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Solar energy in Latin America: A review of the of the four leading markets

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SOCIOLOGIA
E POLÍTICAS PÚBLICAS

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Dedication: To my family and my nephew Pierce Benjamin

Acknowledgement

I would like to give my gratitude to my family for their love and infinite support. Though I miss you all dearly, this experience has been one of the most incredible of my life. Thank you for always believing in me and pushing me to reach my potential. I would not be the man I am today without you all. I would like to thank my nephew, Pierce Benjamin, who I have yet to meet, for bringing light into my life with his beautiful smile. I cannot wait to see you in real life. Thank you to my friends old and new for their encouragement and helping me to recognize my worth and reminding me that I have a lot to offer to this world.

A huge thanks to my supervisor Catarina, for sharing her wisdom and wealth of knowledge, and wonderfully positive spirit and energy. I am inspired by your passion for sustainability and deeply respect you for your invaluable perspectives on how to address the challenges of climate change. You have opened my mind to new patterns of thought which is something I will carry with me for years to come. I greatly appreciated your advice and consistently rapid feedback. Thank you so much for your patience and excellent guidance throughout this process.

Resumo

Um método que os países de todo o mundo estão a utilizar para fugir aos combustíveis fósseis é através do aumento da quota de energias renováveis na produção de eletricidade. Investir em projetos de energia eólica e solar é a opção menos dispendiosa para a produção de eletricidade em muitas partes do mundo, devido à queda significativa dos custos nos últimos anos. A energia solar é especialmente rentável em locais com grande radiação solar, como a América Latina.

Estes custos mais baixos levaram a que a energia solar fosse uma opção atraente para geração de eletricidade na região. Assim, a capacidade dos painéis solares fotovoltaicos cresceu significativamente nos últimos cinco anos especificamente no Brasil, México, Chile e Argentina. Este crescimento pode ser atribuído ao apoio dos governos através de várias políticas regulatórios e outros mecanismos, como os leilões de energias renováveis. Este trabalho procura fornecer uma visão geral da indústria solar na América Latina, focando-se nos quatro maiores mercados acima listados. Analisará os sectores de eletricidade, o estado atual da indústria, avaliará os mecanismos de apoio utilizados para ajudar a estabelecer o mercado e discute barreiras e obstáculos comuns. A dissertação terminará com uma análise comparativa dos quatro mercados elaborando as razões pelas quais o Brasil e o Chile têm tido relativamente mais sucesso no desenvolvimento da indústria solar, as razões dos lentos progressos verificados na Argentina e as questões que o México enfrenta devido à atual administração.

Palavras-chave: solar fotovoltaico, leilões de energia renovável, setor elétrico, América Latina

Abstract

One method countries around the world are employing to transition away from fossil fuels is through increasing the share of renewable energy in electricity generation. Wind and solar energy projects are the least expensive option for electricity generation in many parts of the world due to costs falling significantly over the past several years. Solar energy is especially cost effective in places with high solar radiation such as Latin America.

These lower costs have led to solar energy being an attractive option for satisfying the growing electricity demand in the region. Capacity in photovoltaic solar plants therefore grew significantly over the past five years specifically in Brazil, Mexico Chile and Argentina. This growth can be partially attributed to the government support through various regulatory policies and other mechanisms such as renewable energy auctions. This work seeks to provide an overview of the solar industry in Latin America, focusing on the four largest markets listed above, looking at their electricity sectors, the current state of the industry, evaluating the most effective support mechanisms used to help establish the market, and discussing common barriers. The report will end with a comparative analysis of the four markets, elaborating on why Brazil and Chile have been relatively more successful in developing the solar industry, the reasons for the slow progress witnessed in Argentina, and the issues Mexico is facing due to the current administration.

Key words: solar photovoltaic, renewable energy auctions, electricity sector, Latin America

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Glossary of Abbreviations

ABCM – Argentina, Brazil, Chile, Mexico

BNEF – Bloomberg New Energy Finance

BNDES – National Development Bank of Brazil

CO_2 – Carbon dioxide

CEC – Clean Energy Credits

CFE – Federal Electricity Commission (Mexico)

CNE – National Energy Commission

DG – Distributed Generation

EY – Ernst & Young

FF – Fossil fuels

FODER – Renewable Energy Fund (Argentina)

FODIS – Distributed Generation Fund

FIT – Feed in tariffs

GDP – Gross domestic product

GHG – Greenhouse gas

GHI – Global horizontal irradiation

GW(h) – Gigawatt(hour)

IEA – International Energy Agency

IFC – International Finance Corporation

IDB – Inter-American Development Bank

IRENA – International Renewable Energy Agency

kW(h) Kilowatt (hour)

kWp – Kilowatt peak

LAC – Latin America and the Caribbean

LCOE – Levelized Cost of Energy

LULUCF – Land use, land-use change and forestry

LTA – Long term auction

MATER – Renewable Energy Term Market (auction mechanism)

MW(h) – Megawatt (hour)

MME – Ministery of Mines and Energy

MEM – Wholesale electricity market (Mexico)

NCRES – Nonconventional Renewable Energy Sources

NDC – Nationally Determined Contributions

PPA – Power Purchase Agreement

PV – Photovoltaic

RECAI – Renewable Energy Country Attractiveness Index

REN21 – Renewable Policy Network for the 21st Century

RPS – Renewable Portfolio Standards

SENER – Mexico Ministry of Energy

CENACE – National Energy Control Center

SOE – State Owned Enterprise

UNFCC - United

USD – United States Dollar

VAT – Value Added Tax

CHAPTER 1

Introduction

In response to the growing concerns over anthropogenic global warming and resulting natural disasters that are occurring with rising frequency and severity, 195 nations that make up the United Nations Framework Convention on Climate Change (UNFCCC) drafted the Paris Agreement in 2015. In December of 2016 the PA was ratified as a global consensus that the world needs to collectively act to mitigate the consequences of climate change with the goal of limiting the global average temperature to well below 2ºC in comparison to pre-industrial levels, with a concerted effort to keep warming to 1.5ºC (UNFCCC, 2015). The current nationally determined contributions (NDCs) defined to reach the goals of the accord will not achieve sufficient emission reductions by 2030 to reach the goal of limiting warming to 1.5ºC and delays will result in more drastic effects of climate change including greater costs to economies and result in more challenges maintaining warming well below 2ºC (IPCC, 2018). According to a transition pathway outlined in a recent report by International Renewable Energy Agency (IRENA), Global Renewables Outlook, the use of renewable energy and energy efficiency, offer the potential to reduce over 90% of carbon dioxide emissions necessary by 2050 to accomplish the goals of the Paris Agreement (IRENA$_b$, 2020). Working towards net-zero emissions is entirely feasible as the cost of renewable energies such as wind and solar are the least expensive option for investing in electricity generation in more than two-thirds the world (BNEF, 2019); moreover decarbonizing economies can also provide millions of jobs, save billions of dollars in stranded assets, aid in making steps towards fulfilling the United Nations Sustainable Development Goals, as well as reducing harmful health impacts stemming from pollution (IDB, 2019).

IRENA predicts that in order to achieve an energy transition, solar would play a significant role and could potentially become the second largest source of electricity, behind wind, and provide at least 25% of the world's electricity needs in the future (IRENA$_b$, 2020). In Latin America and the Caribbean (LAC), it is already less expensive to install a wind or solar farm than to build a new fossil fuel plant (BNEF, 2019). The energy mix in LAC is one of the cleanest among emerging markets due to the large share of hydropower; however, droughts have put the energy supply at risk and resulted in unstable prices due to a shortage of dam reservoirs and a lack of supply in many countries (Aquila et al., 2017). Wind energy is a more established energy source in the region with 5% of the energy generation with solar at less than 1% in 2018 (BNEF, 2019) and although it has grown, the incipient market for solar PV remains relatively untapped. Countries in LAC have incredible potential with significantly higher levels of solar radiation than markets like Germany, a world leader in the solar industry (Pravalie et al., 2019). Capacity growth has mostly been limited to Brazil, Chile, Mexico and Argentina. These countries make great case studies as four of the largest economies, with notable contributions to the region's greenhouse gas (GHG) emissions. The goal of this work is to provide an overview of the top four markets for solar

energy in Latin America; it seeks to analyze the history of the electricity sector, the various regulatory policies employed by governments (with a greater focus on auctions for renewable energy), and finally how the economic and political environments along with other barriers have influenced the growth of the market in Argentina, Brazil, Chile, and Mexico.

The first section of this work will provide a brief overview of global energy and electricity consumption. Next the literature review will describe the main sources used to support this research. The following chapter will open with a discussion of trends in the Levelized Cost of Energy (LCOE) of Non-conventional Renewable Energy Sources (NCRES). expand on solar energy, the state of the global markets, specifically in respect to photovoltaic (PV) solar, and explain the current technologies in use. The fourth section will provide a broad look at the Latin America and Caribbean region, which has excellent potential for taking advantage of the high levels of solar radiation. The next sections will present country profiles for Argentina, Brazil, Chile, and Mexico, the four leading markets of the solar industry in the region. After providing a base of information about the PV solar industry in these countries, the final section will compare and contrast the various policy support mechanisms that enabled each country to reach the level of growth witnessed today. The comparative analysis will be performed using a market attractiveness framework to rate the countries in various categories and discuss relative strengths and weaknesses. After this discussion, the results will be resumed in the conclusion.

1.1. Global Energy Overview

The global primary energy consumption in 2018 increased by 2.9% from 2017, the highest growth witnessed since 2010, and amounted to an additional 2% of carbon dioxide (CO_2) emissions (BP, 2019). Natural gas accounted for more than 40% of this growth due to a larger number of days with extreme temperatures resulting in a greater demand for heating and cooling (BP, 2019). Following this spike in energy consumption, the rate fell by more than half (1.3%) and the emissions also dropped below the average growth rate witnessed over the last ten years (1.1.%) to .5% (BP, 2020). Coal consumption decreased in 2019 while renewable energy consumption reached a new record, however oil and natural gas consumption also increased and coal remained the largest source for power generation with 36% compared to 11% generated by renewable energy (BP, 2020). York and Bell argue that in order for an energy transition to occur, renewable sources must replace fossil sources not simply supplement to increase the energy supply (2019). Historically there is a trend for an increase in consumption of all energy sources despite some periods of decline (see Figure 1.1). According to predictions in the Bloomberg New Energy Finance (BNEF) Climatescope report, the global energy needs in 2050 could increase upwards of 62% from 2018, with 70% of the demand coming from emerging economies (BNEF, 2019). The report also highlights the continued reliance on coal in emerging economies. In 2018 nearly half of the energy produced, in the countries covered in the Emerging Markets Outlook, was from

coal; however, over half of the added capacity in these markets was clean energy (BNEF, 2019). Amidst the global pandemic, 2020 poses an exceptional case and energy demand in the first quarter fell by nearly 4% and emissions are projected to decline by 8% (IEA, 2020). As most sectors of the economy slowed, so too did some aspects of the renewables sector, but it is essential for governments to use this as an opportunity to combine economic recovery with growth in renewables (FS-UNEP, 2020). It is possible to make 2019 the peak of global emissions and with continued deployment of renewable energies along with other mitigation efforts, a genuine energy transition could be underway.

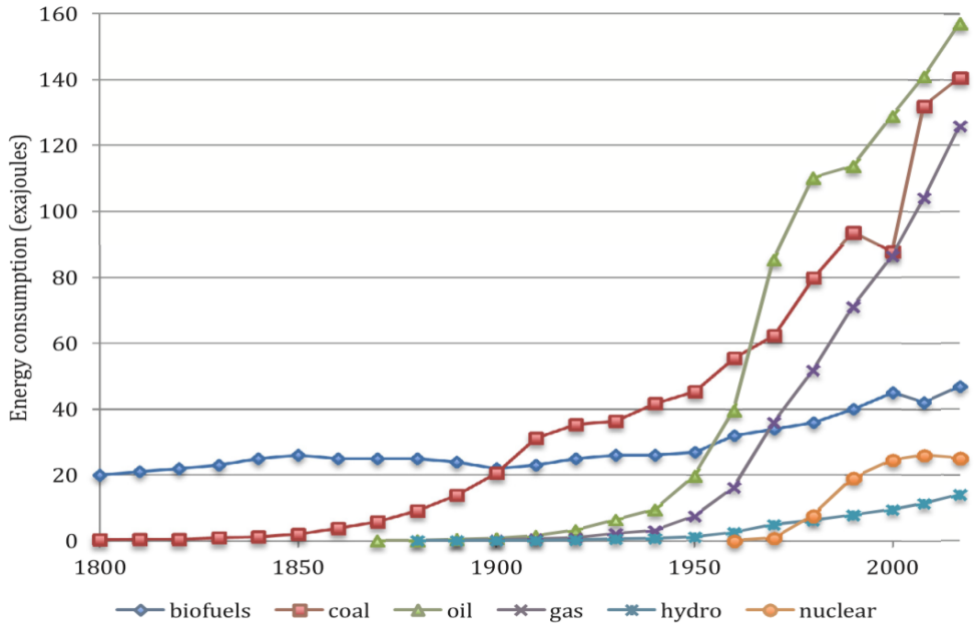
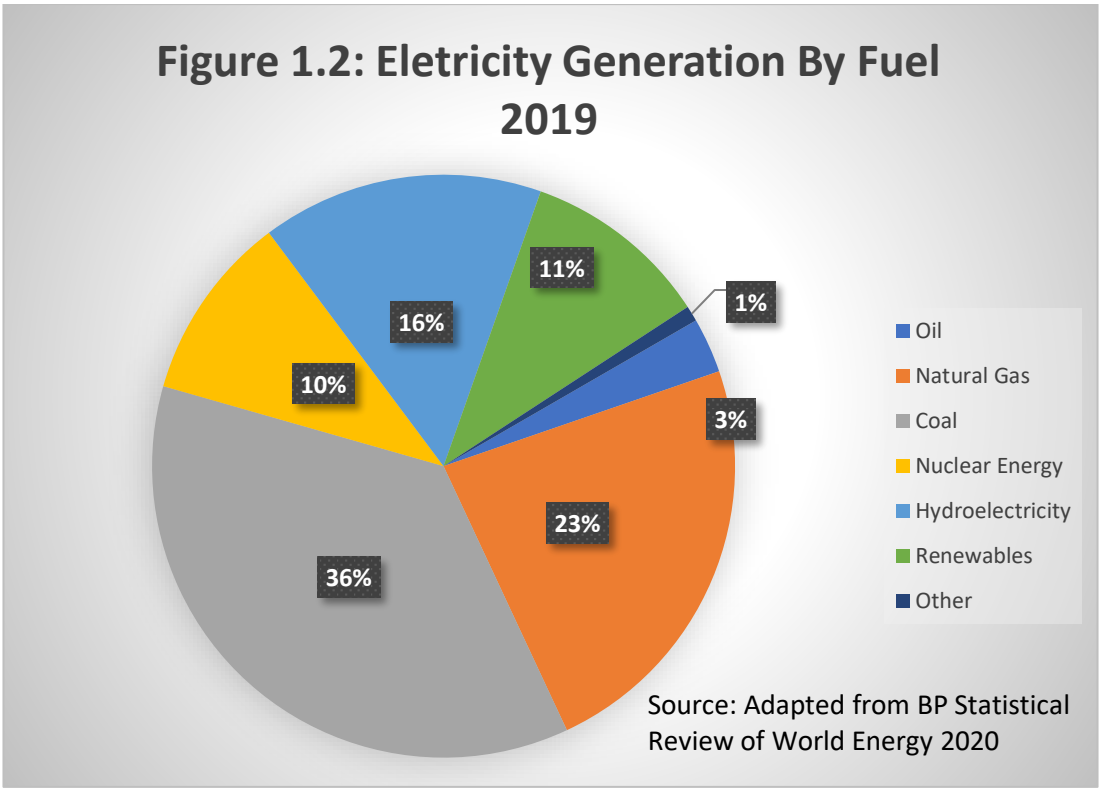


