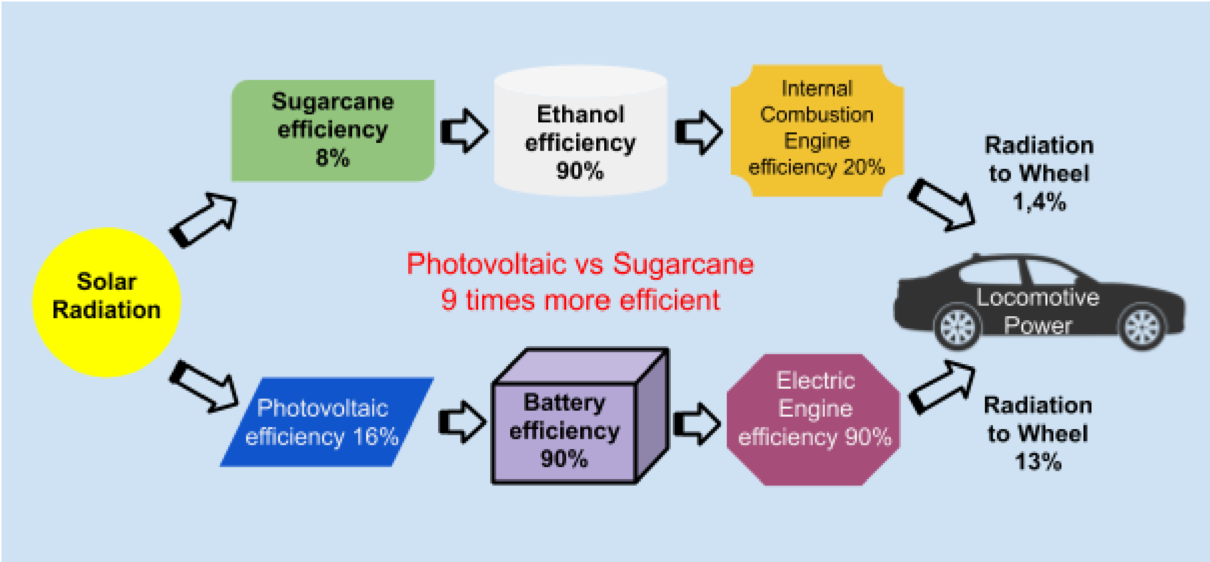
Table 7 shows the comparison of rooftop PV against community solar parks. We can see their differences according to solar radiation values in kWh/m^2/year, the increase of 25% in energy production by the use of Tracker, the PV system cost per kWp, the obtainable system size considering the same investment, power generation/kWp/year and the system's final electricity output. Due to the benefits derived from economies of scale, tracker technology and higher radiation, the electricity output of the PV allotment in a community solar park is nearly double that of a rooftop PV installation with the same capital expenditure.

4.1.1 Conversion Efficiency

Mass-market polycrystalline PV panels are typically about 15–16% efficient converting the incoming full spectrum solar radiation to useful electricity (Kalogirou, 2007). Experimental laboratory PV technologies reach as high as 44,7% efficiency using multi band gap layers and less common elements or more complex manufacturing processes (Dimroth, 2016).

To evaluate the importance of these figures, we need to put these conversion efficiencies into a wider energy perspective. Typical internal combustion engines used in road vehicles run around 15% to 25% efficiency, converting the energy content of liquid or gas hydrocarbon fuels into locomotive power. As in the case of PV, there are also laboratory grade experimental engines reaching above 40% (Porter, 2008). However, they use materials and processes way too expensive to be economically applicable to the mass market. Electric engines are much more efficient around 90% conversion rate (Porter, 2008). If fossil fuels were used to generate that electricity in a thermal power plant at a 35% efficiency, electric cars would have an overall well to wheel efficiency of only around 25 to 30%, considering efficiency losses during battery charging and electric power transmission (Khanna, 2010). Biofuels are widely used in Brazil, but conversion efficiencies via the photovoltaic process of biology is way below the current commercial level photovoltaic conversion (Khanna, 2010). Corn ethanol has a solar to fuel efficiency of only 1.5% (Porter, 2008). In the plant kingdom, the most advanced photosynthesizer is the sugarcane, which can change over 7-8% of solar radiation into biomass. (Khanna, 2010). Unfortunately, sugarcane ethanol burned in an 20% efficient internal combustion engine results a mere 1,4% solar radiation to locomotive power overall efficiency (Porter, 2008). The conventional PV module directly charging a motorized vehicle’s battery that is transformed to locomotive power at an 85% efficiency by the electric motor (Fonash, 2015). We can calculate a 13% radiation to wheel efficiency, around 9 times more efficient compared to the biologically most efficient sugarcane ethanol (Christiansen, 2018).

Figure 7. – Solar radiation to locomotive power efficiency estimate flowchart



Author's conception

Figure 7 shows the comparison of solar radiation to locomotive power efficiency estimate between the biofuel and the photovoltaic conversion cycle. It demonstrates that the photovoltaic process powering electric vehicles is more energy efficient than the photosynthesis process via biofuels to power the internal combustion engine (Vedana, 2019).

4.2 Impacts of PV Plant Size

Photovoltaics is a modular, highly scalable technology that has applicability from the micro PV cells of just 1 cm^2 found on solar wrist watches and CASIO calculators of the '80s to the giant, gigawatt size PV power stations such as the Tengger Desert Solar Park (1,5 GW) in China or the Kurnool Ultra Mega Solar Park (1000 MW) in India (Jaiswal, 2017). And this is still only to mark the beginning of the solar era and the end of the century of oil. Nothing shows this more evidently as the memorandum of understanding signed between Softbank and the Government of Saudi Arabia about the enormous 200 GW Softbank Solar Project requiring some US$200 billion of investment (Financial Times, 2018).

Figure 8. – Synchronar, first solar watch, invented by Roger Riehl in 1968

Source: Unique Watch Guide, Solar Watches

Figure 9. – Kurnool Ultra Mega Solar Park of 1000 MW in India (2017)

Source: Andhra Pradesh Solar Power Corporation, http://www.apspcl.ap.gov.in/

Although gigawatt sized PV power stations certainly enjoy the best economies of scale, they also impact large areas and require costly high voltage direct current electricity transportation lines across large distances between the sunniest deserts and the most populous cities.

At a minor scale, private household rooftop installations generate electricity right where it is used, and increasingly connected to battery storage, which allows for grid independence (Goldsworthy, 2018). Such small installations in the range of a few kWp of capacity lack economies of scale and therefore produce electricity with a high levelized cost compared to megawatt scale power plants. Also, most of the electricity produced on rooftops is injected into the grid and distributed to nearby commercial customers, as most residents do not consume significant electricity during the middle of the day. As the electricity has to be distributed, such PV installations pose a challenge on the grid infrastructure. Further, this model is often restricted in high rise cities where rooftop access in unavailable and shading is common.

The middle ground is the 500 kWp to 5 MWp PV mini plants that could be the ideal compromise, enjoying both economies of scale and proximity to electricity consumers, hence avoiding the need of costly transmission lines. Table 8 compares the three PV installation models of micro, mini and utility-scale photovoltaics, showing the economic benefits and disadvantages of each model.

Table 8. – Economic Comparison Estimate by PV Installation Model

	Rooftop micro PV	Community distributed mini PV	Utility centralized PV
Size	2 -100 kWp	500 kWp - 5 MWp	30 - 3000 MW
Environmental impact[1]	Slight	Moderate	Significant
Cost of externalities[2]	R$0,01 /kWh	R$0,02 /kWh	R$0,04 /kWh
Connection distance[3]	Locally	Close to the city	Large distance
Transportation need[4]	0 - 10 km	30 - 300 km	500 - 3000 km
Solar radiation (kWh /m^2 /yr)[5]	1600	1900	2100
Operation & Maintenance[6]	R$0,06 /kWh	R$0,04 /kWh	R$0,03 /kWh
Installation CAPEX[7]	R$7,5 / kWp	R$4,2 /kWp	R$3,6 /kWp
Generation cost[8]	R$0,48 /kWh	R$0,27 /kWh	R$0,25 /kWh
Transmission cost[9]	R$0,01 /kWh	R$0,02 /kWh	R$0,05 /kWh
Total LCOE	R$0,56 /kWh	**R$0,35 /kWh**	R$0,37 /kWh

Sources: 1: UCSUSA, 2016; 2: Al-Heji, 2014; 3: estimate; 4: ONS, 2012; 5: SolarGis, 2010; 6: ERPI, 2012; 7: IDEAL, 2017; 8: EPE, 2017; 9: IEA, 2014.

In Table 8, the three main PV implementation models in terms of Economic estimates are compared. The rooftop micro PV, community mini PV and utility-scale centralized PV in this case are distinguished. There are different factors influencing the economic feasibility of each model, most importantly economies of scale, transportation costs of the electricity, and levelized cost of energy (LCOE).

As Table 8 illustrates, the LCOE of photovoltaic generation depends on a number of factors, most notably on the economies of scale, solar radiation, use of tracker, operation and maintenance (O&M) costs, transmission and distribution costs, and environmental externalities. These calculations also estimate the costs of negative externalities, meaning the costs to the natural environment or to local communities (Moslehi et al, 2019). While rooftop installations cause negligible impact besides future recycling needs, mini power plants cause moderate impact on the few hectares of land they need. Centralized, utility-scale PV power stations of hundreds of megawatts, occupying large land areas may case significant environmental costs. Transportation needs also vary greatly, meaning very little economic and environmental cost in the case of rooftop installation, moderate costs in the case of community mini power plants close to consumers, and significant costs and environmental impacts in case of large utility-scale plants.

An interesting comparison aspect could be to consider the internal rate of return (IRR) of the three scenarios, however as electricity prices in the wholesale government auctions are much lower than the retail prices that rooftop installations could avoid paying, such comparison could be misleading. On a pure economic bases, considered all price variables equal, the larger MW range PV plants would offer around the double of IRR than the small rooftop installations. If we consider real market values however, the IRR of government auctioned centralized PV plants is low, around 4 to 8% due to the low bid prices negotiated in the power auctions. Rooftop installations offer a moderate IRR of around 8 to 12% even though they compensate retail electricity prices of R$0,60 to R$0,90 /kWh. The current distributed generation rules offer the highest IRR for the 1 to 5 MW range mini PV plants that both enjoy economies of scale and retail price compensation. In this case the IRR could be as high as 15 to 22% for the investor, however without the 20 years price guarantee of the government auction model.

4.3 Financial Planning

As discussed in chapter 3, photovoltaics is a capital intensive energy source. Besides solar radiation, the impact of the price of capital is the largest factor to influence the economic viability and the LCOE. In this section we will analyse energy price fluctuations in order to determine the long term profitability of a solar project. It is important to note that in the Brazilian market, electricity prices are composed of the following main components:

a. Generation
b. Transmission and distribution
c. Tax

4.3.1 Rate of Return & Payback

The rate of return of an investment is the yearly net income (profit) compared to the initial investment as its percentage. The 10 kWp PV lotment in a 5 MW PV plant in Bahia state to illustrate the profitability and payback period of a R$ 40.000,00 (US$ 12.000) investment must be considered (using 2018 values). The average market price of a 5 MW PV plant at R$ 4 per Wp, and an O&M cost of 2% of the the initial investment per year. The inflation rate is set at a fixed yearly 8%, while the yearly increase of energy price is set at 12% in accordance with the average of the past 20 years (ANEEL, 2018). The 2018 energy price in Bahia State is R$ 0,69 /kWh including tax. (ANEEL, 2018).