Figure 1.1: Global Energy Consumption by Source (York & Bell)

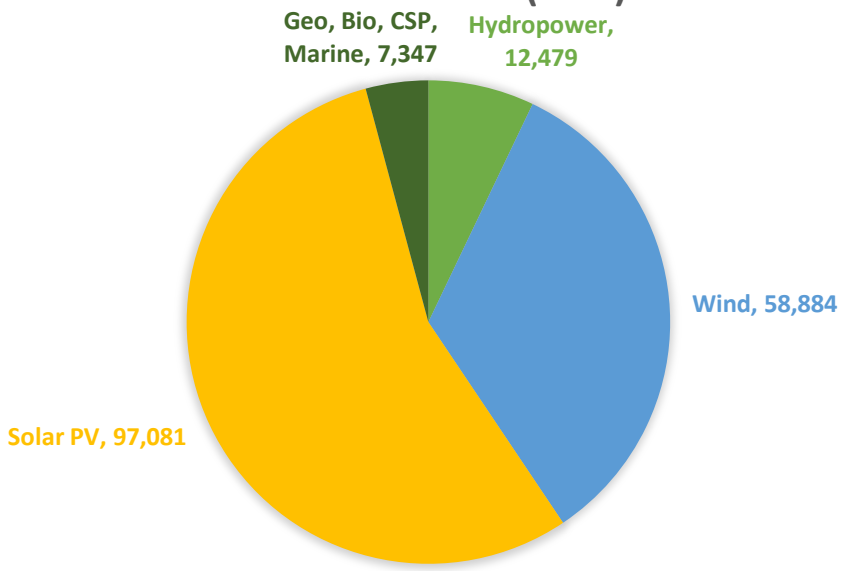
A key step in making this transition a reality is increasing the share of electricity production coming from NCRES. Figure 1.2 shows the makeup of the global electricity matrix by fuel. Last year marked a shift in the right direction as electricity production from oil and coal decreased, but electricity from natural gas increased by 3.5% (BP, 2020). The share of NCRES in electricity production grew by 13.6% in 2019 (BP, 2020).



1.2. NCRES Overview

The global renewable energy cumulative capacity at the end of 2019, including wind, solar PV, Concentrating Solar Thermal Power (CSP) Biofuels, Hydropower, and Marine energy, reached over 2,356 GW (IRENA$_b$, 2020). The added 175 GW over the year marked a nearly 7% increase from 2018 majorly led by growth in solar PV and wind power (see Figure 1.3). Solar PV capacity grew by 25% and wind energy by almost 10% (IRENA$_b$, 2020). According to the Frankfurt School and UNEP study, these additions were the highest ever, and investment was also up from last year at $282.2 billion (2020). In order to make an energetic transition possible, the world will need to take advantage of all various sources that are available in each country. Solar energy is a less mature technology, but growing rapidly, and this work focuses more on ways the industry is being supported to increase the generation of solar photovoltaic energy.

FIGURE 1.3: GLOBAL INCREASE IN RENEWABLE ENERGY CAPACITY (MW) 2019



Source: Adapted from IRENA Renewable Energy Statistics 2020

Source disclaimer: International Renewable Energy Agency (IRENA) was the main source used to review data on renewable energy capacities because other organizations such as the International Energy Agency (IEA) do not provide detailed data on all four countries that this report seeks to analyze. Although the data provided for the member countries of the IEA is more complete and includes more detailed data in regard to distributed generation capacities, the reports are lacking specific data for Brazil and Argentina.

CHAPTER 2

Literature Review

2.1. Renewable Energy Systems

In order to decarbonize economies, countries are investing in non-conventional renewable energy sources (NCRES) such as wind, solar, biomass, geothermal, tidal, and small-scale hydropower plants. Many of the resources supporting this work that address renewable energy systems are reports by various international organizations such as the Renewable Policy Network for the 21st century (REN21), the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), Bloomberg New Energy Finance, (BNEF) and the Inter-American Development Bank (IDB). IRENA has a wide array of reports, some including yearly updates on capacity ($IRENA_a$, 2019; $IRENA_b$, 2020) regional reports such as an analysis of markets in Latin America (IRENA, 2016), as well as analyses on the levelized cost of electricity (LCOE) for various NCRES, exploring the reasons for downward trends (IRENA, 2018). In the report Global Renewables Outlook: Energy Transformation 2050, the organization's huge database of statistics is used to make predictions on how to move towards a more sustainable future ($IRENA_a$, 2020). In the Statistical Review of World Energy (BP, 2020) and the World Energy Outlook, (IEA, 2019), British Petroleum and IEA provide information about global energy trends looking at industry trends, fossil fuel and renewable energy consumption. REN21 is an organization compiling data from governments, scientific studies, non-governmental organizations and other actors in the renewable energy industry, and the yearly global status report provides a comprehensive assessment of developments in the renewable energy markets around the world (REN21, 2020).

BNEF and IDB provide studies on investment trends for renewable energy specifically in developing markets. The Emerging Markets Outlook highlights markets that are attracting attention for the recent growth in NCRES, and explains the main factors leading to this growth (BNEF, 2019). The development bank's report on The Evolution of Costs of Renewable Energy and Storage focuses more specifically on the cost breakdown and potential for continued decreases in price (Garcia de Fonseca et al., 2019). Vega-Coloma and Zaror rate the environmental impact of electricity generation from different sources like GHG emissions in comparison to renewables, demonstrating the vast benefits of renewable energy sources for healthy humans and ecosystems (2018). Kabir et al., share the value of solar energy: its abundance, lower emissions, less water consumption than with fossil fuels, and job creation (2018). In another study, the advantages of electricity supply security and insulation from imported volatile fossil fuel prices are explored (Corrêa da Silva et al., 2016). Other articles relevant to this work focus more specifically on the progression and current state of solar photovoltaic (PV) technology. Zurita et al. provide an extensive study on the various types of solar panels, and how geography can greatly affect production (2018). De Souza and Cavalcante talk about the truly globalized nature of solar energy, how

the supply chain of solar is very influenced by large players in the industry, especially China, and it is important for countries to consider how to adapt to best fit in and learn from industry leaders (2016).

2.2. Potential Energy Transitions

As previously stated, the shares of NCRES must grow significantly in the coming years to bring about a replacement of fossil fuels and not just supplement current consumption with additional capacity (York & Bell, 2019). There are studies exploring the strong correlation between rising emissions and growing economies (Hdom, 2019; BNEF, 2019), while some other articles analyze the difficulties of breaking this trend and allowing lower income countries to maintain economic growth while achieving their NDCs for a just transition (Nieto et al., 2018; Postic et al., 2017). Recent reports explore practical pathways to use decarbonization as a means to continue GDP growth while working towards net zero emissions by 2050 (IDB & DPPLAC, 2019; IRENA$_a$, 2020;).

Some research explores specific combinations of different NCRES necessary to provide enough electricity even with the intermittent nature of wind and PV as they only produce when the wind is blowing or during the day when the sun is shining (Garcia-Heller et al., 2016). Using these sources in combination with storage or hydropower, a relatively stable source in comparison can be a good option for providing a base of only renewable energy (De Barbosa et al., 2017). Other studies look at the opportunity to transition away from fossil fuels using a diverse energy mix using countries as a case study. Schmidt et al. explore the opportunity in Brazil to use PV, Wind and Hydro to create a greener electricity matrix (2016). Other researchers provide potential combinations of NCRES to effectively transition away from fossil fuels in Mexico (Vidal-Amaro et al., 2015; Vidal-Amaro & Scheinbaum-Pardo, 2018). Grande-Acosta and Islas-Samperio highlight the Mexican electric sector as a good opportunity to transition and reduce GHGs as it was responsible for almost a quarter of emission in 2016 (2017). Nasirov et al., 2018 discuss the mechanisms in Chile that are employed to encourage a transition away from fossil fuels (2018). Clementi et al. provide a road map for the energy transition in Argentina elaborating on the various NCRES available (2019).

2.3. Policy measures to promote NCRES

Even as the cost of renewable energy becomes more and more competitive with traditional fuel sources and there is a trend for increasing shares of NCRES, the current progress is insufficient to achieve the Paris Agreement and avoid the potential climate related disasters described in the IPCC report. For this reason, several studies express the importance of policy support for renewable energies (IRENA$_a$, 2020). Climatescope, a project developed by BNEF and IDB, provides a comprehensive database of in-depth information on current and past policy mechanisms used to support NCRES in markets all over the world. The policies listed on global-climatescope.org/policies employed are clean energy targets, emission reduction targets, tax-based incentives, utility regulation, clean energy credits, access to low

interest funding, auctions and tenders along with net metering and feed-in tariffs (FIT). There is a lot of literature describing these various policy instruments and how they incentivize the growth of NCRES in different regions and countries. The report Latin American Policies discusses the various mechanisms such as renewable energy targets, auctions, and financial support for NCRES (IRENA, 2015). Washburn & Pablo-Romero provide a very detailed analysis of the different mechanisms used in Latin American Countries (2019). FIT, an instrument designed to guarantee investors will have access to the electricity grid, and that their energy will be purchased, were an early mechanism employed in Brazil but replaced by Power Purchase Agreements (PPAs) contracted through auctions (Aquila et al., 2017) Aquila et al., explain the benefits of auctions reflecting real prices of technologies instead of predetermined prices of FIT (2017). Del Razo describes the Clean Energy Credit system employed in Mexico (2016). Simsek et al., explain the Chilean government's detailed plans on how to achieve the country's ambitious renewable energy targets (2019).

The auction or tendering process has been employed by governments all over the world as a means to procure NCRES projects. In these tenders, governments define a desired capacity addition and companies make bids on the projects to compete for a long term a power purchase agreement, a contract that guarantees the project developer will be paid by the offtaker for the electricity produced (Dovrotkova et al., 2018). Some studies analyze how auction design can lead to more successful auctions and provide truly competitive prices for NCRES (Nasirov et al., 2019; IFC, 2019). An Inter-American Development Bank reports on tenders provides a detailed analysis auctions in Latin America discussing design features and their auction results (Viscidi & Yepez, 2019) while another also looks at design along with net metering policies in the region (Soto et al., 2019). The report Global Trends in Renewables 2020 describes tool as a Latin American favorite due to the resounding success of auctions in the region (FS-UNEP, 2020)

2.4. Centralized vs Distributed Generation

One of the benefits of NCRES is the potential for distributed generation, where the energy produced is distributed to consumers nearby or even on site where the energy is produced as opposed to traditional centralized power plants that require electricity to be transmitted over far distances to reach the end user (Bradshaw, 2017). The benefits of distributed generation (DG) include contributing to grid stability, adding to the utility's electricity capacity, smoothing daytime demand peaks (Ruther & Zilles, 2011). Net metering and net billing are two of the main support mechanisms for DG systems compensating where surplus electricity not consumed by the producer is injected back into the grid. Watts et al., explain that net metering is a better tool for promoting DG because energy injected back into the grid is valued at the same price that the consumer pays whereas with net billing the value is discounted (2015). The rules for system sizes eligible for net metering benefits varies from country to country. Bradshaw explains the stipulations of DG laws in Brazil (2017) while the efficacy of the law can be found in other

studies (Vilaça Gomes et al., 2018; Vazquez & Hallack 2018). Chile is the only country in Latin America with a net billing scheme and Watts et al., explore the potential benefits for various system sizes based on user electricity consumption (2015). Other relevant studies discuss net metering and DG potential in Mexico (Hancevic et al., 2017; Langone et al., 2020) as well as Argentina (Garcia & Eisenstein, 2018; Porcelli & Martinez, 2018).

CHAPTER 3

Solar Energy

3.1. Levelized Cost of Energy of Renewables

Many factors contribute to the falling cost including advances in efficiency, reductions in equipment costs, and government support, especially tenders (Gaëtan Masson and Izumi Kaizuka, 2019). Another factor leading to decreasing LCOE for PV specifically is expansion into countries with higher yields due to excellent solar radiation (Dobrotkova, 2018). Renewable energy tenders, or auctions, drive competition and push global prices down as companies fight for PPAs offering the lowest price per kWh they can (Dobrotkova et al., 2018). Figure 3.1 shows how solar costs have fallen drastically into the fossil fuel cost range.

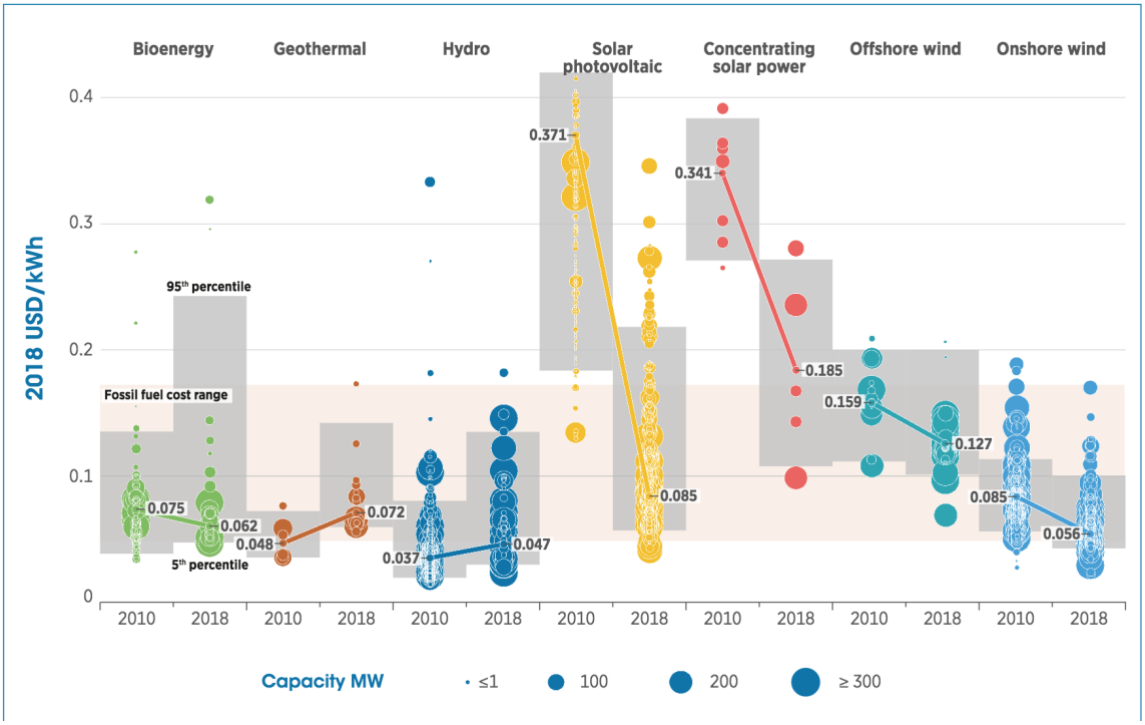


Figure 3.1: Global LCOE of Utility Scale Renewable Power Generation in 2018 (IRENA, 2018)

Based on IRENA's database of auctions and power purchase agreements, of projects to be commissioned in 2020, 77% of onshore wind and 83% of solar PV projects will be less expensive than the cheapest fossil fuel options for new generation (2018). These trends are even moving towards a tipping point where costs of investing in new wind or solar projects will be even less than the marginal costs of continued operation of existing coal plants (BNEF, 2019**)**.

The continued course towards lower LCOE of renewables makes investment in clean technologies more appealing. The number of corporations investing in PPAs for clean energy more than doubled in 2018 (REN21, 2019). In 2018, investment globally in the renewable sector fell over $30

billion due to a constriction of investment from China ($36 billion), as well as a decrease from Brazil and India (BNEF, 2019). Even with less investment in 2018, China still came in first place for domestic investment and net capacity additions for the majority of clean energy technologies (REN21, 2019). Despite the dip in total investment, foreign direct investment in renewable energy increased by $2 billion with a new record of investment in developing economies of $24.4 billion, over half of which came from the EU (BNEF, 2019). In 2019 investments jumped back up to a record high for Latin America with $18.5 billion due to returning investment from Brazil and 300% increase from Chile (FS-UNEP, 2020). The main investments in renewables come from development banks, project developers, and international utilities of which Enel of Italy is the lead investor with $7.6 billion contributed over the last decade (BNEF, 2019).

3.2. Solar Photovoltaic Technologies

There are various technologies used to harness the power of the sun to create energy. The most common applications are Solar PV, Solar Thermal Heating and Cooling, Concentrating Solar Thermal Power (CSP). The latter two technologies create energy using heat from sunlight while solar PV uses the electromagnetic energy in sunlight to create electricity (Gonzalez, 2019). This work will focus solely on solar PV and any remarks regarding the solar industry are referring to this technology. CSP has some relevance to this work as the technology offers storage capacity acting as battery, a very useful in combination with intermittent solar PV (Hamilton et al., 2019)). Traditional solar modules (panels) can only generate electricity on the front side while more recently designed bifacial modules can generate electricity using both sides and have higher capacity factors (Zurita et al., 2018). Axis tracking systems also increase output by following the sun throughout the day instead of remaining fixed in one location (Gonzalez, 2019). A key component in modules is silicon which is produced from quartz, a resource found in Brazil and Argentina (Ferreira et al., 2018).

3.3. Global Solar PV Outlook

The solar industry has been growing steadily for the past several years with a slight contraction in 2018 (REN21, 2019). Even with less growth, the 25% increase in solar PV capacity accounted for 56% of additional renewable capacity in 2018 ($IRENA_a$, 2019). After the slowed growth of PV in 2018, the global market grew around 12% in 2019 (Detollenaere et al., 2020). PV contributed around 3% to the global electricity demand and reduced 5.3% of electricity related CO_2 emissions (Detollenaere et al., 2020) The industry saw unprecedented low bids in auctions with Portugal setting the world record with 16. 44 USD/MWh (REN21, 2020).

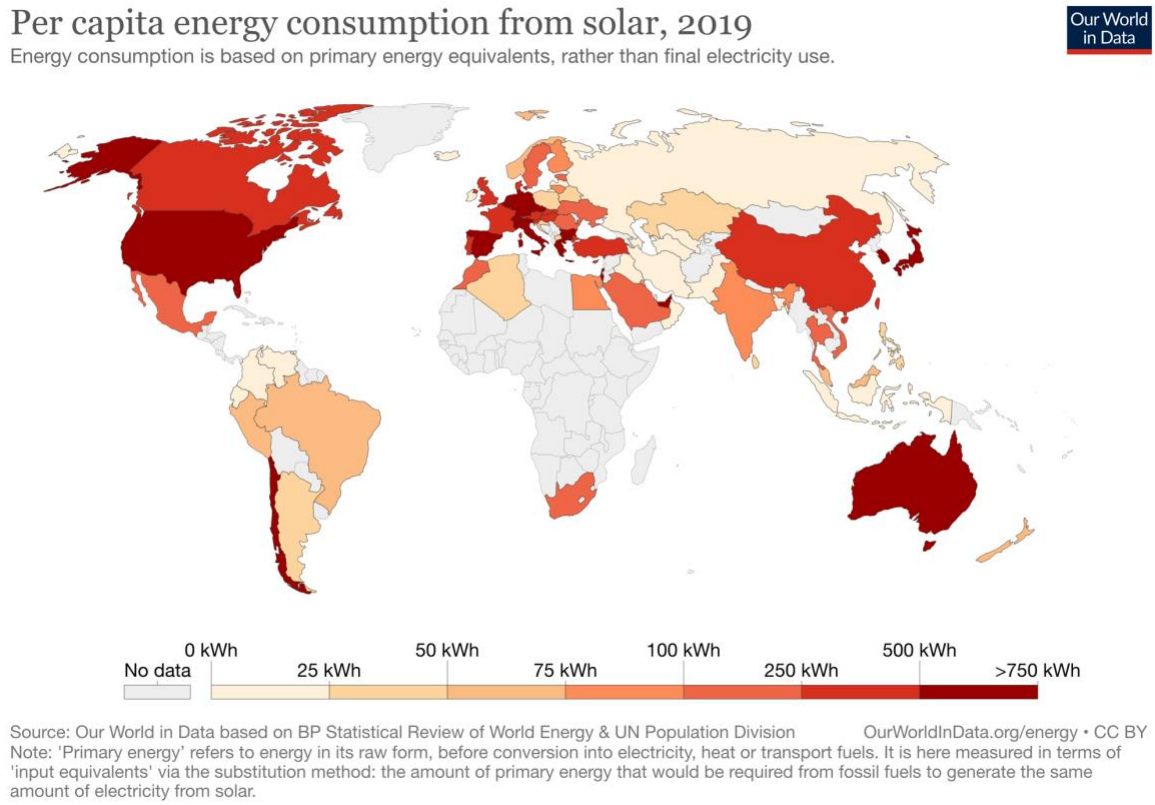


Figure 3.2

The industry continues to be led by China with a cumulative capacity of about 204.7 GW, followed by the United States (75.9 GW), Japan (63 GW), Germany (49.2 GW), and India coming in 5th place with an estimated 42.8 GW (Detollenaere et al., 2020). As a region, the EU ranks 2nd to China with three countries in list of top ten (Germany, Italy, and France) and 13 other countries with capacities of over 1GW (IRENA$_b$, 2020). Figure 3.2 demonstrates other solar industry leaders that may not have as large of capacities but still generate and consume a significant amount of solar electricity per capita. The figure also shows how solar is a viable energy source even in countries with less sunshine like northern Europe. As previously stated, the benefits of the decreasing LCOE of solar PV energy have driven further expansion of the solar market. The LCOE of solar PV in 2018 fell to .085 USD/kWh representing a 77% decline from the global weighted average LCOE in 2010 (IRENA, 2018). Solar module prices decreased by 29% in 2018 because of a surplus of Chinese modules flooding the world market and driving the price down to a global average of 22.4 cents per watt (REN21, 2019). The solar PV industry is on track to provide an increasingly large portion of the planet's electricity needs in the future. IRENA predicts that in order to achieve an energy transition, solar would play a significant role and could potentially become the second largest source of electricity behind wind and provide 25% of the world's electricity needs (IRENA$_a$, 2020).

The benefits of solar PV extend beyond being a low carbon energy source. They require very little maintenance, large-scale failure is rare due to the module nature of the technology, and systems

can be expanded after being installed with new panels being retrofitted (Kabir et al., 2018). Some companies in energy intensive industries such as mining and manufacturing recognize the value of the decreasing LCOE of solar power and are constructing solar systems to power their operations (REN21, 2020). Other advantages include rapid installation of utility scale solar PV plants, which can take as little as 6 months (compared to the 4-10 it takes for hydro or fossil fuel plants), and an average life of 30 years (Dobrotkova et al., 2018). The solar industry has also created jobs for millions of people around the world. In 2018 3.6 million people were working in the industry, while the next largest employer in the clean energy sector was biofuels with just over two million (REN21, 2019).

CHAPTER 4

Solar PV Leaders in Latin American and the Caribbean

4.1. LAC

LAC accounted for 2% of the solar PV capacity in 2019, a result of significant growth in the past several years (IRENA$_b$, 2020). The region in general has one of the highest shares of renewable energy, primarily due to hydropower, with less than 60% of total generation coming from fossil fuels (BNEF, 2019). This relatively low portion of generation still amounts to 5% of the world's CO_2 emissions (BP, 2019). Although solar provides less than 6% of power (BP, 2020), the region has seen unprecedented growth in the solar sector.

The region has been attracting a lot of investment as new wind and solar plants have become more affordable than constructing new fossil fuel plants. In 2018 LAC received the second highest amount of foreign direct investment in clean energy technologies with $6.7 billion, two-thirds of which came from the EU (BNEF, 2019). From 2009 to 2018, the region received the lion's share of 40% of foreign direct investment for renewables (BNEF, 2019). Part of this is due to the falling LCOE, but in the case of solar, the region is privileged with some excellent solar radiation creating higher output for with less panels (Dobrotkova et al., 2018).

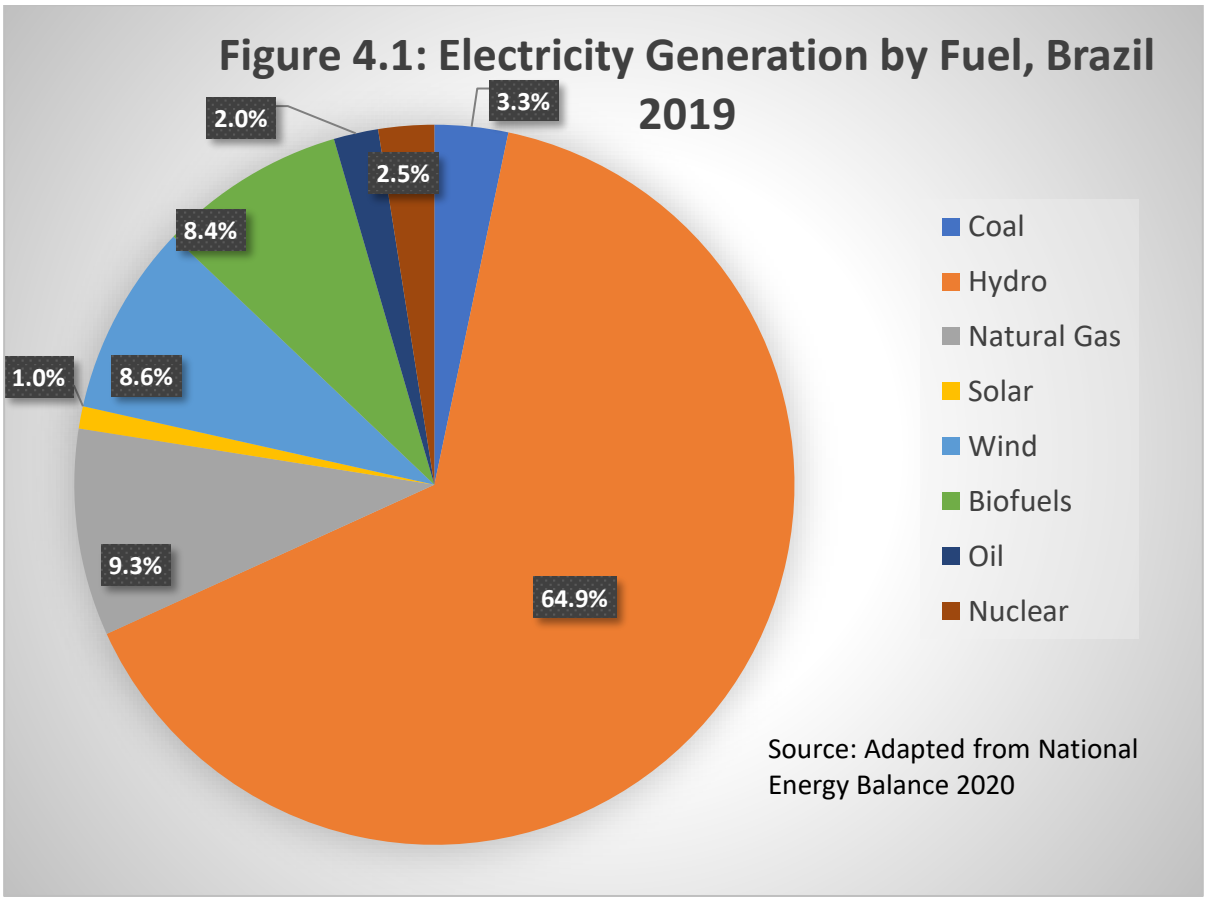
4.2. Brazil

Brazil is the largest country in LAC at 8,515,800 km^2, the largest population in the region with 211,049,527 people, and the largest economy with 1.84 trillion USD (World Bank, 2020). The country is one of the leading markets for renewable energy in the world and the number one producer in Latin America (IRENA, 2016). Due to the vast size and abundance of rivers in Brazil, hydroelectric dams have been integral to the country's power supply, contributing to their high ranking on the list of producers of renewable energy. Droughts diminishing the capacity of hydroelectric dams have been the main cause to push for diversification (Bradshaw, 2017).