For this model, we considered an effective price discount of 10% compared to the utility energy tariff. The 10% discount was chosen as this gives sufficient motivation to energy consumers to switch to a new provider and understand the new business model. This means that the energy consumer could generate their own solar energy 10% cheaper than buying the same energy from the utility. We have also factored in a 0,8% amortization of the PV panels over time, that is a 0,8% decrease of energy production year by year. Table 5 of Appendix I illustrates that the payback period is approximately 4.5 years, while the return of investment increases from 18% to 154% during the 20 years of the plant operation.

4.4 Financing Community Solar

Finding a reliable source of financing could be the Achilles heel of a mini generation community solar PV plant project, requiring a R$ 2 Million to R$ 20 Million (US$ 5 Million) investment for the 0,5 MW to 5 MW installed PV capacity (Gomes et al, 2018). There are, however, a variety of options one can choose from, including Brazilian state financial institutions such as BNDES, Banco do Nordeste, or the government retail banks of Caixa Economica Federal and Banco do Brasil, all with distinct credit lines for solar energy projects, offering low interest rate financing, usually slightly below inflation rates (ibid.).

In order to achieve a competitive weighted-average cost of capital (WACC) for community solar, it is important to secure a high proportion of low-cost debt financing for the project (Coleman, 2017). In Brazil, such financing is available through national and regional development banks such as Banco do Nordeste ou Desenvolve SP, however at the time of research, both require physical loan guarantees such as real estate or even a letter of bank guarantee based on real estate from a commercial bank as explained in chapter 4.4.2.

As the Brazilian distributed generation legislation does not currently allow mini power plants to directly sell electricity to the power utility or to energy consumers, the only way to commercialize community solar projects is through rental contracts with electricity consumers. In this model, the energy consumer will generate their own electricity with the rented or leased equipment, as a percentage of the total installed capacity. From the lender's perspective this means the lack of a long term power purchase agreement (PPA) with a credit worthy off-taker.

In spite of the described credit lines of the aforementioned development banks, these credits are largely inaccessible for project developers of mini generation power plants. As banks are only willing to provide such loans on the bases of real guarantees, essentially, the bank is trying to pass on the project risk to a landowner who provides the guarantee. As the largest risk in the distributed generation market is the regulatory risk, meaning that ANEEL or the Brazilian Federal Government suddenly changes the rules of the compensation system, no landowner would be risking his property on the erratic and unpredictable changes of the rules of distributed generation that are prone to the lobby activities of utility companies. Therefore, we can conclude that there is no viable low cost debt financing option currently available in Brazil for community solar mini power plants in the 0,5 to 5 MW range.

A state guarantee scheme could make the financing of the mini generation feasible. The risk of default of an individual electricity consumer in the consortia of hundreds or thousands of small consumers is not a considerable financial risk, and as such, a tenant can be easily replaced by a new one. The single largest risk is the regulatory risk in the sole control of the federal government energy ministry. Therefore, as one of the main recommendations of this thesis, it is suggested that the Federal Government evaluate the possibilities of providing guarantees for the development banks it controls. Simply outsourcing the regulatory risk to landowners will create considerable problems first to the landowner, who would lose their land as soon as the distributed generation regulation is changed, and second for the commercial banks, who will have the problem of having to sell thousands of land estates, as they will all be insolvent the day following a regulatory change. With thousands of land estates worth billions of reais in total, the commercial bank will have a serious credit problem as it will be difficult to liquidate such a large quantity of land in a short period. In summary, we can clearly see how a badly designed model of financing community solar projects by requiring real estate guarantees and later changing the rules of the compensation system could eventually create a possible serious financial crisis, where the Federal Government will be forced to bail out the commercial banks who end up with bad debts as thousands of land plots will start to lose their value as a result of the regulatory change of distributed generation.

4.4.1. National Bank for Economic and Social Development (BNDES)

The Brazilian National Development Bank, or BNDES, offers credits for photovoltaic power plants from its Climate Fund (BNDES, 2014).

The following documents are required to apply for financing according to BNDES:

a. Environmental licence, either provisory or "installed" or equivalent document issued by competent environmental organization or in case such environmental organization dispenses of the activity of environmental licensing, its declaration of exemption of the licence.
b. Signed contract with the supplier of photovoltaic modules and components.
c. Signed construction contract.
d. Signed Power Purchase Agreement (PPA) for projects under the Free Market (ACL) or strong instrument of the purchase of energy.
e. Presentation of solarimetric studies, indicating the expected amount of energy produced by the park. (BNDES, Solicitações Setoriais, 2014)

Initially no information on how to finance a 1 MW distributed generation PV plant through BNDES credit lines was obtained from the bank. By the end of 2018 however, the research startup company COSOL was awarded as one of the ten best fintech startups in Brazil by the BNDES Fintech Challenge (BNDES[10], 2018). Following the award, COSOL was asked to provide details on the shared generation model by BNDES representatives and received a promise for a financial product especially be structured for this business model during 2019.

4.4.2 Banco do Nordeste (BNB)

Banco do Nordeste (BNB) is a Brazilian development bank controlled by the Federal Government. BNB offers a dedicated credit product for distributed generation project financing called the FNE-SOL. BNB describes this financial product as the following:

> Goals
>
> To contribute to the environmental sustainability of the energy matrix of the Northeast Region, offering a credit line specially designed for the financing of micro- and distributed minigeration energy systems by renewable sources, for self-consumption by the enterprises.
>
> What the Program Finances
>
> All components of micro and mini-generation systems for photovoltaic, wind, biomass or small hydroelectric power plants (PCH), as well as their installation. To find out what is micro or mini generation of energy, see the leaflet on Financing Distributed Energy.
>
> Target Audience
>
> All sizes of industrial, agroindustrial, commercial and service companies, rural producers and rural companies, cooperatives and legally constituted associations.
>
> Source of Funds
>
> Constitutional Fund for Financing the Northeast - FNE.
>
> Source: [Website of BNB FNE SOL, https://www.bnb.gov.br/programas_fne/fne-sol, accessed on 29. August 2018.]

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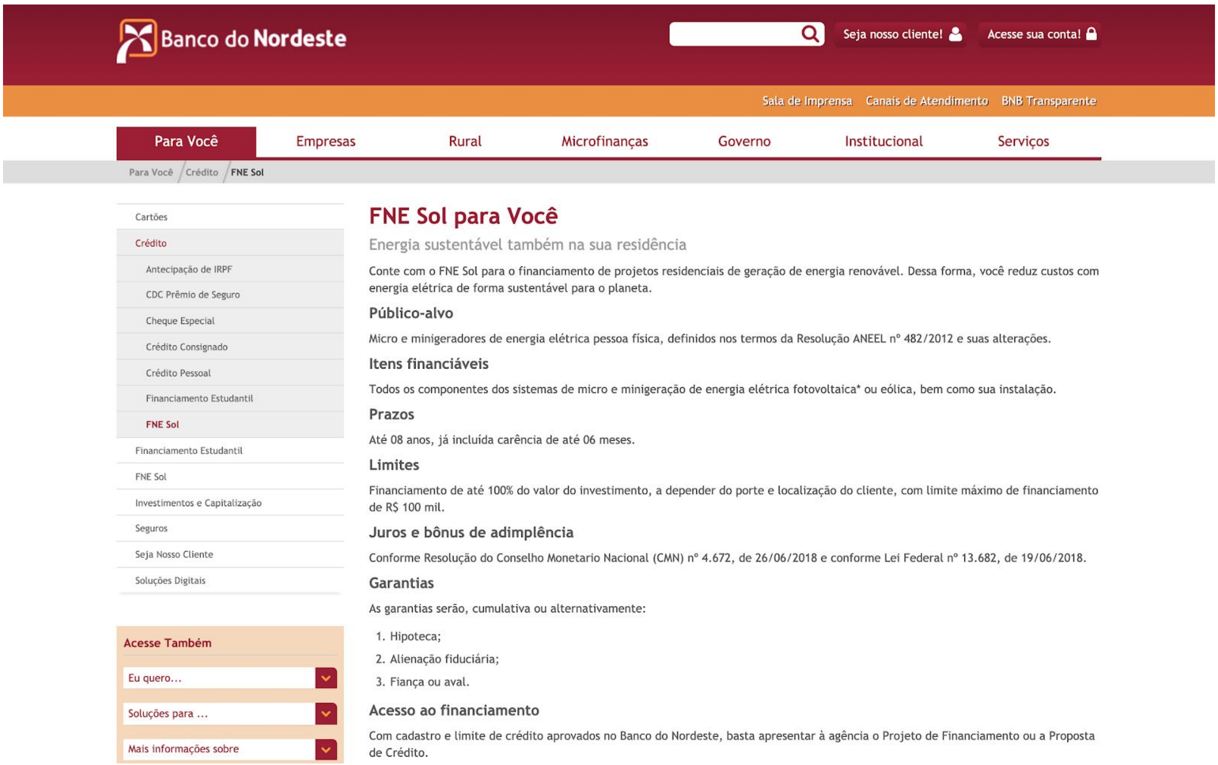
10 https://www.bndes.gov.br/wps/portal/site/home/transparencia/licitacoes-contratos/licitacoes/concursos/desafio-bndes-fintech

Figure 10. – BNB FNE SOL Webpage



Source: Website of Banco do Nordeste, 2019

In the Northeast of Brazil, BNB is often the sole option for low cost financing of renewable energy projects, therefore a considerable portion of research was directed to understand how accessible this financing option is, given that large parts of the private PV industry depends on it.

As part of the COSOL startup case study, in order to collect research material first hand, the representatives of BNB were contacted. To begin thee investigation, one of the bank's agencies in Salvador, the capital of Bahia State was visited, and presented the community solar project, asking for financing options in early 2016. A personal interview was conducted with the branch manager who showed interest in the project, but advised to look for bank guarantees with a private commercial bank, or find a creditworthy business partner, as the bank would have difficulties securing financing for a greenfield project without presenting guarantees. Based on follow up calls with the bank, it can be concluded that project finance requires either real estate guarantees or the guarantee of the financial turnover of a company responding for payment of the loan.

In early 2017, BNB was contacted again, this time by emailing one of the managers in the bank's central headquarter. A great exchange of emails involving some four bank officials was developed. However, again, real guarantees in the form of a credit letter or a real estate guarantee were required. The development of the understanding of the PV financing model by the bank officials was impressive, however real guarantees were still requested behind the PV plant itself. It has become clear that BNB is not willing to take any risk, and is shifting all project risk to the commercial bank who in turn shifts the risk to the land owner.