4.2.1. Electricity Sector

Largely due to hydropower, Brazil is ranked number one in Latin America for the highest share of renewables in its total primary energy supply and is a world leader with a share of 42% while the global average is only 13% (EPE, 2020). Natural gas and oil make up the biggest domestic sources of fossil fuels as the coal in Brazil is low quality (Aquila et al., 2017). The use of oil and natural gas may continue to grow with the great reserves available; one of the largest stores of oil discovered in the last 30 years was found off the coast of the states Rio de Janeiro and São Paulo, in the Santos Basin (IRENA, 2016). When looking specifically at the domestic electricity supply, about 82.9% of the mix comes from renewable energy sources, while fossil fuels account for 14.6% (EPE, 2020). Heavy reliance on

hydropower for electricity production caused serious problems when severe droughts hit the country in 2001 and 2015. With low reservoirs there was a shortage in electricity, which resulted in mandated energy cuts and elevated costs to consumers (Aquila et al., 2017). Currently the average retail electricity price is 186.55$/MWh (Climatescope, 2019).



The electricity sector was public until 1993 when a shift to privatization began, and by 2003, 70% of distribution assets and 30% of generation capacities were privatized, with the Electrobras, a state controlled electricity company, maintaining control of the bigger assets, leading to a more hybrid structure (Bradshaw, 2017). Ministério de Minas e Energia (MME) is the main state-run institution that oversees energy policy and energy-related activities and agencies; it is run by the Conselho Nacional de Política Energética a panel of fourteen council members with nine members of state (De Melo, et al., 2016). Due to the lack of regulatory institutions with the transition from a public energy sector to a private one, several organizations were created with the purpose of regulating the electricity sector.

One of the most important of these new organizations was the Agência Nacional de Energia Elétrica (Aneel). It was created in 1996 to "promote development, expand the labor market and enhance energy resources, protect consumer interests...and the environment, promote energy conservation, identify appropriate solutions for domestic power supply in different regions of the country, and use alternative energy sources…" according to Law No. 9478 Article 1 (Bradshaw, p 159, 2017). The

Operador Nacional de Energia Elétrica (ONS) manages the grid through the coordination and control of electricity generation and transmission (Aquila, et. al, 2017). The Empresa de Pesquisa Energética (EPE), created in 2004 is concerned with the research and planning of long-term expansion of the electricity sector (Bradshaw, 2017). Finally, the Câmara de Comercialização de Energia Elétrica (CCEE) manages long-term contracts between energy generators and distribution utilities, defined during auctions for commissioning power plants.

4.2.2. Support Mechanisms

Before 2001 there were no explicit initiatives to move away from hydropower and promote other renewable energies, but in 2002 with the Act No. 10,438/2002 the Program of Incentives for Alternative Energy Sources, or Programa de Incentive às Fontes Alternativas de Energia, (PROINFA) was created (de Melo et al., 2016). This organization made great steps towards inserting more energy sources into the market, especially wind, biomass, and small hydropower. The main mechanism used initially was FIT until a shift to energy auctions in 2009, although solar was not included in the national auctions until 2014 (Bradshaw & Jannuzzi, 2019). The main two designs for auctions are New Energy Auctions (LEN) meant to increase the overall supply, typically technology specific and held twice a year, and Energy Reserve Auctions (LER) meant to increase grid security (Viscidi & Yépez, 2019). The National Development Bank, or Banco Nacional do Desenvolvimento (BNDES) was vital to the growth of these renewable energy sources because it is the only bank that makes loans for these projects and does so at very favorable rates (Aquila et al., 2017).

The first solar specific auction took place at the state level in Pernambuco, a region with high solar radiation (Bradshaw & Januzzi, 2019) The state also created or collaborated with several programs to facilitate the distribution of solar (AD Diper), provide inexpensive lines of credit (PE Solar Program), build a network for the industry and to train workers SEMPETQ (Secretaria da Micro e Pequena Empresa, Trabalho e Qualificação) (Bradshaw & Januzzi, 2019). In 2012 Normative Resolution 482 was passed to encourage DG systems creating a net metering incentive for residential solar systems or small systems for commercial buildings (Vilaça Gomes, et al., 2018). In 2015 the law increased the size of eligible systems from 1 MW to 5 MW, lengthened the period that DG producers can keep the credits they earned from injecting energy into the grid, and required more cooperation from the distribution companies (Bradshaw, 2017). Also, during 2015, the Conselho Nacional de Política Fazendária (CONFAZ) passed Agreement 16 which gave states the right to give tax exemption of the Good and Service Tax (VAT) to distributed generators (Vilaça Gomes, et al., 2018).

4.2.3. NCRES and Solar Energy

The first LER held solely for wind power was held in 2009 and since then the installed capacity soared from less than 1000 MW to nearly 6000 MW in 2015 (Aquila et al., 2017). After launching programs to

encourage the development of wind farms, it was the fastest growing energy source in the country at 39.3% of total supply growth, placing Brazil in 9th place worldwide for wind production in 2017 (Bradshaw, 2017). Today the country ranks 8th globally for total wind capacity (REN21, 2020) In 2019, Brazil set world record low prices for wind and solar projects awarded at 20.8 USD per MWh and 16.48 USD per MWh respectively, with solar even beating natural gas (REN21, 2020). Brazil was the top country in the world for hydropower additions in 2019, and second for biofuels production (REN21, 2020).

In March of 2015 only 564 PV DG systems were installed, but after expanding the net metering benefits with the amendment to the law in conjunction with the VAT exemption, the number of DG systems jumped to 6017 in October of 2016 (Bradshaw, 2017). These strong DG incentives contributed greatly to this sector of the solar industry and brought DG capacity in Brazil to 3.7 GW (ABSOLAR, 2020). The capacity of utility solar projects jumped from 24 MW in 2016 to 2485 MW ($IRENA_b$, 2020). Most of these projects are located in the northeast which has the highest GHI and where there has been the most support for solar (Ferreira et al., 2018). The top four companies that commissioned these projects, the Italian group Enel, Canadian Solar Inc., Lintran do Brasil Participações S.A., a subsidiary of a Spanish company, and the French Solairedirect, account for over half of this added capacity (Vazquez & Hallack, 2018).

Another advantageous resource in Brazil is the large reserves of quality quartz, which is used to make silicon, a key component of PV panels (Rüther & Zilles, 2011). This could present a valuable competitive advantage for the production of solar cells and modules with high purity silicon (Ferreira et al., 2018). Further research and development will be necessary to overcome the challenge of silicon purification and solar cell production which are costly procedures that would require achieving economies of scale to be competitive (Ferreira et al, 2018).

4.3. Chile

Chile has a population of 18,952,038, and a GDP of 282.318 billion USD (World Bank, 2020). The geography of the country consists of alpine environments with mountain ranges running north to the south stretching, 4337 km creating a wide variety of biomes including from some of the driest deserts in the world (Zurita et al., 2018). Chile holds 29% of the world's copper reserves, and mining is one of the largest industries in the country (Simsek et al., 2019). This energy intensive sector contributes significantly to the electricity demand, accounting for 90% of the demand in the northern region in 2015 (Agostini et al., 2016), and amounted to 30% of the electricity consumption in 2017 (Vega-Coloma & Zaror, 2019).

With few fossil fuel resources in the country, Chile relied heavily on hydropower in the 1980s and 1990s until severe droughts stressed the supply as occurred in other countries in the region (Carrasco & Rosner, 2017; Vega-Coloma & Zaror, 2019). This led to a dependence on imported fuel sources for

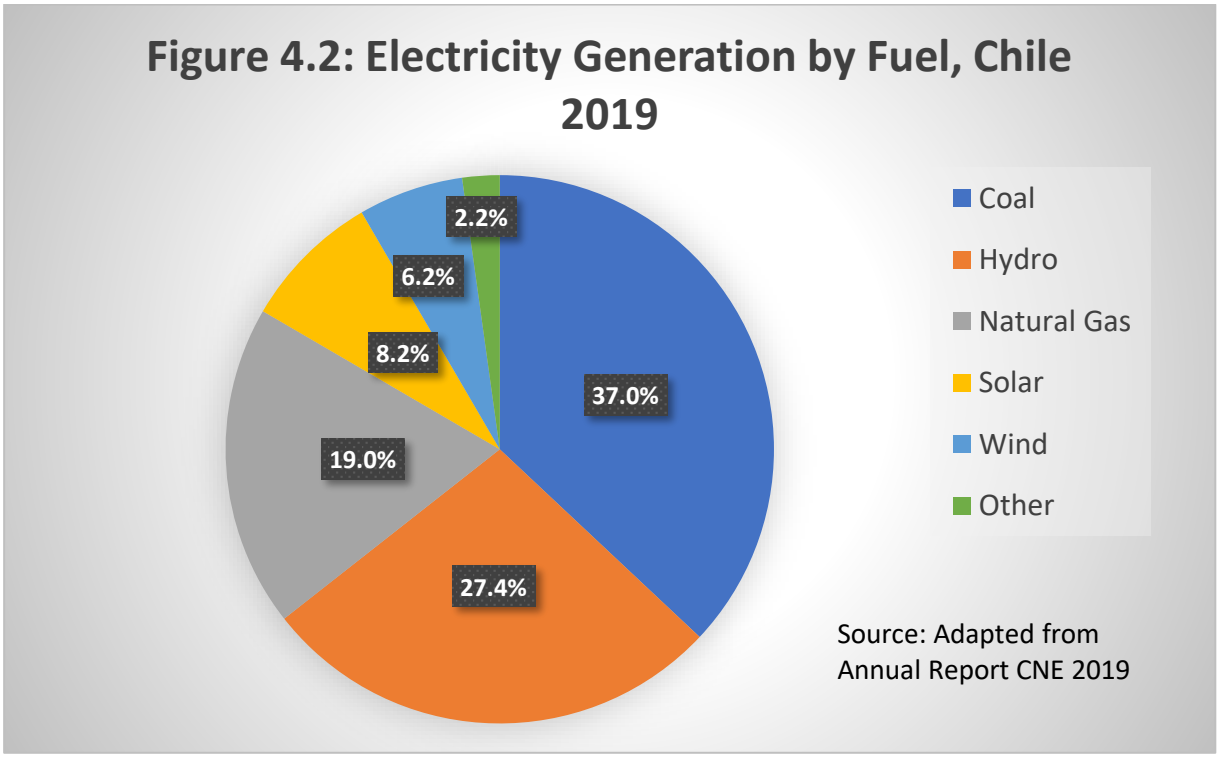
electricity production and the country only satisfied 26% to 38% of its energy needs from domestic sources over the last ten years (CNE_a, 2020). Chile has some of the highest electricity tariffs partially due to dependence on imported fuels and volatile fossil fuel prices (Agostini et al., 2016). Chile had the highest energy consumption per capita in LAC in 2014 with 3,880 kWh/capita (World Bank, 2020). GHG emissions of the energetic sector amounted to 86,895 kt CO_2 in 2018 (CNE_a, 2020) partially stemming from the heavy use of coal. The solar irradiation in the north of the country is some of the highest in the world offering an excellent opportunity for greater energy independence and the chance to establish a more sustainable electricity matrix. This high radiation coincides with the carbon intensive mining industry that is also located in the northern region (Grágeda et al., 2016). In the past several years, Chile has been very successful in stimulating growth in development of NCRES.

4.3.1. Electricity Sector

Over half of the electricity generated in 2019 was produced from fossil fuels – coal and natural gas (CNE_a, 2020) (see figure 4.2). Hydropower is the second largest source of electricity, but large hydropower projects have faced serious opposition and protests with movements like Patagonia Sin Represas (Without Dams), drawing attention to the ecological damage and negative effects on the local communities (Nasirov et al., 2019). After the droughts in the late 90s, Chile relied heavily on Argentina for natural gas until 2003, at which point the country restricted exports and nearly halted them completely in 2008 due to an energy crisis and shortages of supply (Nasirov et al., 2017). As a consequence, Chile moved towards importing expensive diesel oil and coal leading to higher GHG emissions and higher electricity tariffs (Agostini et al., 2016). In 2016, 98% of the oil, 77% of natural gas and 80% of coal had to be imported (Simsek et al., 2019). This shift to diesel and coal induced a price jump to an all-time high of US$300/MWh in 2008 (Nasirov et al., 2017) although the prices have come down rates are still high for the region; the average retail electricity price is 193.41 USD/MWh (Climatescope, 2019).

Chile was the first country in the world to deregulate the electricity sector in the 80s creating privatized segments for generation, transmission and distribution (Nasirov et al., 2019). Though the goal of privatizing state-owned companies was to create a more competitive environment, the market remains under the control of a few companies – Endesa, AES Gener, and Colbún accounting for nearly two thirds of the market (Agostini et al., 2016). Since deregulation of the sector, the government has very little oversight and the state institutions like the National Energy Commission (CNE), Ministry of Energy (Ministerio de Energia), and the Superintendent of Electricity and Combustibles (SEC) play minor regulatory roles (Agostini et al., 2016). The nation was divided into four separate transmission lines until 2018 when the Central Interconnected System (SIC) and the North Large Interconnected System (SING) were joined to create the National Electric System (SEN) which provides energy for 99% of the electricity users (Diaz et al., 2020). As in other countries, the capacity of transmission lines is a limiting factor to further expansion of NCRES and upgrades and additions are being explored. The country also

has plans to build further transmission lines to neighboring countries, especially Peru and Argentina to create an international network to capitalize on the various renewable energy resources available in each country(Nasirov et al., 2019).



4.3.2. Support Mechanisms

The Chilean Government has set ambitious goals to transition towards a more sustainable energy system. In 2008, the government approved the Renewable Energy Law (Ley ERNC 20.257) requiring an increasing amount of electricity to come from NCRES. This law was updated in 2013 with the "Law 20/25" (20.698 NCRES), setting renewable energy targets of 12% in 2020, 18% in 2024 and 20% by 2025 (Simsek et al., 2019). This amendment reflects the continued effort and success in promoting the growth of NCRES, as the country will achieve the target well ahead of schedule with the share of NCRES for 2019 already reaching 19.4% (CNE_a, 2020). Law 20.571 originally drafted in 2012, established regulations for net billing as the support mechanism employed to incentivize the use of DG; however, the net billing scheme hasn't proven very effective (Watts et al., 2015). In 2018 the law was modified increasing the benefits of net billing for DG systems from 100kW to 300kW, and the capacity of DG systems nearly doubled in 2019 but still remains minimal at 42MW (CNE_b, 2020). Chile stands out as the only country in LAC with specific plans for phasing out all coal-fired power plants by 2050 (BNEF, 2019).

As mentioned earlier, a significant factor that allowed NCRES to compete directly with fossil fuels without subsidies are the renewable energy tenders with unique design features. In 2014, auctions

went under reforms, with the most noteworthy addition being eight-hour blocks for bidding, allowing for project developers to choose the time block with highest resource availability, addressing the intermittent nature of NCRES (Nasirov et al., 2017). Other beneficial design implementations included increasing PPA contracts from 15 to 20 years, longer lead times between auctions and completion dates for plants, and fewer prerequisites for companies joining auctions (Nasirov et al., 2019). The capacity of NCRES has more than doubled since 2014 in part due to the success of the auction program (Viscidi & Yépez, 2019; CNE$_a$, 2020).

4.3.3. NCRES and Solar

As of November 2020, Chile had 6.22 GW of NCRES in operation and roughly half of this capacity comes from PV with 3.12 GW of solar and wind being the second largest source with 2 GW (CNE$_b$, 2020). Historically biomass and hydropower (mostly nonrenewable) consistently contributed to the electricity matrix, but over the past 15 years, the country has begun to take advantage of the other resources available especially wind, and solar, with potential for development of geothermal and marine power (Simsek et al., 2019; Agostini et al., 2016). From 2009-2018, Chile attracted $11.5 billion of investment (mostly from Europe and China) in NCRES although investment in 2018 was significantly lower than previous years (BNEF, 2019). After a slower year in 2019, Chile set a country record for investment in NCRES at $4.9 billion, $2.2 billion of which went to solar (FS-UNEP, 2020).

Chile boasts some of the highest levels of irradiance in the world with a maximum daily GHI of 7.43 kWh/m^2 (ESMAP, 2020). The energy source overtook wind in 2016 soon after the introduction of energy auctions (CNE$_a$, 2020). The unique geography of Chile provides an excellent environment for solar energy; the location of the Atacama Desert is especially favorable for solar radiation because it sits on the east side of the Cordillera mountain range, which impedes the storms and cloud cover from reaching the plateau where the desert rests (Zurita et al., 2018). With such excellent solar radiation, the capacity factor of solar plants is estimated at 33% making the technology even more efficient and partially what allows for prices to compete directly with traditional combustion sources of electricity (Carrasco & Rosner, 2017). The high electricity tariffs also contribute to the profitability of investment in all NCRES projects (Agostini et al., 2016).

According to the IEA theoretical PV penetration, the estimated global average was at 3% at the end of 2019, and Chile ranked fourth in the world with 8.2% of electricity demand met with solar energy (Detollenaere et al., 2020). As of October, 3.65 GW of PV plants were under construction, with an estimated commercial operation date range between November 2020 and March 2022 (CNE$_b$, 2020). In addition to these jobs, 195 PV projects are in the environmental impact assessment stage amounting to 8.6 GW (CNE$_b$, 2020). Copper mines have been contracting solar systems for self-consumption to capitalize on the excellent solar radiation in the north (Grágeda et al., 2016). Mining requires energy 24 hours a day year-round which poses a challenge for PV solar, but further development of CSP could meet the demand at night. The first CSP plant in Chile, Cerro Dominador, may come online this year

and would provide 17 hours of stored energy that could supply clean energy year-round (Diaz et al., 2020).

While there is a lot of promise for the solar industry in Chile, it not only faces the general obstacles that the entire region faces, but also challenges specific to the country. The extreme weather in the Atacama Desert is well out of the manufacturers rated use of modules as the testing is done in much less harsh environments (Zurita et al., 2018). This study also discusses the issues of reduction in efficiency of modules that get covered in dust from the as well as lack of clean water in the desert to wash the panels (Zurita et al., 2018). Other difficulties include market concentration that precludes entry of smaller local players as the industry is dominated by international companies, long distances between the best solar radiation in the north from the greatest electricity demand in Santiago located in the center, complications stemming from gaining land permits and delays in projects due to the lengthy environmental impact assessment (Haas et al., 2018).

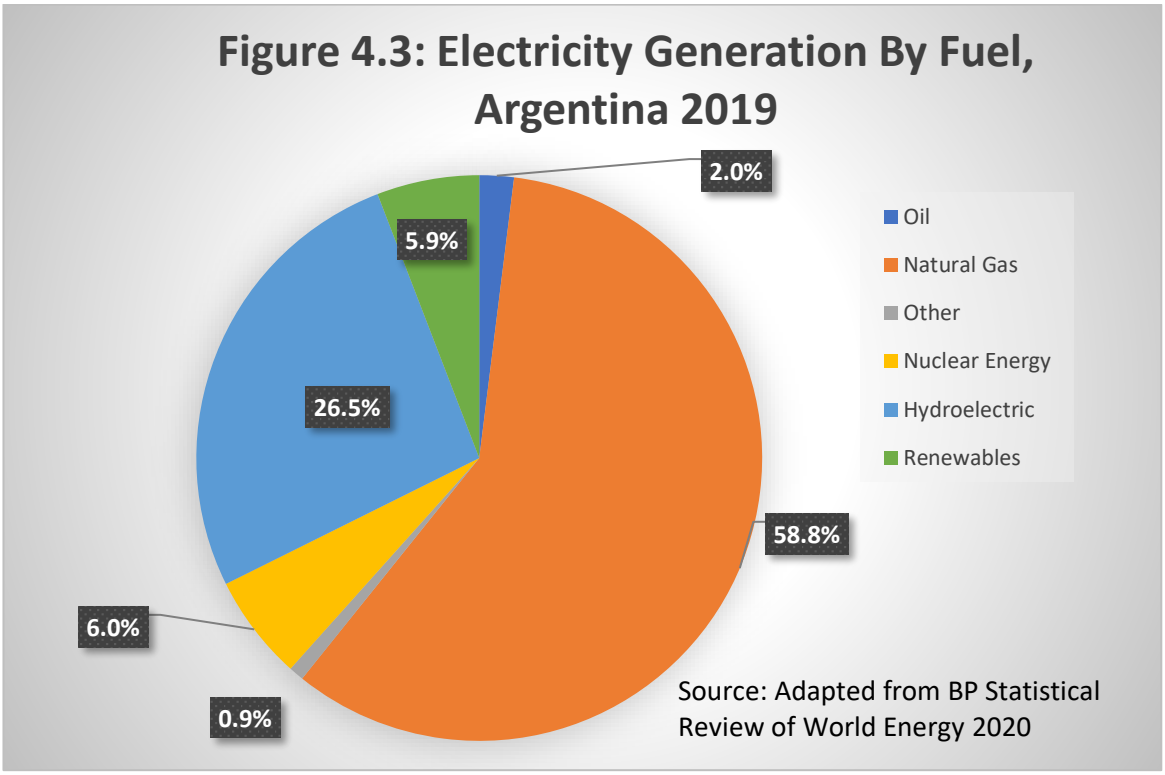
4.4. Argentina

Argentina is the 2nd largest country in LAC with a land mass of 2,780,400 km^2 and a population of 44.49 million people (World Bank, 2020). Argentina is one of the largest natural gas producers in Latin America, but the production has been in decline since the turn of the century (IRENA, 2016). Lack of private investment in capacity additions and poor management of natural gas led to shortages and a need to import fossil fuels (Jimeno et al., 2015). In order to diversify the energy matrix and to achieve the goals of the Paris Agreement, the government passed a Renewable Energy Law in 2006 which set renewable energy targets and established various support mechanisms (Porcelli & Martínez, 2017) The contribution of NCRES to electricity demand has been minimal until recently, due to a lack of investor confidence stemming from a history of macroeconomic crises, high inflation, large subsidies for electricity tariffs, and high interest rates (Recalde et al., 2015). New legislation passed in 2016 replaced the first Renewable Energy Law and amended the missed targets establishing a goal of 8% in 2018 and 20% in 2025 (Porcelli & Martinez, 2017). This law also established a new tendering program backed by the World Bank, and although the country awarded over 4 GW in the first three rounds of auctions, the International Finance Corporation (IFC) estimates a need for a total of 10.4 GW in order to meet the goals of the Renewable Energy Law (IFC, 2019). The large country has a lot of potential for development of various forms of NCRES, with high solar radiance, favorable wind resources, further potential for development of small hydro projects, and the production of biofuels (Clementi et al., 2019).

4.4.1. Electricity Sector

Argentina relies heavily on fossil fuels for primary energy sources with a total of 84% in 2019, nearly half of which came from natural gas, a third from oil, and a minor contribution from coal (BP, 2020). Carbon dioxide emissions decreased 3.1% from 2018 to 2019 to 174.9 mt (BP, 2020) due to more mild

days and a higher contribution of renewable energy (CAMMESA, 2019). Looking at the electricity matrix, over 60% is produced from natural gas, around a quarter from large scale hydropower, low contributions of nuclear and NCRES (see Figure 4.3) (BP, 2020). The majority of electricity demand stems from residential consumers, with 37% of the demand coming from the Greater Buenos Aires area (CAMMESA, 2019). Electricity demand increased steadily at 4.35% for over 20 years resulting from low tariffs due to large subsidies and economic recovery (Jimeno et al., 2015). The contribution of NCRES to the total electricity demand increased more than threefold from 2018 to 2019, contributing to 6.1% of the demand (CAMMESA, 2019).



Beginning in the 90s, the government began privatizing the electricity sector including transmission, distribution, and generation (IFC, 2019). The wholesale electricity market or Mercado Eléctrico Mayorista (MEM) is overseen by CAMMESA (Compañía Administradora del Mercado Eléctrico Mayorist), which is a private company though today, the state holds a large stake in the company and maintains a lot of oversight in the company (Jimeno et al., 2015). Its main functions include the operation and dispatch of generated energy, price calculation in the spot market and negotiation with generators of electricity tariffs related to renewable energy PPAs (Jimeno et al., 2015). Argentina's history of high inflation and economic instability had negative effects on the privatized electricity sector (IFC, 2019). In 1991, the government fixed the value of the Argentine peso to the US dollar which resulted in major repercussions for the economy and the electricity sector (Recalde et al., 2015). In response to a huge drop in GDP in 2001, the government converted all tariffs for electricity transmission

and distribution back to pesos creating huge deficits in the electricity sector and resulted in a halt in investment in the expansion of transmission and capacity for the market (Recalde et al., 2015).

In hopes of stimulating the economic recovery, the government provided large subsidies to support the electricity sector, creating artificially low prices which led to an increase in demand for electricity (Jimeno et al., 2015). Consumers only paid for about 30% of the average cost of energy supply, amounting to nearly 4% of the country's GDP in 2015 (IFC, 2019). Due to the fact that CAMMESA is the only off taker for electricity, the company relied heavily on support from the government and was deeply indebted (Porcelli & Martínez, 2017); this in combination with low electricity prices made investment in NCRES less profitable (Jimeno et al., 2015). The government is planning on procuring investment in new high-tension transmission lines nationally as well interstate lines to connect with other countries to trade electricity (IRENA, 2016).