As a result, a landing page on COSOL's website was created as of May 2018, targeted towards land owners interested in financing a PV plant and commercializing the generated electricity to the local community through the COSOL online marketplace. After four months, there were 200 landowners signed up in COSOL's database. This market research I found highly relevant for my thesis, as this is the key to distributed PV plant financing. Therefore, I have conducted interviews with many of these landowners who had difficulties understanding the complexity of ANEEL's distributed regulation model. Their general concern was the reliability of the government regulation, as any modification of the ANEEL normative rules n°482 and 687 could jeopardize the economic feasibility of the community solar model COSOL was presenting. As landowners did not trust the longevity of the government regulations and therefore perceived a high risk of losing their land (the collateral behind the PV plant's financing), none of the interested landowners have moved forward with the financing of their community solar PV project, until early 2019 when an entrepreneur in Roraima finally decided to invest his land to obtain financing for his PV plant. It has become evident that the current ANNEL rules are perceived to be very fragile in terms of offering legal security to distributed generation plant owners and can be modified with little warning by the government. In my view, the distrust in the government rules is much more a cultural issue in Brazil than a real threat of ANEEL modifying the rules with retroactive effects of existing distributed generation assets.

Concluding the above experience, it can be assumed that the FNE-SOL credit line offered by BNB is not completely capable of financing community solar (or similar shared distributed generation) infrastructure, as the required credit letter puts the full regulatory risk on the shoulders of the private landowners who are not in the position to trust ANEEL or the Brazilian Federal Government. Normative rules n°482 and 687 will remain, as it is today, offering the sole legal security to the financial institution's investment.

4.4.3 Consumer Financed Plants

Another financing option is the direct investment of the energy consumer, who could buy a share of the power plant and receive energy credits in return, effectively substituting their future energy bills with the purchase of the PV allotment. This financing option lacks feasibility, as very few electricity consumers have the capital for the large upfront investment required to acquire a PV allotment in a shared community solar project, which I validated during this research. After a few months of validation, I have excluded this option as a feasible financing option.

4.4.4 Crowdfunding PV plants

The Securities and Exchange Commission of Brazil (Comissão de Valores Mobiliários – CVM) regulated the crowdfunding model in June 2017 by the Instruction CVM 588. This rule allows that private investors buy shares of a power plant project and rent the allotments to energy consumers, who in turn would pay a monthly rental fee to the owner of the PV capacity. This way, the financing options open up to the general public, who can become a partial owner of renewable and distributed generation capacities via one of the permissioned crowdfunding platforms. As part of my case study startup project COSOL, I have extensively negotiated with CVM and have contracted ADV Junior, a legal advisory of Federal University of Bahia (UFBA) law students.

In order to comply with the CVM instruction 588, the crowdfunding platform has to be developed, and an independent information technology (IT) auditor has to inspect the website and send the certificate to the CVM for approval. Finding such an IT auditor, however, has proven to be very challenging. I have sent out emails to IT auditors and consultants, but none could recommend a certified auditor capable of supplying the required certificate. In spite of several emails asking CVM to indicate a certified IT auditor, I have repeatedly received the answer that CVM is not authorized or required by law to make such indication. Finally, after several months of trying to present the community solar crowdfunding model to CVM, submitting to them the legal analysis by ADV Junior and asking to indicate an IT auditor, I have received an official email from a

CVM representative and in spite of immediately replying to it, the following week, CVM published an official decision imposing a daily fine of R$5.000,00 on my research startup COSOL and requesting the immediate removal of any offering of collective investment on COSOL's website.[11]

Therefore, in spite of crowdfunding being legally regulated in Brazil, there are significant bureaucratic and financial barriers that turn the crowdfunding of distributed generation projects difficult for a startup company. The less complicated way to crowdfund a PV project is through the so called gatekeeper platforms that have obtained a license from CVM. These platforms however charge a significant upfront cost of over R$10.000 (US$3.000) just to begin the process. All marketing efforts are expected to be financed by the company offering the project, however a large 10% commission is retained by the gatekeeper platform. As solar PV is a very capital intensive business, a 10% commission significantly reduces the economic feasibility of the PV project.

4.4.5 Investment Funds

As having the consumer finance itself the PV allotment, and the use of credit lines of development banks or crowdfund has proven to be unavailable, I have tried to finance the 1 MW PV project through an investment fund that in turn would become the owner of the plant and receive the rental fees collected by the COSOL marketplace platform. I have moved to São Paulo and presented the community solar pilot project to several investment funds. However, none of the funds were willing to finance the project as they were looking for more evidence of the model being tested, and also showed distrust in the ANEEL rules remaining for the lifetime of the project.

4.4.6 Angel Investors

I have registered the COSOL research startup in every possible acceleration programme in order to present the community solar marketplace to angel investors and venture capitalists. During 2016, COSOL was selected by SEBRAE's (Brazilian Micro and Small Enterprises' Support Service) Capital Entrepreneur programme, completed the Baanko Challenge designed to support startups with one of the 17 sustainable development objectives of the United Nations, accomplished the accelerator programme of

[11] http://www.cvm.gov.br/noticias/arquivos/2018/20180418-1.html

Unreasonable Lab, and have been selected by InnovaBra, the startup programme of one of the major Brazilian commercial banks, Bradesco. In 2017 I moved COSOL to São Paulo as I realized that most angel investment activity is centralized there, in the economic capital of Brazil. During 2017, the COSOL research startup has been selected by several startup programmes such as InovAtiva Brasil organized by the Federal Government, and Fabrica de Startups, supported by the Portuguese power utility EDP (Energias de Portugal). I have been invited to present a short pitch in front of the major angel investor groups such as Anjos do Brasil and conducted in depth negotiations with several angel investors interested in the renewable energy sector or in impact investing.

In spite of COSOL receiving various innovation prizes and ongoing interest from angel investors, in particular those focusing on impact investing, the only real criteria of this group to decide on an investment is whether a startup has already started billing for its services. As it is clearly impossible to build million reais power plants or convince other to do so with the limited capital of the founders, and for the lack of other capital sources, angel investors have not contributed to COSOL's community solar model.

4.4.7 Energy Utilities

Traditional power utilities have an ambivalent attitude towards distributed generation in general and community solar in particular. On one hand, they consider the current rules of distributed generation as a threat to their traditional business model and to their monopoly position as micro- and minigeneration plants are currently exempt from distribution charges, and could create a parallel market through rental contracts of the power equipments (Feingold, 2015). On the other hand, more forward thinking utilities have started to understand that the new technologies of renewable generation shift the sector from large centralised hydro and thermal plants to much smaller distributed wind, biomass and solar plants (Sandalow, 2018). Instead of trying to lobby against distributed generation rules, these modern utilities adapt to the new challenges and create new departments or subsidiaries with new business models exploring distributed generation (Pollitt, 2016). Such progressive utilities also recognize that they often lack the human resources of the open minded entrepreneurs capable of innovation, therefore often choose to adapt the open innovation methodology and establish so called startup acceleration programmes in order to modernize their conservative business models (Greco et al, 2017). Often large utilities face difficulties in adapting their business models to quickly changing technologies and new regulatory frameworks.

The trajectory of COSOL is an example of how large utilities try to adapt to distributed generation rules. Among the electric power giants that have selected COSOL as a top startup, EDP (Energias de Portugal) in particular showed considerable interest by involving COSOL first in a two weeks startup selection process called EDP Starter, and later inviting COSOL to the international innovation competition EDP Open Innovation in Lisbon, where COSOL was awarded the silver medal of energy innovation.

4.5 Plant Development

The EPC (Engineering, Procurement and Construction Company) is primarily responsible for the engineering, procurement and construction of a power plant. Responsibilities include selecting the suppliers of solar modules, inverters and other key items of equipment, and finalising and underwriting the final design and output projections for the plant. The EPC is also responsible for constructing the power plant, and to guarantee its proper functioning.

4.6 Interpretation Of The Legal Framework

As already discussed in section 2.7 Policy Review, distributed generation is regulated by the the ANEEL's normative rule nº 482 of 2012 and its update by the normative rule nº 687 of 2015. In this section, we will clarify the most fundamental detail that is decisive when evaluating the opportunities offered by the rule.

4.6.1 Rental Of Solar Lots – Shared Generation

The legality of the rental model has been frequently questioned by market players citing the Art. 6-A of the normative rule 687/15 that states:

> Art. 6-A. The distributor can not include consumers in the electricity compensation system in cases where it is detected, in the document proving ownership or lease of the property where the microgeneration or distributed minigeration is installed, that the consumer has rented or leased lands, lots and properties in conditions in which the value of the rent or lease is in reais (R$) per unit of electric energy (kWh).

This prohibits the sale of electricity when offering kWh (unit of energy) for the monetary unit, R$ (rental fee). However, if one does not offer the sale of energy in terms of R$/kWh, but the rent of the installed potential of the photovoltaic generation, then transaction is fully legal between the generator and consumer. The tenant pays a monthly fixed amount to be able to use the equipment of the generation and to produce its own solar energy, independent of the kWh received. Therefore, the lease or rent of installed capacity (kWp) for a value not directly related the the energy produced is completely legal and does not configure the sale of electric power in terms of kWh.

According to the Official Letter Nº 0275/2016-SRD-SGD-SRM-SCG / ANEEL and the official letter Nº 0284/2016-SRD / ANEEL, regarding the rental of electricity generating equipment for distributed generation and remote self-consumption of energy:

> A consortium may lease a power plant and compensate for the energy in the consortium's consumer units, provided that they are within the same concession area of the distributor and that the capacity of the plant does not exceed 3 MW for the hydro source or 5 MW for the other renewable sources and qualified cogeneration. [Official Letter No 0275/2016-SRD-SGD-SRM-SCG / ANEEL, 2016]

> There is no normative restriction for captive consumers to exercise the self-production of electric power (...), and they may exercise the possession of the land and the generation equipment by means of rental and lease agreements whose counterpart is not, fundamentally, the payment for the energy produced. – [Official letter No 0284/2016-SRD / ANEEL, 2016][12]

According to these official letters, a group of consumers united in a consortium may lease or rent the powerplant, provided that they are all in the same concession area of a power utility. There is no restriction for consumers to exercise the self-production of renewable energy and they are able to exercise possession of the land and the generation equipments by means of rental and lease agreements, as long as the rental contract is not quoted in R$ per kWh.

During the event *Distributed Energy Resources* of FGV ENERGIA in Rio de Janeiro, the ANEEL representative answered this question clearly: “It does not matter who

[12] Source and further information: ANEEL SRD - Superintendence of Regulation of Distribution Services, http://www.aneel.gov.br/srd

owns the power generating equipment, as it does not matter who owns the television in your house. What matters is who is generating or consuming energy.” (Hollanda, 2016).

Therefore, we can conclude that the rental model of the generation equipment for remote and self-generated renewable energy generation is in accordance with ANEEL's 687/15 normative resolution, since the requirements are complied with and it is within the scope of the resolution.

4.7 Startups

Startups are the most innovative technology enterprises that develop highly scalable business models with fast growth potential, impacting entire industries, often revolutionizing how things are done. In order to achieve rapid global impacts, most startups use some form of internet technology, enabling easy accessibility.

The most successful startups disrupt traditional industries: Amazon did to the retail industry, Facebook to media, Netflix to the film and television industries, Uber to the taxi services, or Airbnb to the hotel industry. They did this by directly connecting private people over the internet to services that were traditionally provided by offline models. Apart from internet technology, the concept of economic activities involving online transactions is often applied, offering clients the opportunity to trade their own means of transport or lodging between one another.