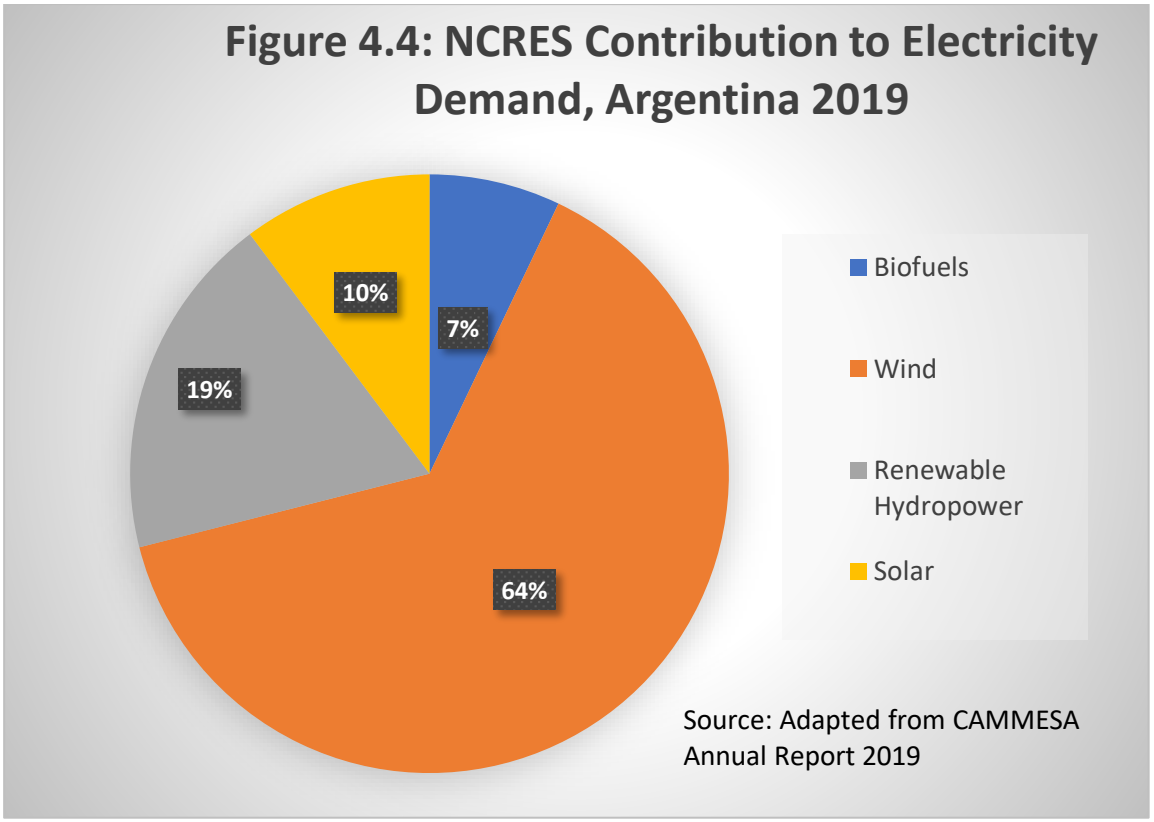
4.4.2. Support Mechanisms

One of the first major pieces of legislation to encourage the growth of NCRES Law 26.190 was the Renewable Energy Law, passed in 2006 which set a target of producing 8% of electricity from renewable energy sources by 2017 (Clementi et al., 2019). This law and other support mechanisms stemming from it proved ineffective in stimulating the market for NCRES (CAMMESA, 2020). In 2015, the law was replaced by Law 27.191 which introduced the new targets of 8% NCRES in the electricity matrix by 2018 and 20% by 2025 (Porcelli & Martínez). Although the country still missed the goal for 2018, this legislation proved much more effective in encouraging growth of NCRES. The law established the RenovAr auction program, a fund to provide financing for NCRES - Fondo de Energía Renovables (FODER), and created a separate auction process and Term Market, Mercado a Término de Energías Renovables (MATER) for large consumers who are mandated to procure a portion of their energy from renewable sources (Clementi et al., 2019). RenovAr functioned better than previous tenders as the government worked with the World Bank and the International Finance Corporation (IFC) to design the auctions, offered 20-year PPAs in USD, and received financial backing from the World Bank, reducing risk for project developers (IFC, 2019). After three very successful rounds of auctions from 2016 to 2018, the government wanted to have the fourth auction in 2019 but, unfortunately, the program has been put on hold due to lack of transmission capacity (Fenes & Gubinelli, 2019). The government aims to link contracting more large scale NCRES projects with transmission line additions in the fourth round of RenovAR (Fenés & Gubinelli, 2019). The fund FODER is partially backed by the World Banks and the rest of the capital is derived from the scaling back of subsidies for fossil fuels which is predicted to amount to 41 billion USD by 2025 (Jimeno et al., 2016). The MATER auctions allow businesses and any consumers with a demand over 300kW to negotiate PPAs with renewable electricity generators in order to comply with the renewable portfolio standards (RPS) of 8% in 2018 and 20% in 2025 (Clementi et al., 2019).

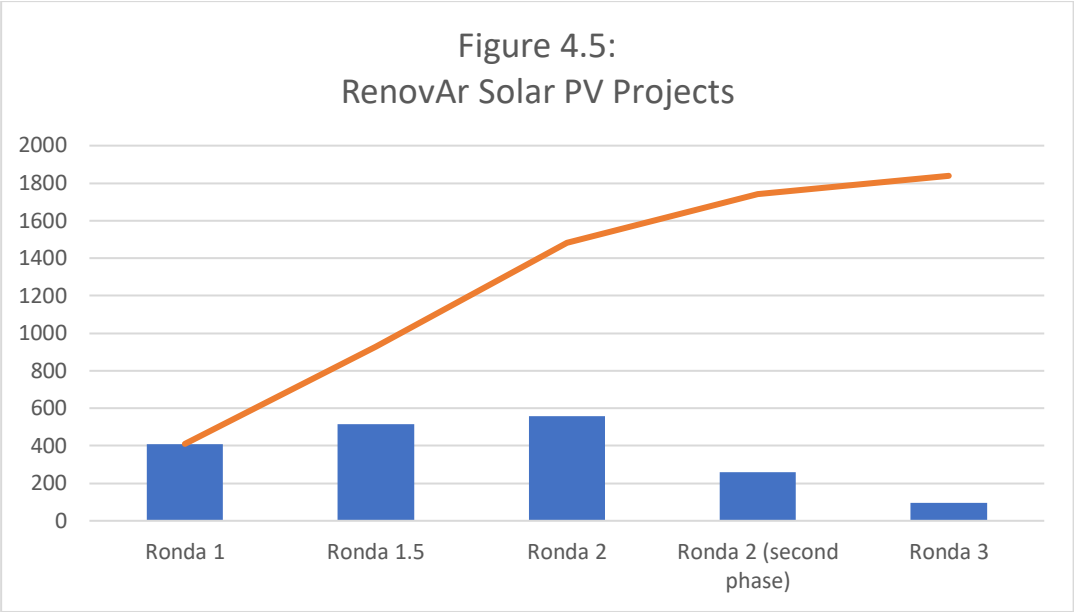
Nearly half of the provinces in Argentina passed local legislation in support of DG such as net metering policies, feed in tariffs, tax benefits and other support mechanisms however, electricity subsidies and low prices for electricity diminished the returns on investing in a solar system (Porcelli & Martínez, 2017). The average retail electricity price is 162.97 USD/MWh (Climatescope, 2019). In 2018 the government passed the first national law for DG defining net metering rules, establishing a renewable energy fund specifically for distributed systems called FODIS (Fondo para la Generación Distribuida de Energías Renovables), and other support for national suppliers of DG equipment, tax incentives and rebates (Porcelli & Martínez, 2017). Over the past several years the government has been slowly decreasing the subsidies with plans to eliminate them completely except for the most vulnerable communities, which may help with the growth of DG (Jimeno et al., 2015).

4.4.3. NCRES and Solar

With such a large territory, Argentina is privileged with a wealth of resources for expansion of NCRES. There is high solar radiance (especially in the northwest), many rivers where hydroelectric power has been established, and opportunities for investment in geothermal energy (Clementi et al., 2019). The northern region of the country has forests and land favorable for the production of biofuels, especially soy, and prominent wind resources in the center conveniently near high electricity consumption in Buenos Aires (Clementi et al., 2019). The contribution of renewable energy in the electricity matrix in Argentina was very low for several years ranging from only 1-2% until last year as the projects from the first round of RenovAr came into operation, increasing the amount to 6.1% (CAMMESA, 2019). All three rounds of auctions proved very successful, each round oversubscribing the allotted capacity, amounting to 185 projects and a total combined capacity of 4.7 GW (Fenés & Gubinelli, 2019). Wind projects dominated the auctions accounting for over half of the winning contracts with 2,466 MW, solar coming in second and small participation of small hydro and biofuels with less than 300MW (Viscidi & Yépez, 2019) (see Figure 4.4). Although the winning bids did not break any records, they were still competitive compared to global prices (Viscidi & Yépez, 2019), proving that as the markets mature and investor confidence continues to increase, Argentina has potential to be a major player in the international market for NCRES. The four rounds of MATER auctions held during 2017 and 2018 also had favorable outcomes resulting in 49 solar and wind projects with a combined capacity of 1,164.4 MW (Fenés & Gubinelli, 2019). Although it was a decrease 18% from the year before, the country still attracted $2 billion in investments with $268 million for solar PV (FS-UNEP, 2020).



The northwest region of the country has the highest solar radiation, specifically the NOA and the Cuyo territories, with an average GHI of 5.09 kWh/m^2 (ESMAP, 2020). These high levels of solar radiation lead to a greater capacity factor of solar plants ranging from 20% – 35% and nearly 90% of the MW awarded for solar in the auctions are located in these regions (Gonzalez, 2019). Although the current capacity of PV at the end of 2019 was only 441MW (IRENA$_b$, 2020), the total capacity of all solar projects awarded from the RenovAr auctions was 1.8GW (see Figure 4.5) with prices decreasing over the auctions, ranging from $60/MWh to $40.80/MWh (Gonzalez, 2019). The mix of investors was a combination of local and foreign companies from China, Germany, Canada, and Spain (Viscidi & Yépez, 2019). JEMSE a state-owned company invested heavily, along with a lot of investment from China, amounting to half a billion dollars between 2009-2018 (BNEF, 2019). Even with the recent success of the auctions in expanding NCRES capacity in Argentina, the industry faces some of the challenges that inhibited growth in the past. The country still struggles with high interest rates to hedge the risk the incipient market, and a lack of transmission line capacity for significant additions of NCRES (IRENA, 2016) and low electricity prices from subsidies reducing the benefit of net metering limiting the growth of DG (García & Eisenstein, 2018).



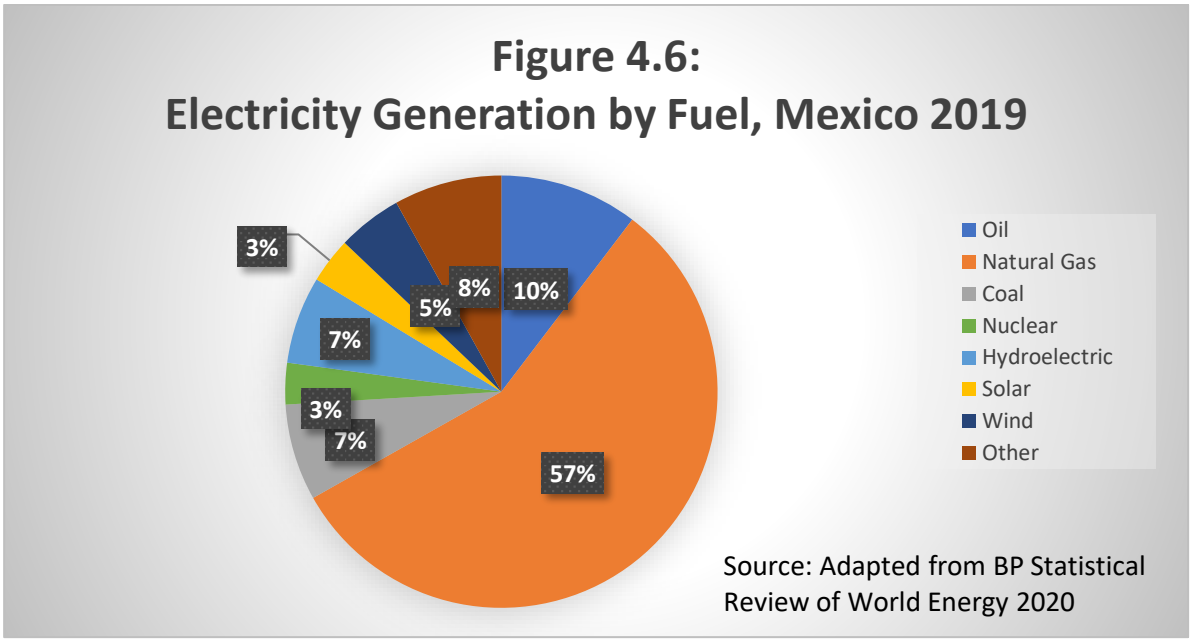
4.5. Mexico

Mexico has the second largest economy in LAC after Brazil with a GDP of 1,258 billion USD (World Bank, 2020). The country spans 1,964,400 km^2 and is home to 127,575,529 million people (World Bank, 2020). In 2002, the country was ranked 9th for largest oil reserves, and 22nd for natural gas (Vidal-Amaro et al., 2018). A heavy reliance on national reserves of fossil fuels has contributed to the highest CO_2 emissions in LAC at 455 $MtCO_2$ (BP, 2020). In order to meet the NDCs for GHG emission reductions, as well achieving goals established by national legislation, the country must increase its share of renewable energy sources (Mundo-Hernández et al., 2014). In 2013 the government passed an energy reform law to encourage private investment in the electricity sector, including auctions and other clean energy incentives. Growth in the solar sector put Mexico as the leading market in terms of capacity with governmental support such as Long-Term Auctions (LTA) (IRENA$_b$, 2020). The current administration is currently working to undo the progress made over the last several years and revert back to the old system by canceling auctions and undermining other incentives such as clean energy credits (Guevara, 2020).

4.5.1. Electricity Sector

Mexico is very dependent on fossil fuels generating 81% of the country's electricity in 2019 (BP, 2020). Natural gas has been an important source for energy and consumption of the fuel increased by 53% from 1990 to 2014 (Vidal-Amaro et al., 2018). In 2019 it accounted for nearly 60% of electricity generation (BP, 2020). As the economy continues to grow the energy demand will increase as well and one study estimates an average growth in demand of 3.4% annually (Pérez-Denicia et al., 2017). Based on this demand increase, by 2050, the country would need an additional 85GW of capacity (Vidal-Amaro et al., 2018). Since the introduction of LTA and other instruments like the Clean Energy Credits (CEC),

renewable sources continue to have a bigger share of the country's energy capacity contributing to 10% of the electricity demand in 2019 (BP, 2020).



Since the 1940s, the Federal Electricity Commission (CFE), a vertically integrated, state-owned monopoly, dominated the electricity sector, controlling the majority of generation, transmission and distribution until the Energy Reform Law was passed (Diaz, 2018). The government run company ran up large debts through inefficient business practices. CFE would purchase fuel oil from another state-owned oil monopoly Petróleos Mexicanos (Pemex) to generate electricity, an alternative that is four times more expensive than using the abundant natural gas available (Robles, 2016). Although the country has significantly reduced the use of this heavy GHG emitting fuel source, 10% of its electricity in 2019 was produced from oil (BP, 2020). Due to lack of investment in production, and transportation of natural gas, the country has relied on importing gas from the US in order to meet growing energy needs (Oswald, 2017).

In order to achieve the goals of the energy reform and ensure smooth operation of the newly decentralized National Electric System (SEN) several public entities were created. The Ministry of Energy (SENER) aims at driving the energy policies to support the reform, the National Energy Control Center (CENACE) is a decentralized agency of SENER that serves as the independent grid operator, and the Energy Regulatory Commission (CRE) controls permitting for power generation and regulates transmission and distribution tariffs (Diaz, 2018). The wholesale electricity market (MEM), overseen by CENACE, was created to provide transparency and competition in hopes of driving down electricity costs (Robles, 2016). The current average retail electricity price is 126 USD/MWh (Climatescope, 2019).

4.5.2. Support Mechanisms

The first official legislation passed in 2008 was the Law for the Use of Renewable Energy and the Financing of the Energy Transition (LAERFTE) which stipulated limits for fossil fuel consumption for generating electricity, to 65% by 2024, 60% by 2035, and 50% by 2050 (Vidal-Amaro, 2015). This was bolstered by the General Climate Change Law in 2012 which established targets to mitigate GHG emissions, later reinforced by the NDC to reduce emissions by 30% (unconditional) by 2030 or 36% (with financial support) to help achieve the goals of the Paris Agreement (Grande-Acosta & Islas-Samperio, 2017).

An important part of the energy reform in regard to promoting the growth of renewable energy was with Article 27, an amendment to the constitution which allowed for private investment in electricity generation (Diaz, 2018). In 2015 the Energy Transition Act (LTE) was passed which repealed the LAERFTE and specified methods and instruments to direct clean energy policy such as LTA, and CEC (Masson & Izumi, 2018). Other methods of supporting renewable energies and clean technologies come from organizations like the National Program for the Sustainable Use of Energy (PRONASE), the Energy Transition Special Program (PETE), and the Commission for the Use of Efficient Energy (CONUEE) (Diaz, 2018).

The most effective instruments that stimulated growth of renewable energy sources were LTAs and CECs. In combination, these two instruments mitigated the risk of investing in utility scale projects by guaranteeing revenue through 15 to 20 - year PPAs and the added revenue of selling energy credits (Dobrotkva et al., 2018). One drawback in the definition of these sources is that efficient cogeneration with carbon capture storage and methane are considered “clean,” incentivizing an increase in the production of natural gas and continued dependence on fossil fuels (Vidal-Amaro & Sheinbaum-Pardo, 2018). The Electricity Industry Act came out of the energy reform law and provided DG rules for net metering benefiting systems under .5 MW (Diaz, 2018). DG has been growing but consumers might have more of an incentive to invest in a system if electricity tariffs were not so heavily subsidized and inexpensive (Hancevic et al., 2017) The outcomes of the first three rounds of auctions were very successful but the current administration canceled the fourth round with no plans to schedule another (Mesbahi & Langone, 2019).

4.5.3. NCRES and Solar

Mexico has potential for most types of NCRES including expansion of hydropower, geothermal, wind, wave and solar (Vidal et al, 2015). Mexico is 5th largest market in the world for geothermal energy with a capacity of nearly 1 GW (IRENA, 2015). During the first three LTAs, just over 7 GW of NCRES projects were awarded, mostly solar with nearly 4,867 MW, and 2,121 MW of wind (Viscidi & Yépez, 2019).

Mexico is situated within an excellent latitude range for converting solar radiation into electricity (Mundo-Hernández et al., 2014). Nearly the entire country is privileged with excellent solar radiation; 75% of the territory boasts 5 kWh/m^2day with certain areas reaching of 7 kWh/m^2day in Baja California, and even the lower values are still significantly higher than that of Germany and Spain, countries with well-established solar industries (Villicaña-Ortiz et al., 2015). In April of 2019, there were 42 operational photovoltaic plants accounting for 3.6GW, mostly in the northern states established by companies from all over the globe including Italy, Spain, China, Canada, and significant projects from Mexican companies (Mesbahi & Langone, 2019). Not only have the auctions significantly increased solar market penetration, but the projects have been awarded for incredible prices for the global industry. The last auction in November 2017 broke the world record for lowest cost for solar at the time with a low bid price of 20.57 USD/MWh (Viscidi & Yepez, 2019). DG systems have also been growing exponentially, jumping from 62 MW in 2014 to nearly 1GW in 2019 (CRE, 2020). The first bifacial system was installed in Mexico with capabilities of capturing solar radiation on both sides of the panel which can increase production by up to 15% as well as providing further durability (Mesbahi & Langone, 2019).

4.5.4. Challenges for the Industry

At the end of 2018, the new President Andres Manuel López Obrador took office and since his current administration is working to undo the work of the Energy Reform Law and return to a state-controlled electricity sector. Last year the administration changed the rule for CECs, originally designated for new renewable projects, and issued certificates for CFE hydro projects constructed before the reform, flooding the market with CECs and subsequently devaluing them (Guevara, 2020). At the end of April in response to the pandemic, CENACE released an agreement with SENER stating that the intermittency of wind and solar put the system at risk and create instability and put a hold on pre-operational tests for new plants (Guevara, 2020). They created limitations on the amount of future permits for generation, and gave CENACE the right to reject these permit requests, favoring the SOE CFE (Warren & De Giovanni, 2020). Many power generation companies have filed lawsuits questioning the legality of the actions of SENER (Cubillo, 2020). This attack on renewables remains unresolved and reflects the motivation of the current administration to revert back to a state-run monopoly favoring the production of fossil fuels (Cubillo, 2020). In June, CFE raised their transmission fees over 800%, to undo legacy permits that were instilled by the energy reform to provide lower fees for clean energy (Warren & De Giovanni, 2020).

CHAPTER 5

Multi-Criteria Analysis of Solar PV Markets

5.1. Market Drivers and Barriers

This section aims to highlight the commonalities and differences regarding development of the solar industry in Argentina, Brazil, Chile and Mexico (referred to as ABCM from this point on). Parallels can be drawn between the motivations to diversify the electricity sector, the methods and mechanisms employed to stimulate growth, and barriers the markets face. The first section will provide a review of the common policies and other governmental support mechanisms with more detailed descriptions of auctions and DG laws. The following section will assess market attractiveness based on the resource availability, the efficacy of regulatory policy support (with emphasis on auctions), and challenges the industry is facing, including political and economic risk. Based on the scale of 1 being least attractive, to 5 very attractive, Chile and Brazil are trending towards very attractive markets, while Argentina and Mexico are relatively less attractive. These results will be explained by an analysis of each country's performance or score in various categories and a comparison of which features are strengths and/or relative weaknesses in relation to the others.

5.1.1. Motivations for Diversification

Hydropower is a common source in Latin America and makes up a relatively significant share of the electricity matrix as shown in each country profile. This results in countries being susceptible to supply insecurity due to climate change related droughts becoming more frequent and severe droughts (IRENA, 2016). With the exception of Brazil, the other three countries have struggled to satisfy electricity demand using domestic sources of energy resulting in a lack of energy independence (Jimeno et al., 2015; Nasirov et al., 2017; Robles, 2016). As mentioned, this subjects them to the inexorably volatile price fluctuations inherent in the global market for fossil fuels. Diversifying the electricity matrix with NCRES not only insulates the electricity sector from FF prices, but also provides more supply security to meet the needs of increasing electricity demand, integral to economic growth (BNEF, 2019). These countries will need to capitalize on the various resources available to grow in a sustainable manner that is in line with goals outlined in the Paris Agreement.

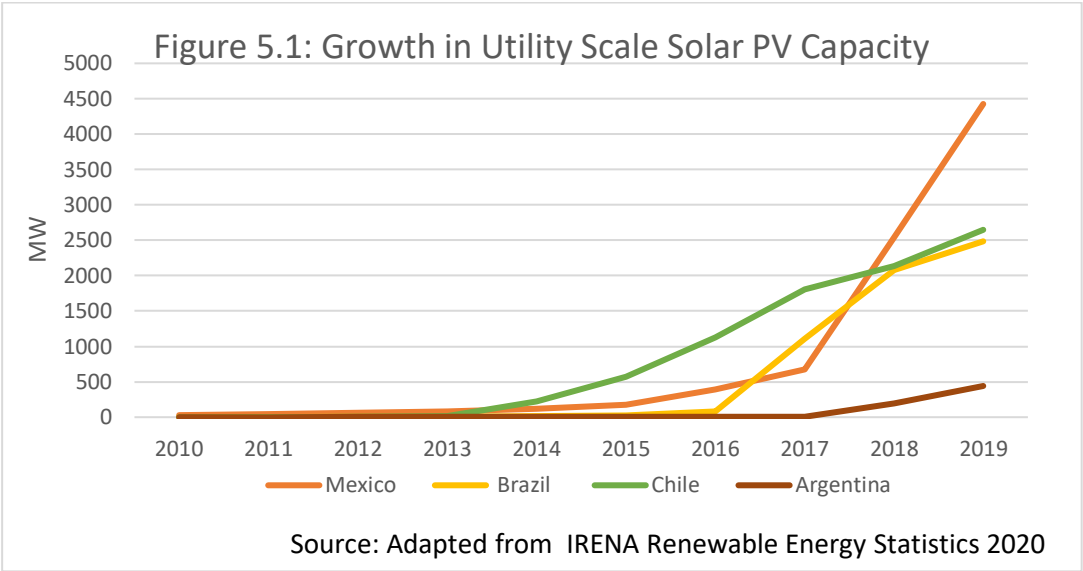
5.1.2. Challenges

Some of the main challenges ABCM face are higher costs associated with importing technology (Haas et al., 2018); large distances between the regions with the best solar radiation and high demand centers, specifically for Chile and Argentina (Haas et al., 2018; Jimeno et al., 2015); and outdated grids and lack of transmission line capacity for new projects (BNEF, 2019; Robles, 2016; Recalde et al., 2015). Other challenges typical in immature markets include a lack of industry expertise and skilled workers and

insufficient access to low-cost funding (Haas et al., 2018; Carstens & Cunha, 2019). Land acquisition for projects also presents difficulties due to environmental concerns, adverse effects on local communities and land rights of indigenous communities (Pimenta da Silva et al., 2019; BNEF, 2017; IRENA, 2016).

5.1.3. Policy Support Mechanisms

In order to overcome these obstacles, the government's role in supporting the incipient market is essential. Strong policies signal a commitment to building a more sustainable energy matrix and inspire investor confidence. This is important due to the nature of NCRES projects requiring large upfront capital and slow rates of return on investment for projects with a lifetime of around 20 years. Recent global developments in the solar industry such as widespread use of tenders, decreasing PV module prices, have pushed the LCOE of solar down so much that it has become competitive with traditional fuel sources (IRENA, 2018). Notable capacity additions in PV solar in Latin America really only began within the last five years, in great part due to policies put in place by governments, namely tenders for utility scale solar plants (see Figure 5.1). Table 5.1 displays some of the key regulatory policies used in ABCM.



Source: Adapted from IRENA Renewable Energy Statistics 2020

Table 5.1: Policy Instruments	Argentina	Brazil	Chile	Mexico
NDC Emission Reduction:	(Both for 2030) 570MtCO2e (unconditional) 469MtCO2e (conditional)	37% reduction by 2025 43% reduction by 2030 (base year 2005)	.71tCO2e per GDP By 2030 (excl LULUCF) Carbon Neutral by 2050	30% reduction by 2020 50% reduction by 2050 (base year 2000)
Renewable Portfolio Standards (exc. Hydro)	12% by 2019 20% by 2025	23% by 2030	20% by 2025 70% by 2030	30% by 2021 50% by 2050
Tax Incentives	VAT Rebate Accelerated Depreciation	VAT and Industrial Products Tax Exemption	N/A	Accelerated Depreciation Benefit
Utility Regulations	N/A	Transmission fee discount	Transmission fee discount	N/A
DG Laws	Net Metering	Net Metering	Net Billing	Net Metering
Unique Instruments	PPA partial Guarantee by World Bank and FODER	Virtual Net Metering	Phase out Coal Fleet by 2050	Clean Energy Certificates

Source: Climatescope 2019

Other policies incentivize the use of NCRES by reducing the cost through tax incentives or utility regulations. Argentina and Brazil offer Value added tax (VAT) exemptions for renewable energy equipment which directly support solar as there is an immediate price reduction, having a favorable effect on the LCOE (Vilaça Gomes et al., 2018). Accelerated depreciation policies in Argentina and Mexico also directly benefit solar as investments can be depreciated more quickly than for normal businesses resulting in lower taxes (IRENA, 2015). In Brazil, systems less than or equal to 30MW only have to pay 50% of transmission and distribution tariffs and in Chile projects smaller than 9MW are exempt, while projects between 9MW and 20MW pay a portion of the tariffs (Climatescope, 2019).

Each country also has unique mechanisms in place to support the solar industry. The RenovAr auction program was designed in coalition with the IFC and the World Bank to partially guarantee investments of project developers who sign PPAs, a fund of $250 million, and the country also has a domestic fund FODER guarantee to reduce risk for developers (IFC, 2019). Brazil is one of a few countries in the world with legislation approving virtual net metering, allowing customers to install a PV system far away from their residence and still receive the benefits of net metering (Bradshaw, 2017). Chile is one of the only countries in the world with plans to retire its coal fleet setting the goal of closing

all coal plants by 2050 (REN21, 2020). Mexico's CEC market to support the carbon tax is also integral to the auction design as the credits are awarded to project winners and they can be sold, adding another line of revenue for projects (Diaz, 2018).

5.1.4. DG Policies

DG is an important subsector of the market for PV. It can play a key role in developing the overall market. As previously discussed, it can help with grid stability, helps toward achieving RPS with little government involvement, and has potential to stimulate the development of domestic supply chains (Soto et al., 2019). It can also reduce the need for additional transmission lines as much of the electricity can be consumed on site (Schmidt et al., 2016). Brazil has the highest capacity of DG installed at 3.7 GW (Absolar, 2020) followed by Mexico with just under 1 GW (CRE, 2020), while Chile's is very small with only 42MW installed by 2019 (CNE_b, 2020). Argentina has the least DG capacity reaching 2.5MW currently, up from .85 in 2019 (CAMMESA, 2020). Brazil has the highest limit for systems eligible for net metering benefits at 5MW (Bradshaw, 2017). Mexico has a limit of 10kW and 30kW for low voltage residential and commercial respectively and .5MW for high voltage users (Climatescope, 2019). Chile modified its net billing law in 2019 to include users from 100kW to 300kW and has seen a greater increase in capacity since (CNE_b, 2019). Argentina passed the DG law in 2017 which has no specification on system limits, new buildings are required to have DG, and the law created organizations and funds to help support the local industry (Porcelli & Martinez, 2018).

5.1.5. Auction Design Review

Auctions are the most essential tool for attracting investment and growing PV capacity. Auction design is crucial to contracting more projects, encouraging project developer confidence and can result in more competitive prices, less speculative bidding and smoother project development procedures. Table 5.2 highlights several auction design elements including frequency, technologies offered, currency of contracts, local content requirements, contract lengths and lead times. Regularly organized auctions can demonstrate consistency and continued commitment to procuring capacity additions to electricity supply (Viscidi & Yepez, 2019). Higher frequency also leads to more capacity awarded over time. Some auctions are technology neutral where developers of various technologies can compete against each other for capacity offered while others are limited to a single technology. Technology specific auctions are especially conducive to stimulating PV in nascent markets where solar is not cost competitive against other technologies or traditional fuel sources and might not win as many contracts if put head-to-head against other more mature technologies (Soto et al., 2019). Technology neutral auctions on the other hand increase competition and drive down prices (Soto et al., 2019). Currency fluctuations and inflation can be a risk for developers in emerging markets (BNEF, 2019) and whether the PPAs are contracted in the local currency or USD along with how they are indexed for inflation can potentially reduce risk.