4.7.1 Renewable Energy Startups

There are only a few successful startups in one of the biggest of all industries: the energy sector. One of the main reasons behind the lack of more successful ventures is that energy is a highly regulated area with large, powerful companies acting as players. This combination often discourages venture capitalists, who fear that a regulatory change or a powerful competitor could jeopardize the startup they invest in (Okike, 2018). A regulatory change can potentially turn innovative business models unviable. Most investors do not perceive that the energy sector is at a major turning point, shifting from fossil fuels to renewable sources, and that this change requires the establishment of new concepts that traditional energy companies will find difficult to implement. Investors still have difficulty perceiving that regulators are trying all possible ways to foster this energy transition, meaning that regulatory changes will be very much in favour of new startups offering alternative ways to radically reform the energy business.

Map 8. – Clean energy startups around the world. The US dominates.

Source: www.startupblink.com, 2018.

Map 8 shows the distribution of clean energy startups around the world. The illustration shows the dominance of the United States where high startup density is denoted by red colour. These new businesses are wanting to change the future of the power sector. In spite of the fact that they all have distinctive technologies, they are united in their main goal to make the future cleaner and more sustainable. Yellow areas denote medium-, while blue circles show low startup concentrations.

4.8 Innovation in the Electricity Sector

After a century of the centralized utility model, where giant hydroelectric and fossil power plants have dominated the electricity landscape, the advent of low cost renewable generation technologies lead to a distributed generation model. Distributed generation, also distributed energy, on-site generation (OSG) or district/decentralized energy is electrical generation and storage performed by a variety of small, grid-connected or distribution system connected devices referred to as distributed energy resources (DER). This new model offers various benefits, from the lower need for transmission infrastructure as generation and consumption are placed nearer to each other, to a lower environmental impact, as there is no need to flood huge areas for water reservoirs or cut through forests for transmission lines, to —most importantly—the possibility of a competitive electricity market without the need of a monopolistic central distribution authority controlling the grid and imposing high transaction costs.

Such a fundamental transformation of the basic model of the electricity grid could not be possible without breakthrough innovations supporting the change. The very reason the grid was built around a centralized distribution system, hence allowing for natural monopolies, was due to the lack of a better alternative as communication infrastructure, database and payment systems weren't nearly as developed as today (PSerc, 2016). The utility model was the only technically viable option to process transactions between giant power plants and millions of electricity consumers, that resulted in a social contract allowing for otherwise undesired or even prohibited large monopolies to dominate the electricity distribution sector. The sector being heavily regulated today is one of the consequences of accepting the monopoly utility model (Pérez-Arriaga, 2013).

However, during the last few decades, technology has improved tremendously in all key areas that previously limited the development of a liberalized electricity market, apart from renewable generation technologies. The internet fully liberated the communication sector, disrupted state monopolies such as landline companies or the postal service, established peer to peer models in any industry requiring the efficient exchange of information such as payment systems, long distance calls, news media or advertising. It would be inefficient today to have a central authority managing our communication system, and a similar trend in the electricity sector can be anticipated. As surely as we have Internet Service Providers (ISPs) maintaining the communication infrastructure, we will have grid service providers in charge of maintaining distribution cables. However, as it is the case with ISPs, the role of the utility will be restricted to the maintenance of the cable infrastructure. The information content such as electricity contracts, accounting and transactions will not have to be dominated by centralized monopolies.

Another important technological improvement is the microchip that has declined in cost and size to such extent to allow for the development of IoT. IoT technology would allow for actively communicating electric power meters, dispensing the need of a central utility reading the power meter just as the advent of the e-mail protocol largely reduced the need for the postman to carry letters and telegrams on paper.

Table 9. – Patents related to energy management and monitoring

Patent number	Date of Publication	Authors and Inventors	Patent title
US 2016/ 0033986 A1	04/02/2016	Michel Roger Kamel, Buena Park; Paul W. Donahue, Jeffrey Alan Dankworth, (US)	System and methods to manage renewable energy on the electric grid
US 2011/ 0138377 A1	09/06/2011	Marc Allen	Renewable energy monitoring system & method
US 7,904, 382 B2	11/03/2008	David Arfin	Methods for financing renewable energy systems
WO2017199 053A1	23/11/2017	MAYNE TIMOTHY [GB] UMANSKY SERGE [CH]	Method of matching renewable energy production to end-user consumption via blockchain systems
US20102181 08A1	26/10/2010	Jason Crabtree	System and method for trading complex energy securities

Table 9 summarises the patents related to energy management and monitoring. The research startup COSOL is developing and integrated marketplace and developing its own technology related to energy management and monitoring. A patent research has been conducted to determine what competing technologies already exists.

Abstract of the listed patents:

Abstract
Systems and methods use a platform to send communications and instructions to one or more distributed resources on the grid or microgrid or facility to directa flow of power from one or more power sources to one or more energy consuming devices. Link: https://patentimages.storage.googleapis.com/fc/42/36/be0e64cd7bab9c/US20160033986A1.pdf
A method and system that is capable of remotely managing processes of a renewable energy monitoring system through the internet. The system is capable of automatic detection and installation of firmware upgrades in renewable energy monitoring device where installed firmware components are dependent on peripheral configuration dataset and there are potentially a large number of peripheral configuration combinations. The system is also capable of processing data received from external instruments such as pyranometers, thermal sensors, or anemometers on a remote server by storing the peripheral configuration dataset of the renewable energy monitoring system in the remote server's database as well as data on how to process data from a wide range of instruments. https://patentimages.storage.googleapis.com/c8/42/8f/b3cca5d2db032f/US20110138377A1.pdf
A business method for financing renewable energy systems includes offering a home loan to a homeowner in which the interest payable by the homeowner are tax deductable. A lease is also offered to the homeowner for the installation and use of a renewable energy system. A deposit of cash proceeds from the home loan is put into a trust held by an escrow agent for the single purpose of paying lease payments for the lease as each payment becomes due. Such that the proceeds from the home loan are effectively used to defease the debt represented by the lease. https://patents.google.com/patent/US7904382B2/en
This invention enables a transparent matching of the electricity produced from renewable sources (1b, 1c, 1d, 1e) with the electricity consumed by end-users (5a, 5b, 5c) that have a preference for clean energy. This goal is achieved through a system of tagging energy using blockchain tokens. The proposed system is transparent, incorruptible and efficient in managing energy blockchain tokens and creates a valuable information resource which can be leveraged to promote and support consumption and production of renewable energy. https://patents.google.com/patent/WO2017199053A1/en
A system for presentation and management of energy-related information and securities, comprising a digital exchange, a client system comprising a plurality of display and input modalities, a communications interface software adapted to allow communications between the client system and the digital exchange, and a control interface within the client system adapted to drive the display and input modalities, wherein the control interface, on receiving input from a user, causes data from the digital exchange to be retrieved and displayed in one or more of the display modalities to the user, and upon receipt of a request from the user via an input modality of the client system after the user has retrieved and reviewed data from the digital exchange, an order to execute a transaction is transmitted to the digital exchange by the client system, and on receipt of an order to execute a transaction from a client system, the digital exchange combines the ordered transaction with other similar transactions from a plurality of users and thereby creates or modifies a marketable security visible to at least one other user via the digital exchange, is disclosed. https://worldwide.espacenet.com/publicationDetails/biblio?CC=US&NR=2010218108A1&KC=A1&FT=D&ND=3&date=20100826&DB=&locale=en_EP

4.9 Environmental Impact Assessments of Photovoltaics

As described in chapter 3.2.6 of the methodology section, the average emission values of the Brazilian electricity sector has been compared to the average emissions of photovoltaic technology. In Table 10, the estimates of average greenhouse gas emissions of the Brazilian electricity sector are shown. In order to obtain the emission reduction potential by the energy generated in the PV plants of various sizes, one can multiply these figures according to size of the PV plant.

Table 10. – Emissions of the Brazilian electricity sector (grid)

Type of Greenhouse Gas (GHG)	Emission value in kg / kWh
CO2 equivalent	0,247 kg / kWh
MP2.5 equivalent	0,000150 kg / kWh
NOx	0,00040 kg / kWh
SO2	0,00081 kg / kWh

Source: Aneel, 2012.

On the other hand, in Table 11, the emissions of low-voltage electricity from photovoltaic source with average Brazilian yield are demonstrated.

Table 11. – Emissions of the PV generation in Brazil

Type of Greenhouse Gas (GHG)	Emission value in kg / kWh	Emission reduction as percentage of the average of the Brazilian grid
CO2 equivalent	0,071	71%
MP2.5 equivalent	0,000076	49%
NOx	0,00018	55%
SO2	0,00030	62%

Source: Aneel, 2012.

Comparing the emission values of the average emissions of the Brazilian grid (Table 10) to the emission values of PV generation in Brazil (Table 11), we can observe an emission reduction potential of CO_2 reduction of 71%, a MP2.5 reduction of 49%, a NO_x reduction of 55% and a SO_2 reduction of 62%.

The emission data was processed by the Software OpenLCA 1.8; An ecoinvent inventory database (Wernet et al., 2016; version 3.5 in Moreno-Ruiz et al., 2018). The electricity production of a 3 kWp photovoltaic rooftop installation, with multi-Si panel, considering average Brazilian solar radiation values.

The average emission data for the Brazilian electricity market of low voltage consumers was established according to the ILCD Impact Method (Sala, 2012) including the IPCC for greenhouse gas emissions (CO_2 equivalent) standards.

4.10 PV Storage in the Brazilian Context

According to EPE estimates, in 2019 some 68% of Brazilian electricity was generated by large scale hydroelectric power plants featuring large water reservoirs. While in other regions it is commonly proposed to build pumped hydro storage as means of cost effective storage of PV generated electricity, in Brazil, given the existing hydroelectric infrastructure, the storage solution could be as simple as reducing the water flow during daylight hours, in order to compensate for the peak production of the installed PV capacity. During these daylight hours with reduced flow in the hydroelectric dams, water could accumulate in the reservoirs, hence eliminating the need of the costly pumped storage infrastructure. Brazil is in a unique position therefore to leverage its already existing hydropower infrastructure to help scale up the emerging PV infrastructure. While this model would impact the capacity factor of the hydroelectric generators, the loss of direct revenue could be compensated by a correct hourly market valuation of the generated electricity. Therefore, with the introduction of an hourly energy pricing model, the hydroelectric plants could be even more profitable by reducing the flow during daytime and increasing the flow at peak hours in the evening when PV is unable to generate (Fang et al, 2017).

On the other hand the reduction of generation from hydroelectric plants is only possible to a certain degree. There are limits to the amount that the stream flow can be reduced due to ecological reasons.

Furthermore, PV has a maximum capacity factor of 25% without real storage and therefore, can only achieve a penetration of approximately 20% of the energy mix. Therefore, above this penetration there would be excess PV generation that would need to be stored via for example pumped hydro, compressed air or battery technologies. (de Jong, 2019)

Besides the most cost effective hydroelectric storage option, the emerging battery technologies also offer economically feasible options, given the hourly pricing of electricity and a premium price paid to storage facilities. With the upcoming shift towards the electrification of mobility, the current fleet of passenger cars and light road vehicles estimated to be 43,4 million (IBGE, DETRAN, 2017) and considering an average battery pack per passenger car of 50 kWh (Yoney, 2018), a total of 2170 GWh lithium ion storage capacity would be available to the grid. To put it into context, this amount is almost half of all electricity storage capacity worldwide. According to IRENA (2018), today an estimated 4670 GWh of electricity storage exists. Even considering that only 5% of the total of light vehicles would be grid connected at any given time due to charging or parking, over 100 GWh of very flexible storage capacity would be available to the Brazilian grid. Startups such as Driivz[13], EVbox[14] or FlexiDAO[15] among others, are already offering electric vehicle (EV) charging solutions that could benefit the owners of electric vehicles by paying a bonus when the electric car is supplying electricity at peak hours back to the public grid. Blockchain technology could pay a significant role in the peer to peer transactions between EV owners, PV generators and energy consumers. Regulators such an ANEEL should prepare incentives in order to enable such storage schemes therefore reducing the need of new storage capacity.

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[13] https://driivz.com/
[14] https://evbox.com/
[15] https://www.flexidao.com/

5 CONCLUSIONS

Solar energy is readily available in Brazil, a country enjoying excellent solar radiation values. As the government auctions guarantee a growing and steady demand and the private sector is also starting to adopt the technology the road is paved for exponential PV growth.

New business models for PV deployment have the potential to expand the solar market client-base dramatically. Options such as remote and shared solar installations can enable rapid, widespread market growth by increasing access to renewables, potentially lowering costs via economies of scale and reduced need of transmission.

Solar plants can be shared between energy consumers lacking the necessary unshaded roof space to host a PV system, or among customers seeking more freedom, flexibility, and a significantly lower cost. Unlike on site PV systems, remote generation installations can be much more easily financed by third party investors as the generation assets are located on the owner's real estate.

Behind the ongoing cost decline of solar electricity is a series of technological and business model innovations. Besides the blessings of economies of scale, there is a shift from traditional silicon wafers to printed thin-film PV. Automation is playing a crucial role both in component manufacturing and in building the power plants with robots, drone inspection, remote management via digital platforms connected to IoT smart inverters and meters. Blockchain technology could further help to decentralize the management of distributed energy resources, establish trust and secure transactions without a monopoly player central authority. Software solutions such as automated PV plant design and preventive maintenance also translate to significant cost reductions. Although it is tempting to imagine that hardware improvements could be the key of cost reduction, the fact is that today over 60% of the capital needed for a PV plant is related to such soft costs as client acquisitions, financial service fees, legal fees, installation labour, logistics, grid connection infrastructure and company overhead. Therefore, innovative startups capable of attacking any of these cost components are the main driving force behind turing solar energy cost competitive with conventional generation sources such as natural gas.

Distributed generation rules in Brazil are innovative and forward thinking even in the international context. The remote and shared generation models could democratize the access to renewable energy for millions of energy consumers in Brazil's high rise cities without adequate rooftop access for PV installations. Shared distributed generation resources have the double benefit of harnessing economies of scale, therefore offering low electricity costs, while generating close to the end consumer, therefore eliminating the need of costly electricity transport from remote regions such as the Amazonas basin where large part of the remaining hydroelectric potential is located. A further benefit is the lower environmental and social impact, compared to large scale centralized generation.

ANEEL and the Brazilian legislators as well as the State Governments are in the key position to either enable and incentivise distributed photovoltaic generation or set up further barriers to hinder PV development. This is a great responsibility in face of the fight against human induced climate disruption and also to prepare Brazil for the consequent water shortages and reduced hydroelectric capacity. A new law offering guarantees for long term financing of distributed generation is an indispensable element. Also the exemption of ICMS tax at least for the payback period of distributed generation assets is crucial to turn PV projects economically viable, especially in face of the reintroduction of partial distribution charges.

One of the limitations of the current distributed generation rules is the lack of providing long term economic security for project financing as there is no price guarantee in form of a feed in tariff. It is a difficult challenge for developers to secure long term power purchase agreements with small, low tension consumers effectively. It is recommended that the current legislation be improved by a distributed generation law that provides long term security for investors. Without scalable financing, the PV model offering the best cost benefit to society, that is the shared mini plants of 1 to 5 MW, will not be made possible to develop in Brazil.

The business innovation of the COSOL online platform offers to the distributed PV market the possibility to reduce the barriers between mini power plants, its investors and energy consumers. The high cost of customer acquisition and the effective management of the quotas of energy credits are the two main challenges the COSOL marketplace is designed to improve significantly. In terms of technological innovation the IoT connected power plants and electricity consumers, who could trade the electricity peer to peer by using the blockchain database architecture, the IoRE – Internet of Renewable Energy solution is pioneering in Latin America.

The PV technologies are improving and the efficiencies are getting better. We must make it our goal to, by the end of this century construct the required installed PV capacity and at the same time reducing our energy demand. For this purpose the necessary PV infrastructure projects must be initiated today in Brazil.

The next industrial revolution occurs through the widespread use of renewable sources of clean electricity, replacing polluting fossil power plants and combustion engines. This new era of the anthropocene will be electrically powered by distributed renewable energy resources and managed via the decentralized grid of the internet. It is precisely this combination of power generation from renewable sources with the management and monitoring via an internet platform that innovative startups like COSOL are developing. Such startup companies are paving the way for a new, non polluting, low cost and sustainable industrial era.

6 SUGGESTION FOR FUTURE RESEARCH

6.1 PV model comparison

Economic research focused on the benefits of distributed generation would need to further compare the three options of local rooftop generation, distributed generation in mini power plants close to consumer units such as community solar plants and large, utility scale centralized power plants. The comparison at table 8 in this work is limited to the most generic aspects and represents a basic estimative, not necessarily true for all Brazilian regions as it partly used sources form the international literature that could be misleading. As PV generation will be a very important part of the electricity mix in Brazil, the cost benefit determination and correct pricing of each PV model is crucial for the development.

6.2 Digitalization of power distribution

Internet connected computing devices such as smartphones, personal computers and most recently low cost IoT devices or sensors could be highly beneficial to electricity grid management and power distribution. The architecture of the power grid and the communication Internet is similar and both interwave human settlements. It makes perfect sense to harness the benefits of the low cost, connected digital devices to turn power transactions and grid monitoring easier and more enhanced. Further research would be sought on how to incorporate such digital technology for the benefit of the power grid, electricity generators and consumers.

6.3 Real time pricing and peak matching

Arguably one of the main future challenges of the power grid will be matching up low cost PV generation around the midday solar peak radiation (10:00 to 14:00) to the peak demand hours (18:00 to 22:00) and therefore highest cost of electricity. This will translate to the need to create economic incentives and apply available, cost effective technology to store electricity for around 8 hours daily. It is recommended that such incentive mechanisms and technical solutions would be further researched as a base of future legislation of the sector. The effects of the electrification of vehicles could shelter one of the possible solutions besides the more obvious hydro storage in Brazil.

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APPENDIX I.

COSOL VIRTUAL RENEWABLE ENERGY MARKETPLACE

1.1. Rationale

Climate change and energy security are one of the major challenges facing humanity. Especially in Brazil with its energy matrix mostly based on hydropower (65%), with high risks of energy supply in dry periods and fossil thermoelectricity (30%) with disastrous environmental impacts due to greenhouse gas emissions. For these reasons the National Electric Energy Agency, ANEEL regulated the distributed generation (DG) of energy from renewable sources, giving special privileges to motivate the sector. The Normative Resolution 482 was launched in 2012 but did not reach much success. By the end of 2015 there were only 1650 consumer units connected to DG, installing photovoltaic systems or wind turbines in a market of 50 million consumer units.

The top 5 issues slowing the spread of distributed generation are:

- Lack of **capita**l of energy consumers to cover the high initial investment.
- Low **economic efficiency** and a long (8 years) payback of the investments.
- Lack of **to rooftop access** in vertical cities to install solar panels.
- Lack of **confidence** in suppliers because there are no recognised brands.
- **Bureaucratic** difficulties and **complexity** of the installation process.

Due to the low level of dissemination of the distributed generation, ANEEL updated the rules on the 1st of March 2016, introducing the concepts of remote and shared generation. Based on this change of the legal framework was born the idea of COSOL, the Solar Condominium in order to join the interests of energy consumers and create shared PV plants with remote generation, developing a business model to solve the 5 problems mentioned above. The solution are:

- Separating the investment from energy consumption, charging a monthly fee for the use of solar generation equipment: the **rent.** Thus enabling the use of solar power for small consumers **without** initial **capital investment**.

- **Doubling the economic efficiency**[16] reducing the payback for half the time.
- Remote PV plants provide solution for the lack of **rooftop access**, shading and security issues.
- It is creating a national **brand** associated with shared solar energy.
- Eliminates the need for paperwork and installation with prefabricated plants.

Solving these challenges COSOL enables the distributed generation of renewable sources of energy. The project's main motivation is to provide sustainable energy with low environmental impact by generating significant economic benefits for all involved as the key motivation.

COSOL develops a new process to take advantage of shared and remote renewable energy generation, thus enabling solar energy projects in distributed generation. The innovation of the service is to integrate and apply the technologies, such as the web platform, electronic customer management system, automation of procurement processes, digital helpdesk on 7 channels, payment processing and online registration of properties of shared renewable power plants in the distributed generation. COSOL's innovative process of is the possibility of joining millions of low voltage energy consumers and connect them to thousands of small to mid-sized investors, thus facilitating the creation of a marketplace of shared PV plants.

To separate the role of the energy consumer from the role of the investor solves the biggest challenge of solar energy in Brazil: the high upfront investment. Without the COSOL platform it would not be possible to divide capital investment from the use of renewable energy via rental on a national scale.

In addition to solving the challenge of the initial investment, COSOL also doubles the economic efficiency in three stages:

- Locating the PV plans in areas enjoying the highest possible **solar** radiation of each State, thereby increasing the generation by **20%** compared to urban centers near the coast or in the southern regions.

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[16] http://bit.ly/cosol_dobra_eficiencia

- Harnessing the economies of **scale** of the larger PV facility. A 5 MW power plant cost **30%** less than a small, 5 to 20 kWp rooftop installation.
- The solar **tracking** further increases the generation by **25%** compared to a fixed installation on the roof. However, trackers only become economically viable on installation larger than 1 MW as one motor moves thousands of photovoltaic panels connected in parallel axes.

COSOL's innovative platform could provide joint benefits of these three elements, offering the opportunity to millions of small energy consumers to use solar energy with an exceptional level of economic benefit. Without COSOL these consumers not only lacked access to such economic advantages but often would not even have physical access to the roof to install photovoltaic panels.

Among the minor challenges slowing the spread of solar energy, potentially creating serious problems in the future, especially in the developing world:

- Future risk of **shading**: The height of buildings is not regulated
- In areas where there are no tall buildings access to the roof is often easier, creating an opportunity to a new type of crime: the **theft** of the easily removable solar panels. Given the high value of each plate, around R$ 500 to R$ 1000 each, this threat could become a serious problem.
- The photovoltaic system requires **maintenance,** periodic cleaning and overhaul of equipment that must be made by trained specialists. Besides being a more expensive process in individual roofs, it can also become a source of **danger to** life, because if done without the proper expertise can cause electric shock during cleaning or maintenance and even initiate fires.

With remote and shared PV plants all these problems could be avoided. The power plants would have armed security and professional maintenance staff around the clock. Given the large surface and isolation of the power plants there is no risk of a future shading either.

Although all these details might be important, the greatest benefit of COSOL's innovation is to provide solar energy with an excellent cost benefit ratio that could jumpstart the industrial development of the photovoltaic industry.

COSOL is basically providing to society all the benefits which were devised during the formatting of the new rules of distributed generation by Aneel's Normative Resolution 687 of 2015.

The legislative framework was precisely developed to make the national energy matrix diverse, sustainable and clean, thereby reducing the environmental impacts of the large hydroelectric projects and by lowering emissions caused by fossil thermoelectric plants. The life quality of a society is proportional to the level of use of clean energy resources.

The challenge of turning clean energy technologies mainstream is no longer a technical one as the **technology is mature**. It is basically an economic challenge, especially in developing regions. And COSOL is indeed solving the **economic challenge** by funding PV power plants independent of the financial ability of the end consumers; thus providing them an immediate saving opportunity without requiring any initial investment.

The benefits of our model are not only the improvement of **human health** by avoiding harmful emissions that could be inhaled, but is solving a much larger problem related to **climate change** with potentially disastrous environmental impacts.

Thus COSOL not only solves the economic challenge facing the spread of renewable energy, but also increases the Brazilian industry’s competitiveness to open up a new market for photovoltaic equipments.

COSOL operates in the renewable energy sector, providing an innovative economic model. Our target groups are all power consumers having a low voltage connection, from residential consumers through the commercial and services sectors to smaller industries. The target audience' main motivation is to reduce energy costs without any initial investment and COSOL provides just that.

On the other hand COSOL serves investors, both individual and institutional, national and foreign, offering high performance and a low risk. Investors are looking for an opportunity with a low risk and high return ratio that is guaranteed by the mature technology, by the lack of environmental hazards like earthquake or hurricane in the country and by ANEEL's regulations.

1.2. Objectives

The main objective of the COSOL project is the dissemination of solar energy by offering the best cost benefit ratio in Brazil. It is achieved through the development of an online platform[17] that can act as a virtual marketplace connecting energy consumers, investors and constructors of solar plants. These PV plants can be shared in distributed generation nationwide. The platform will be able to administer and manage this new market of distributed generation.[18]

Specific objectives[19]

1. Connecting investors and energy consumers via Internet
2. Crowdfunding platform of shared PV plants
3. Virtual marketplace for rental of lots and quotas of PV plants
4. Registered user profiles, connected to their PV properties
5. Monitoring of generation properties
6. Monitoring of the current generation, daily, weekly, annual, etc.
7. Providing a knowledge base to the users of the platform
8. Making the society aware of the generation of their own energy
9. Reduction of environmental impacts of energy generation
10. Compliance with the Paris Climate Agreement, COP21

In order to eliminate the main obstacles facing the widespread use of solar energy COSOL offers an innovative process by eliminating the need for high initial investment for the end consumer. Taking advantage of **economies of scale**, greater **insolation** and using **trackers** results in an attractive financial return to investors of any level, both nationally

[17] COSOL - Condomínio Solar accessible via www.cosol.com.br , 2018
[18] Fig 21. - COSOL registered trademark logo
[19] Physical goals project goals:1. - 7. Theoretical and indirect goals: 8. 10.

and abroad and can attract these investments without offering other benefits required by major banks related to foreign governments, thus preserving the **independence** of the national industry.

The project is developing a **virtual marketplace** that, in addition to joining the stakeholders, offers the possibility of **remote monitoring** of the properties of renewable generation for both owners and energy consumers (tenants).

Figure 11. – Solar Allotment (illustration) with logo COSOL

Source: cosol.com.br, 2016

The project addresses the key challenges of the spread of solar power by **connecting** millions of consumers with investors and facilitating **transactions** between them. On the other hand it creates an opportunity to develop the national **industry** of photovoltaic systems, trackers and inverters. There is a significant opportunity offered by the project to directly **involve the population** in the power generation business. It could increase consciousness about the environmental and economic impacts of energy waste. Power generation would no longer be an abstract and distant phenomena of consumer reality but something they could control directly.

This personal experience with power generation may be the first step of a new paradigm characterized by distributed generation, smart grid, smart metering, accounting via blockchain, virtual monitoring in real time, energy independence and electric mobility. Once consumers become familiar with the concept of **controlling energy** generation as property, they will become more **aware** of the sources of emissions. They could influence future energy policy decisions, effectively **defending the environment** via their votes in future elections. Today the issue of power generation is still insignificant for the largest portion of the Brazilian population as a major political issue, even though this is a matter of survival of humanity, considering the effects of climate change.

The COSOL project not only meets the **market demand** for clean and renewable energy sources but, of course, the demand for lowering the costs of energy. Parallel to this also meets the **institutional demand** of the public sector, concerned with compliance of reducing greenhouse gas emissions, as signed by the Paris climate agreement of COP21.

The proposed platform is creating value by the **system** that can serve millions of power consumers, offering immediate **savings** and the use of **clean energy**. At same time it can attract investors of all levels, both Brazilian and foreign, offering the interface to monitor and control the properties of power generation.

Summarizing the above, the general goal of the project is to increase the participation of the solar power and other sources of **renewables** in the energy mix and at the same time to provide an **economic incentive** directly to the consumers without requiring upfront investment.

1.3. Benefits

The proposed platform would offer different benefits for the COSOL **company** itself with its relational database and automation, for the national photovoltaic **industry** and supply chain by increasing demand dramatically and finally for the **society** by enabling the access to low cost, low environmental impact solar energy.

1.3.1. Company

The virtual marketplace of renewable energy to be developed through the project will add features able to **automate** many processes. The main benefit would result from a **relational database** where each share of the plant could be managed, connected to a tenant and owner and monitored as property. The benefit of this database would be the ability to automatically establish the **lease** agreements between owners and tenants. It would offer keeping the **records** updated related to monthly rental fees and monitoring the generation using real time graphical and numerical data comparison. Thus consumers could easily compare utility tariffs and the cost of self consumption to perceive the economic benefits. The online platform tool will open new opportunities and the management of solar lots. One will be able to estimate the economic benefits so the users get a clear understanding of how much they will save through the lease of PV lots of the powerplants. Moreover, it could offer a social impact as it would create a community among users.

In more developed markets such as the US, Europe or Japan the cost of customers acquisition and management in the solar industry is equivalent to the value of the photovoltaic panels, meaning around 30% of the aggregate PV costs. (NREL, 2016) COSOL's virtual market is aimed at reducing this elevated cost to a lower level, effectively increasing the company's and the photovoltaic industry's competitiveness in general.

1.3.2. National industrial

The online market of community solar could create the demand to initiate the **new solar industry** in Brazil. Since our solution **doubles the economic efficiency** of solar energy, **demand** is expected to grow much faster than through expensive rooftop installations. The economic impacts of a new solar industry are immense, creating a **new sector** of jobs, adding value from the mining of raw materials, through processing and manufacturing of the various components of the photovoltaic system to the construction and maintenance of the PV plants.

Harnessing solar energy at a **low cost** means a large impact on the competitiveness of the national economy. Within the next 20 years solar PV is expected to evolve from being the most expensive energy technology to be the most **economical** of all generation alternatives. This is due to the rapid technological development and the fact that the central component, the photovoltaic panel only needs a thin surface material, the cost of which can be reduced thanks to advances in the manufacturing processes. Developing a **national photovoltaic industry** through the increased demand, that results from the platform that COSOL seeks to create, can mean a big difference not only for the solar industry but also for all sectors where the cost and accessibility of energy is a significant factor.

1.3.3. Society

COSOL's model most obvious social benefit is to provide the low voltage energy consumer an immediate **cost reduction** without requiring investments.

Given the Brazilian electricity mix is based mainly on hydropower (60%) and polluting thermoelectric generation (30%) the model of distributed generation using renewable sources offers great potential to **diversify** the energy mix. But the benefit of diversification and consequent increase in energy security would not be possible without the platform that COSOL is proposing, offering high **economic efficiency** and enabling the creation of shared renewable power plants. Once COSOL succeeds in increasing the use of renewable sources of **low environmental impact**, there will a reduction in energy demand generated by nonrenewable sources. This would result in the significant **reduction of greenhouse gas** emissions.

The COSOL platform could provide renewable energy contracting with a **simplified process** to consumers. Today's bureaucratic process could be reduced to a simple **registration** in the COSOL website.

Low costs renewable energy will mean major **social advances** as the energy input is of significant importance in all sectors. New technologies such as **electrified mobility** or artificial intelligence will **increase demand** for electrical energy and release a large part of society from the mechanical tasks that could be replaced by new intelligent technologies using renewable electricity. For this reason it is essential to create models as proposed by COSOL, which can provide easy access to this clean and distributed source.

Finally the most notable social impact is to return the power of energy generation for the individuals. Whether investors or consumers, creating a more direct relationship between generation and consumption, thereby increasing the consciousness about energy and its environmental consequences.

1.4 MARKET ANALYSIS

Although shared renewable energy facilities exist for a few years now in developed markets such as Holland, the US, Australia or Japan, this model is so far nonexistent in

Brazil. As the key feature of COSOL is not the shared generation facility in itself, rather the online marketplace that intermediates between energy consumers, investors, constructors and equipment manufacturers, we can easily confirm that it is an innovative concept with no similar platform in existence in the Brazilian energy market.

1.4.1 Competitor Analysis

According to our market research, we found that the vast majority of companies in the Brazilian solar industry are micro integrators, installing panels on rooftops. In a way COSOL offers electricity and therefore competes not only with solar integrators but also with traditional distribution companies. In addition to the existing power distributors we can consider competitors those companies offering diesel and gas generators for self-consumption as wells. On the other hand COSOL provides a means of investment as crowdfunding, thus competing with banks and investment funds.

The most direct Brazilian competitor considered as a solar energy platform is the Solar Portal that offers information and recommends integrators for rooftop installation.

On the international market we have identified the US based PowerScout and Ethical Electric, both receiving US$ 1 Million each from the US Department of Energy for developing the platform.

> PowerScout project develops a direct-to-consumer eCommerce platform called the PowerScout Community Solar Marketplace that aggregates tens of thousands of residential customers and connects them with high quality community solar projects, accelerating the maturation of a very fragmented market. (PowerScout, 2016)

> Ethical Electric builds a platform to enable the sale of community solar at a significantly lower cost per acquisition than comparable residential solar sales. Ethical Electric will be the first competitive retail electric provider in deregulated states to offer community solar—creating the customer acquisition, finance, and development tools needed to offer solar as a subscription at scale. This project will generate the demand for community solar and a method to deliver it at scale, dramatically increasing the availability and cost-effectiveness of community solar projects. (Ethical Electric, 2016)

In France we contacted Lumo, a renewable crowdfunding platform that has certain features similar to COSOL's. Lumo's CEO, Alex Raguet is currently looking for angel investment in the US. According to Mr Raguet their power plants so far were mostly financed in cooperation with French banks.

1.4.2. Existing energy services

The main alternatives to access electricity in Brazil:

- *Solar Portal* connecting consumers with integrators applying the traditional rooftop model, high initial investment and rooftop access is required. www.portalsolar.com.br
- Existing distributors offering electricity in the traditional way (up to 20% more expensive compared to the offer of COSOL)
- Integrators making assembly in rooftops like *Blue Sol* or *Solar Energy* (requires high initial investment, with long payback 8-9 years)
- Diesel or gas generator installed in the consumer's property (high variable fuel cost and polluting operation)

Table 12. - Estimated return on investment and payback of a 10 kWp solar lot

System size	10 kWp	Investment	R$ 6,00 /Wp	O&M yearly	2% of investment	Inflation rate	8%
Price of energy	R$ 0,66	Energy price increase	12%	PV module amortization rate	0,8%	Consumer price discount	10%
Year	**Production kWh**	**Yearly income**	**O&M**	**Net return per year**	**Net return accumulated**	**ROI**	**Payback**
2017	20.000,00	R$ 11.950,91	R$ 1.199,88	R$ 10.751,03	**R$ 10.751,03**	**17,92%**	17,92%
2018	19.840,00	R$ 13.277,94	R$ 1.295,87	R$ 11.982,07	**R$ 22.733,10**	**19,97%**	37,89%
2019	19.681,28	R$ 14.752,32	R$ 1.399,54	R$ 13.352,78	**R$ 36.085,88**	**22,26%**	60,14%
2020	19.523,83	R$ 16.390,42	R$ 1.511,50	R$ 14.878,91	**R$ 50.964,79**	**24,80%**	84,94%
2021	19.367,64	R$ 18.210,41	R$ 1.632,42	R$ 16.577,99	**R$ 67.542,78**	**27,63%**	112,57%
2022	19.212,70	R$ 20.232,49	R$ 1.763,02	R$ 18.469,48	**R$ 86.012,25**	**30,78%**	143,36%
2023	19.059,00	R$ 22.479,11	R$ 1.904,06	R$ 20.575,05	**R$ 106.587,31**	**34,29%**	177,65%
2024	18.906,52	R$ 24.975,19	R$ 2.056,38	R$ 22.918,81	**R$ 129.506,11**	**38,20%**	215,85%
2025	18.755,27	R$ 27.748,44	R$ 2.220,89	R$ 25.527,54	**R$ 155.033,65**	**42,55%**	258,39%
2026	18.605,23	R$ 30.829,62	R$ 2.398,57	R$ 28.431,06	**R$ 183.464,71**	**47,39%**	305,78%
2027	18.456,39	R$ 34.252,94	R$ 2.590,45	R$ 31.662,49	**R$ 215.127,20**	**52,77%**	358,55%
2028	18.308,74	R$ 38.056,39	R$ 2.797,69	R$ 35.258,70	**R$ 250.385,90**	**58,77%**	417,32%
2029	18.162,27	R$ 42.282,17	R$ 3.021,50	R$ 39.260,67	**R$ 289.646,57**	**65,44%**	482,75%
2030	18.016,97	R$ 46.977,18	R$ 3.263,22	R$ 43.713,96	**R$ 333.360,54**	**72,86%**	555,61%
2031	17.872,83	R$ 52.193,53	R$ 3.524,28	R$ 48.669,25	**R$ 382.029,79**	**81,12%**	636,73%
2032	17.729,85	R$ 57.989,10	R$ 3.806,22	R$ 54.182,88	**R$ 436.212,66**	**90,31%**	727,03%
2033	17.588,01	R$ 64.428,21	R$ 4.110,72	R$ 60.317,49	**R$ 496.530,15**	**100,53%**	827,56%
2034	17.447,31	R$ 71.582,32	R$ 4.439,58	R$ 67.142,74	**R$ 563.672,89**	**111,91%**	939,47%
2035	17.307,73	R$ 79.530,82	R$ 4.794,74	R$ 74.736,07	**R$ 638.408,97**	**124,56%**	1064,03%
2036	17.169,27	R$ 88.361,92	R$ 5.178,32	R$ 83.183,60	**R$ 721.592,56**	**138,64%**	1202,67%
2037	17.031,91	R$ 98.173,63	R$ 5.592,59	R$ 92.581,04	**R$ 814.173,60**	**154,30%**	1356,98%

APPENDIX II.

As demonstrated in the comparison table of chapter 4.1, the economic efficiency of solar generation depends on three main factors:

- Economies of scale
- Solar radiation
- Use of trackers

The following three tables are calculated and downloaded from the PVWatts tool of the National Renewable Energy Laboratory, NREL[20]. The three calculations represent the following models:

1. **1 kWp** of PV capacity installed in **Bom Jesus da Lapa**, BA, receiving some 20% more solar radiation than Salvador, BA, using conventional PV modules with **1 axis tracker**.
2. **1 kWp** of PV capacity installed in Salvador, BA, on a **fixed** support system, facing North with an ideal tilt degree.
3. **0,7 kWp** of PV capacity installed in Salvador, BA, on a **fixed** rooftop support, facing North with and ideal tilt degree. The size of the kWp installed capacity is adjusted to the cost difference of the investment between a small, residential and large utility-scale installation with a 30% difference of the CAPEX due to economies of scale.

[20] http://pvwatts.nrel.gov/pvwatts.php

II.I. PV generation estimate, 1 kWp capacity, Bom Jesus da Lapa, using tracker.

RESULTS

2,014 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value ($)
January	7.58	171	N/A
February	8.01	161	N/A
March	7.74	173	N/A
April	7.49	163	N/A
May	7.32	166	N/A
June	7.27	162	N/A
July	7.59	174	N/A
August	8.36	188	N/A
September	8.47	180	N/A
October	7.72	172	N/A
November	6.75	148	N/A
December	6.87	156	N/A
Annual	**7.60**	**2,014**	**0**

Location and Station Identification

Requested Location	bom jesus da lapa, brazil	
Weather Data Source	(INTL) BOM JESUS DA LAPA, BRAZIL	1.2 mi
Latitude	13.27° S	
Longitude	43.42° W	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Standard
Array Type	1-Axis Tracking
Array Tilt	13.3°
Array Azimuth	0°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1
Ground Coverage Ratio	0.4

Economics

Average Cost of Electricity Purchased from Utility	No utility data available

Performance Metrics

Capacity Factor	23.0%

II.II. PV generation estimate, 1 kWp capacity, Salvador, fixed installation.

RESULTS

1,449 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value ($)
January	5.80	132	N/A
February	6.03	123	N/A
March	5.86	132	N/A
April	5.25	117	N/A
May	5.02	116	N/A
June	4.54	102	N/A
July	4.87	114	N/A
August	5.26	123	N/A
September	5.73	128	N/A
October	5.55	128	N/A
November	5.15	114	N/A
December	5.17	119	N/A
Annual	**5.35**	**1,448**	**0**

Location and Station Identification

Requested Location	salvador, brazil	
Weather Data Source	(INTL) SALVADOR, BRAZIL	3.5 mi
Latitude	13.02° S	
Longitude	38.52° W	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	0°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Economics

Average Cost of Electricity Purchased from Utility	No utility data available

Performance Metrics

Capacity Factor	16.5%

II.III. PV generation estimate, 0,7 kWp capacity, Salvador, fixed installation.

RESULTS

1,014 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value ($)
January	5.80	92	N/A
February	6.03	86	N/A
March	5.86	93	N/A
April	5.25	82	N/A
May	5.02	81	N/A
June	4.54	72	N/A
July	4.87	80	N/A
August	5.26	86	N/A
September	5.73	90	N/A
October	5.55	90	N/A
November	5.15	80	N/A
December	5.17	83	N/A
Annual	**5.35**	**1,015**	**0**

Location and Station Identification

Requested Location	salvador, brazil
Weather Data Source	(INTL) SALVADOR, BRAZIL 3.5 mi
Latitude	13.02° S
Longitude	38.52° W

PV System Specifications *(Residential)*

DC System Size	0.7 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	0°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Economics

Average Cost of Electricity Purchased from Utility	No utility data available

Performance Metrics

Capacity Factor	16.5%

Appendix III.

Photovoltaic Power Plants in Operation in Brazil in August 2019 - ANEEL BIG

PV power plant name	Start of operation	Installed Capacity (kW)	Owner	Location: City - STATE
Apodi I	28-11-2018	33 000,00	100% para APODI I ENERGIA SPE S/A	Quixeré - CE
Apodi II	28-11-2018	33 000,00	100% para APODI II ENERGIA SPE S/A	Quixeré - CE
Apodi III	28-11-2018	33 000,00	100% para APODI III ENERGIA SPE S/A	Quixeré - CE
Apodi IV	28-11-2018	33 000,00	100% para APODI IV ENERGIA SPE S/A	Quixeré - CE
Paracatu 3	09-01-2019	33 000,00	100% para SOLAIRE PARACATU III ENERGIA SOLAR SPE S.A	Paracatu - MG
Paracatu 4	09-01-2019	33 000,00	100% para SOLAIRE PARACATU IV ENERGIA SOLAR SPE S.A	Paracatu - MG
Paracatu 1	09-01-2019	33 000,00	100% para SOLAIRE PARACATU I ENERGIA SOLAR SPE S.A.	Paracatu - MG
Paracatu 2	09-02-2019	33 000,00	100% para SOLAIRE PARACATU II ENERGIA SOLAR SPE S.A.	Paracatu - MG
Floresta II	23-12-2017	32 000,00	100% para SOLAIRE FLORESTA II ENERGIA SOLAR SPE S.A	Areia Branca - RN
Floresta I	23-12-2017	32 000,00	100% para SOLAIRE FLORESTA I ENERGIA SOLAR SPE S.A	Areia Branca - RN
Guimarania 1	12-12-2018	31 000,00	100% para GUIMARANIA I SOLAR SPE S.A.	Guimarânia - MG
Guimarania 2	12-12-2018	31 000,00	100% para GUIMARANIA II SOLAR SPE S.A.	Guimarânia - MG
Assuruá	06-02-2018	30 500,00	100% para SPE ASSURUA GERADORA DE ENERGIA SOLAR S.A	Itaguaçu da Bahia - BA
Guaimbé 1	13-03-2018	30 000,00	100% para GUAIMBÉ I PARQUE SOLAR S.A.	Guaimbê - SP
Guaimbé 2	06-02-2018	30 000,00	100% para GUAIMBÉ II PARQUE SOLAR S.A.	Guaimbê - SP
Guaimbé 3	03-10-2018	30 000,00	100% para GUAIMBÉ III PARQUE SOLAR S.A.	Guaimbê - SP
Guaimbé 4	26-04-2018	30 000,00	100% para GUAIMBÉ IV PARQUE SOLAR S.A.	Guaimbê - SP
Guaimbé 5	13-04-2018	30 000,00	100% para GUAIMBÉ V PARQUE SOLAR S.A.	Guaimbê - SP
Bom Jesus da Lapa I	30-06-2017	30 000,00	100% para Enel Green Power Bom Jesus da Lapa Solar S.A.	Bom Jesus da Lapa - BA
Bom Jesus da Lapa II	30-06-2017	30 000,00	100% para Enel Green Power Bom Jesus da Lapa Solar S.A.	Bom Jesus da Lapa - BA
Nova Olinda 8	09-12-2017	30 000,00	100% para Enel Green Power Nova Olinda Norte Solar S.A	Ribeira do Piauí - PI
Nova Olinda 9	09-12-2017	30 000,00	100% para Enel Green Power Nova Olinda Norte Solar S.A	Ribeira do Piauí - PI
Nova Olinda 10	09-12-2017	30 000,00	100% para Enel Green Power Nova Olinda B Solar S.A	Ribeira do Piauí - PI
Nova Olinda 11	09-12-2017	30 000,00	100% para Enel Green Power Nova Olinda B Solar S.A	Ribeira do Piauí - PI
Nova Olinda 12	09-12-2017	30 000,00	100% para Enel Green Power Nova Olinda C Solar S.A	Ribeira do Piauí - PI
Nova Olinda 13	09-12-2017	30 000,00	100% para Enel Green Power Nova Olinda C Solar S.A	Ribeira do Piauí - PI
Nova Olinda 14	09-12-2017	30 000,00	100% para Enel Green Power Nova Olinda Sul Solar S.A	Ribeira do Piauí - PI
Pirapora 2	18-05-2016	30 000,00	100% para PIRAPORA II ENERGIAS RENOVAVEIS S.A.	Pirapora - MG
Pirapora 3	04-05-2018	30 000,00	100% para PIRAPORA III ENERGIAS RENOVAVEIS S.A.	Pirapora - MG
Pirapora 4	04-05-2018	30 000,00	100% para PIRAPORA IV ENERGIAS RENOVAVEIS S.A.	Pirapora - MG
Pirapora 5	26-09-2017	30 000,00	100% para Pirapora V Energias Renováveis S.A	Pirapora - MG
Pirapora 6	06-10-2017	30 000,00	100% para Pirapora VI Energias Renováveis S.A	Pirapora - MG
Pirapora 7	26-09-2017	30 000,00	100% para Pirapora VII Energias Renováveis S.A	Pirapora - MG
Pirapora 9	26-09-2017	30 000,00	100% para Pirapora IX Energias Renováveis S.A	Pirapora - MG
Pirapora 10	26-09-2017	30 000,00	100% para Pirapora X Energias Renováveis S.A.	Pirapora - MG
Juazeiro Solar I	12-12-2018	30 000,00	100% para CENTRAL FOTOVOLTAICA JUAZEIRO SOLAR I SPE	Juazeiro - BA
Juazeiro Solar II	18-12-2018	30 000,00	100% para CENTRAL FOTOVOLTAICA JUAZEIRO SOLAR II SPE	Juazeiro - BA
Juazeiro Solar III	13-12-2018	30 000,00	100% para CENTRAL FOTOVOLTAICA JUAZEIRO SOLAR III SPE	Juazeiro - BA
Juazeiro Solar IV	19-12-2018	30 000,00	100% para CENTRAL FOTOVOLTAICA JUAZEIRO SOLAR IV SPE	Juazeiro - BA
Assú V	23-12-2017	30 000,00	100% para CENTRAL FOTOVOLTAICA ASSU V LTDA	Açu - RN
Lapa 3	30-06-2017	30 000,00	100% para Enel Green Power Nova Lapa Solar S.A	Bom Jesus da Lapa - BA
Sertão 1	09-09-2017	30 000,00	100% para SERTÃO I SOLAR ENERGIA SPE S.A.	João Costa - PI
Sobral 1	09-09-2017	30 000,00	100% para Sobral I Solar Energia SPE Ltda	São João do Piauí - PI
Lapa 2	30-06-2017	30 000,00	100% para Enel Green Power Nova Lapa Solar S.A	Bom Jesus da Lapa - BA
Fazenda Esmeralda	18-04-2019	29 000,00	100% para ESMERALDA ENERGIAS RENOVÁVEIS S.A.	Agrestina - PE
Horizonte MP 1	17-03-2018	28 700,00	100% para Enel Green Power Horizonte MP Solar S.A.	Tabocas do Brejo Velho - BA
Horizonte MP 2	15-03-2018	28 700,00	100% para Enel Green Power Horizonte MP Solar S.A.	Tabocas do Brejo Velho - BA
Ituverava 1	05-08-2017	28 000,00	100% para Enel Green Power Ituverava Norte Solar S.A.	Tabocas do Brejo Velho - BA
Ituverava 2	28-11-2017	28 000,00	100% para Enel Green Power Ituverava Norte Solar S.A.	Tabocas do Brejo Velho - BA
Ituverava 3	04-11-2017	28 000,00	100% para Enel Green Power Ituverava Solar S.A.	Tabocas do Brejo Velho - BA
Ituverava 4	23-12-2017	28 000,00	100% para Enel Green Power Ituverava Solar S.A.	Tabocas do Brejo Velho - BA
Ituverava 5	23-12-2017	28 000,00	100% para Enel Green Power Ituverava Sul Solar S.A	Tabocas do Brejo Velho - BA
Ituverava 6	23-12-2017	28 000,00	100% para Enel Green Power Ituverava Sul Solar S.A	Tabocas do Brejo Velho - BA
Ituverava 7	29-12-2017	28 000,00	100% para Enel Green Power Ituverava Sul Solar S.A	Tabocas do Brejo Velho - BA
Angico I	29-09-2018	27 000,00	100% para ANGICO ENERGIAS RENOVÁVEIS LTDA.	Malta - PB
Malta	27-10-2018	27 000,00	100% para MALTA ENERGIAS RENOVÁVEIS LTDA.	Malta - PB
Coremas I	01-02-2019	27 000,00	100% para COREMAS I GERAÇÃO DE ENERGIA SPE S.A	Coremas - PB

Photovoltaic Power Plants in Operation in Brazil in August 2019 - ANEEL BIG

PV power plant name	Start of operation	Installed Capacity (kW)	Owner	Location: City - STATE
Vazante 1	16-12-2017	27 000,00	100% para Vazante I Energias Renováveis S.A.	Pirapora - MG
Vazante 2	07-12-2017	27 000,00	100% para Vazante II Energias Renováveis S.A.	Pirapora - MG
Vazante 3	07-12-2017	27 000,00	100% para Vazante III Energias Renováveis S.A.	Pirapora - MG
Coremas II	16-10-2018	27 000,00	100% para COREMAS II GERAÇÃO DE ENERGIA SPE S.A	Coremas - PB
São Pedro II	08-11-2018	27 000,00	100% para Central Fotovoltaica São Pedro II Ltda	Bom Jesus da Lapa - BA
São Pedro IV	08-11-2018	27 000,00	100% para Central Fotovoltaica São Pedro IV Ltda	Bom Jesus da Lapa - BA
Sol do Futuro I (Steelcons Sol do Fu	02-03-2019	27 000,00	100% para CENTRAL FOTOVOLTAICA SOL DO FUTURO I S.A.	Aquiraz - CE
Sol do Futuro II (Antiga Steelcons S	02-03-2019	27 000,00	100% para CENTRAL FOTOVOLTAICA SOL DO FUTURO II S.A	Aquiraz - CE
Sol do Futuro III (Antiga Steelcons S	02-03-2019	27 000,00	100% para CENTRAL FOTOVOLTAICA SOL DO FUTURO III S.A.	Aquiraz - CE
Floresta III	23-12-2017	22 000,00	100% para SOLAIRE FLORESTA III ENERGIA SOLAR S.A	Areia Branca - RN
Horizonte MP 11	17-03-2018	20 000,00	100% para Enel Green Power Horizonte MP Solar S.A.	Tabocas do Brejo Velho - BA
BJL 11	12-05-2018	20 000,00	100% para BJL11 SOLAR S.A.	Bom Jesus da Lapa - BA
BJL 4	07-12-2018	20 000,00	100% para BJL4 SOLAR S.A.	Bom Jesus da Lapa - BA
Verde Vale III	22-08-2018	14 300,00	100% para UFV VERDE VALE III ENERGIA SOLAR S/A	Guanambi - BA
Tauá	01-07-2011	5 000,00	100% para TAUA GERACAO DE ENERGIA LTDA.	Tauá - CE
Fontes Solar I	02-09-2015	5 000,00	100% para Enel Soluções Energéticas Ltda,	Tacaratu - PE
Fontes Solar II	08-09-2015	5 000,00	100% para Enel Soluções Energéticas Ltda,	Tacaratu - PE
Sol Maior 2	06-02-2019	5 000,00	100% para SOL MAIOR GERADORA DE ENERGIA S.A.	Miracema do Tocantins - TO
Oiapoque	26-10-2017	4 039,00	100% para OIAPOQUE ENERGIA SA	Oiapoque - AP
Ita 01	09-03-2019	3 375,00	100% para MULTIPLAN EMPREENDIMENTOS IMOBILIÁRIOS S/A	Itacarambi - MG
Ita 02	09-03-2019	3 250,00	100% para MULTIPLAN EMPREENDIMENTOS IMOBILIÁRIOS S/A	Itacarambi - MG
Nova Aurora	31-03-2014	3 068,00	100% para ENGIE BRASIL ENERGIA S.A.	Tubarão - SC
Sol Moradas Salitre e Rodeadouro	12-02-2014	2 103,00	100% para Brasil Solair Energias Renováveis Comércio e Indústria S.A	Juazeiro - BA
Central Mineirão	25-04-2014	1 418,00	100% para CEMIG GERAÇÃO E TRANSMISSÃO S.A	Belo Horizonte - MG
Solar Alto do Rodrigues	14-05-2014	1 100,00	100% para PETRÓLEO BRASILEIRO S A PETROBRAS	Alto do Rodrigues - RN
Tanquinho	-	1 082,00	100% para SPE CPFL SOLAR 1 ENERGIA S.A.	Campinas - SP
Fazenda Ouro Branco	31-07-2018	1 000,00	100% para Arni Alberto Spiering	Porto dos Gaúchos - MT
Sergio Varnier	30-04-2018	960,00	100% para SILVANA MARIA VEZZOTO VARNIER	Campo Novo do Parecis - MT
Solar Dos Sambaquis	01-01-2019	960,00	100% para USINA FOTOVOLTAICA SOLAR DOS SAMBAQUIS	Miguel Pereira - RJ
Solar Das Brisas	01-01-2019	960,00	100% para USINA FOTOVOLTAICA SOLAR DAS BRISAS LTDA	Miguel Pereira - RJ
Solar Dos Palmares	01-01-2019	960,00	100% para USINA FOTOVOLTAICA SOLAR PALMARES LTDA	Nova Iguaçu - RJ
MEGAWATT SOLAR	24-06-2014	930,00	100% para Companhia de Geração Térmica de Energia Elétrica	Florianópolis - SC
Fazenda Solar	01-06-2015	900,00	100% para Enel Green Power Fazenda S.A.	Alta Floresta - MT
Vitoria Stone	24-01-2019	757,90	100% para VITORIA STONE INDUSTRIA E COMERCIO S/A	Serra - ES
CENTRAL SOLAR ITACÁ III	20-06-2016	750,00	100% para ITACA ENERGIA S/A	Arceburgo - MG
ALGAR TECH	12-02-2016	655,00	100% para Algar Tecnologia e Consultoria S.A	Uberlândia - MG
TV Globo	26-05-2017	470,40	100% para GLOBO COMUNICACAO E PARTICIPACOES S/A	Rio de Janeiro - RJ
Pituaçu Solar	-	404,80	100% para Superintendência dos Desportos do Estado da Bahia	Salvador - BA
Loréal Innova	18-05-2018	330,00	100% para L'OREAL BRASIL PESQUISA E INOVACAO LTDA.	Rio de Janeiro - RJ
Dallon Solar	09-10-2018	150,00	100% para DALLON PLASTICOS LTDA	Rolândia - PR
GLOBO BRASIL	01-01-2018	117,00	GLOBO BRASIL INDUSTRIA DE PAINEIS SOLARES E ACM	Valinhos - SP

Source: ANEEL, BIG; 2019