Some countries elect to encourage developers to source equipment and services from local companies in an attempt to bolster the local economy and develop the domestic supply chain (IRENA$_b$, 2019). While this requirement can be beneficial in the long run, it can have a negative effect on the price of bids as nascent markets rarely have the ability to achieve economies of scale necessary for competitive prices (IRENA$_b$, 2019). The length of the time between the auction and the designated commercial operation date is relevant as longer lead times can lead to speculative bidding in hopes of prices declining in the future; however, lead times that are too short reduce timely completion of projects (Viscidi & Yepez, 2019)

Table 5.2: Auction Features	Argentina	Brazil	Chile	Mexico
Frequency	Annually	2/year	Annually	Annually
Technology Specific or Neutral	Specific	Specific and Neutral	Neutral	Specific
Lowest Prices for PPAs awarded	40.80 USD/MWh (2019)	39.30 USD/MWh (2019)	32.5 USD/MWh (2017)	20.60 USD/MWh (2017)
Denomination and indexing of PPAs	Priced in USD, Paid in ARG	BRL	USD	MXN
Local Content Requirement	Priority for access to FODER fund and tax credit eligibility	Priority for financing from BNDES with 70% local content	No Requirement	No Requirement
Contract Length	20 years	15-30 years	20 years	15 years
Lead times	2 years	3-7 years	4-6 years	2 years

Source: Adapted from International Development Bank Clean Energy Auctions in Latin America (Viscidi & Yepez, 2019)

5.2. Solar PV Market Attractiveness Comparative Analysis

The solar industry is a young market in ABCM, and things are changing every year. Due to the dynamic nature of the market, the most up to date and accurate information is limited. Also, current studies discussing the solar industry in Latin America typically give a broader overview and rarely provide detailed data on all four of these markets or how they compare to one another. Other studies only provide information on the market for NCRES in general. In order to have a framework to qualitatively compare the countries in this study using the most current data available, a market attractiveness rating system was developed. The categories selected for the rating system were derived from the Renewable Energy

Country Attractiveness Index (RECAI) by Ernst & Young Global Limited (EY) and the Climatescope country ranking system by BNEF. The Climatescope study covers 104 emerging markets and analyzes their performance based on 167 indicators. The three main topic areas are Fundamentals, analyzing clean energy policies, and barriers, Opportunities, looking at short-medium term opportunities for renewable energy procurement, and Experience which includes installed capacity and historical investment trends (Climatescope, 2019). The categories for the EY methodology are shown below in Figure 5.2. Both of these rating systems are applied to rank countries in order of attractiveness but Climatescope provides more detailed country specific data than the EY RECAI reports. Neither Climatescope nor EY break down the ratings by technology.

Due to the more general scope of this work, the Market Attractiveness rating system was formulated through identifying the key general categories addressed in both methodologies. The categories and corresponding ratings for each country can be found in Table 5.3. The rating system is a scale of 1 to 5, higher values reflecting a more attractive market. For example, a 1 would denote a very unattractive market based on the situation in the country, a 3 being somewhat attractive, and 5 meaning the country is very attractive or favorable for investment. The ratings for Policy Support are based on the number, strength and breadth of the policies excluding Auctions. The Auction category rating is based on the quality of design, success in contracting solar projects, as well as the future outlook for auctions. The Economic and Political Stability category ratings are based on the risk, or lack thereof, in each country due to these factors. The ratings under the Impact of Barriers category are judged on how the barriers are being addressed in each country and the extent to which the barriers hinder the market; a 5 would mean that the barriers have little to no impact creating a very attractive environment. Table 5.3 displays the Market Attractiveness assessment which will be further explained below.

Table 5.3: Market Attractiveness	Argentina	Brazil	Chile	Mexico
Resource Availability	**5**	**5**	**5**	**5**
Policy Support	**4**	**5**	**4**	**3**
Auctions	**4**	**5**	**5**	**2**
Economic and Political Stability	**2**	**4**	**5**	**1**
Impact of Barriers	**3**	**4**	**4**	**2**
Overall Score	**3.6**	**4.6**	**4.6**	**2.6**

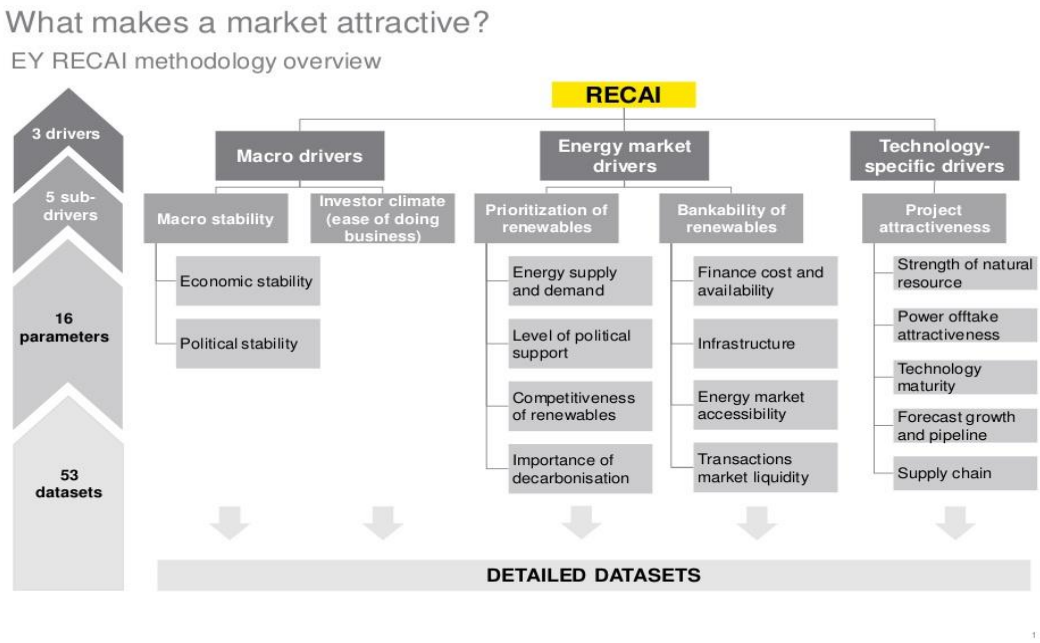


Figure 5.2: EY RECAI Methodology Overview

5.2.1 Resource Availability

The solar radiation in all four countries is excellent, which is one of the strongest aspects of market attractiveness in the region. The Energy Sector Management Assistance Program (ESMAP) funded the Global Solar Atlas which provides in depth detail about the solar radiation all over the world along with potential PV electricity output. The report Global Photovoltaic Power Potential by Country provides an analysis of the data compiled by Solargis in the Global Solar Atlas. Daily GHI values range from roughly 2kWh/m^2 – 8kWh/m^2 and values in Germany for example range from 2.75 – 3.34 kWh/m^2 (ESMAP, 2020). The highest PV power potential is found in the Andes region in northwest Argentina, and northern Chile (as well as Bolivia and Peru), due to the full sun exposure with few cloudy days, low air temperature and the thinner atmosphere at high altitudes (ESMAP, 2020). The report also concludes that around 20% of the global population resides in countries with potential PV output exceeding 4.5 kWh/kWp which includes Argentina, Chile, and Mexico, while Brazil falls just under, fitting in the favorable mid-range category of 3.5 to 4.5 kWh/kWp (ESMAP, 2020). These high ranges of solar radiation are shown in Table 5.4, along with the estimated average LCOE in 2018 of large-scale PV plants. This chart shows a snapshot of LCOE estimations based on 2018, demonstrating the competitive prices leveraged due to elevated GHI, even when compared to fossil fuels ranging from .05 - .15, (see LCOE chart in Chapter 3). The lower range of potential PV output is defined as below 3.5 kWh/kWp consisting mostly of European countries (ESMAP, 2020). Although Chile is ranked the highest for potential output, the other three countries have solar radiation that is very attractive to developing PV as well. Brazil and Argentina also have quartz reserves, a valuable resource for producing solar panels

(Jimento et al., 2015; Rüther& Zilles, 2011). For these reasons all countries are rated 5 as the resource availability contributes to a very attractive market.

Table 5.4: Global Solar Atlas Statistics	Argentina	Brazil	Chile	Mexico
GHI Range (kWh/m^2)	4.31 – 7.2	4.31 – 6.17	3.37 – 7.43	4.7 – 6.3
Average GHI (kWh/m^2)	5.09	5.39	6.13	5.77
Average Practical Potential Output (kWh/kWp)	4.599	4.404	5.365	4.924
Average Practical Potential World Rank	63	84	2	20
Est. Average LCOE ¢/kWh in 2018	.11	.12	.07	.09

Source: Global Solar Atlas

5.2.2 Policy Support Mechanisms

Argentina - 4

The government has a long history of legislation drafted to encourage and signal a concerted effort from the state to stimulate NCRES markets and a commitment towards developing a more sustainable economy with a wide range of instruments. The targets for NDCs and RPS are not very ambitious however they are realistic considering the contribution of NCRES to the electricity matrix is only 6% (CAMMESA, 2020). The net metering rules are very extensive, and the lack of system limits provides great opportunity for growth. Although they have not significantly stimulated the DG capacity so far (partially due to the low electricity tariffs which are steadily increasing as subsidies are slowly decreasing) (Jimeno et al., 2016), the law offers great incentives and aims to support the local solar industry. The FODER fund to provide guarantees for PPAs has dual benefits as it encourages investor confidence and the money is sourced from phasing out fossil fuel subsidies (Jimeno et al., 2016). The country earns a rating of 4 because of the wide breadth of policies including NCRES funds, RPS, DG laws, and tax incentives. As Argentina is the least developed out of the four countries in terms of the solar industry, the efficacy of these mechanisms is yet to be fully realized.

Brazil - 5

This country has a long track record of policies to support NCRES although historically there was more success in stimulating the wind market (Aquila et. al, 2017). After the introduction of solar into the

auction program along with several policies encouraging DG, solar capacity began to grow significantly, creating a very attractive environment for the technology. The DG laws in particular have the most positive influence on the country's market attractiveness. The net metering laws are so effective, the capacity for DG has surpassed that of centralized utility scale projects this year reaching 3.7 GW accounting for 55% of installed capacity (ABSOLAR, 2020). In combination with the tax incentives, utility regulations and development bank for NCRES, the variety of mechanisms creates a very attractive environment for solar resulting in a rating of 5.

Chile - 4

Chile has very ambitious RPS and NDCs with a recently updated goal to be carbon neutral in 2050 and stands out in the region as well globally with the country's plans to phase out coal (REN21, 2020). The country's policies have contributed to creating an attractive environment for solar and the capacity has steadily increased over the past several years. The main reason Chile is rated 4 instead of 5 is due to the weaker DG laws. It is the only country with net billing instead of net metering which immediately is less attractive as the credits received from injecting surplus energy into the grid is valued less than the energy consumed (Watts et al., 2015). Although the law was amended to increase the system size limits, this policy may need more changes to stimulate this side of the sector. The country also does not have national funds for NCRES or solar.

Mexico - 3

Although the country has several mechanisms in place that normally would create an attractive market, the current administration has diminished the effect of these laws. The value of the CECs was decreased when the government retroactively issued credits to existing plants owned by the government (Guevara, 2020). Also, the current administration is looking to invest more in fossil fuels which will make it very difficult to achieve the NDC emission reductions and RPS (Cubillo, 2020). The DG rules are still effective, and the new administration has created some obstacles but there is still hope for this policy (Langone et al., 2020). Although the country has several policies to support the solar market, the current administration has rendered most of them ineffective except for the potential for continued growth in DG, resulting in a neutral rating of 3.

Comparison

Aside from tenders, Brazil's unique DG laws are the single most important category of policies to support the solar industry and are far more effective than in any other of the three countries. The DG capacity itself eclipsed Chile's total installed capacity and combined with utility scale systems, Brazil also surpasses Mexico. The net metering laws in Mexico also have helped to steadily increase the number of installed systems but at a slower rate than Brazil. Chile's and Argentina's recent growth may yet prove more successful. Chile has already reached the RPS goals for 2025 (CNE, 2020) With a defined timeline for shutting down coal mines, the country is an especially attractive market as completion of these goals will likely be driven by continued growth in the solar market.

5.2.3 Auction Design

Argentina - 4

The most important factor stimulating the solar industry has been well-designed auctions, each of which were overprescribed. Contracts priced in USD and paid in ARG along with partial backing of the World Bank bolstered investor confidence. This led to the greatest capacity additions in the country's history with relatively competitive prices (IFC, 2019). MATER auctions have also provided another outlet for users with a demand over 300kW to contract PPAs through auctions, a more effective mechanism than the DG law thus far, awarding over 1GW of capacity (Fenés & Gubinelli, 2019). Shorter lead times have led to high rates of delay with only 33% of projects completed on time (Viscidi & Yepez, 2019). Local content benefits have resulted in a higher percentage of local players (Viscidi & Yepez, 2019) The country didn't score a 5 due to the fourth installment of auctions being put indefinitely on hold due to transmission capacity issues; however when it is scheduled it will also auction transmission capacity additions to address this issue (Fenés & Gubinelli, 2019).

Brazil - 5

This country has the most experience with renewable energy auctions due to the higher frequency although solar was only introduced in 2014 (Aquila et al., 2017). Initially PV was only allowed to compete in technology specific auctions, the prices awarded were still competitive globally (Bradshaw & Januzzi, 2019). In 2019 solar PV hit record prices in the technology specific auction A4 and again when it was admitted to the A6 technology neutral auction for the first time with average prices of $20.8/MWh and $16.48/MWh respectively; however, the record is being contested as some energy will be sold in the spot market and not solely through the PPA (REN21, 2020). Regardless auctions have pushed prices down and solar has even proven competitive in the technology neutral auctions. Longer lead times have led to the highest on time completion rate of 78% (Viscidi & Yepez, 2019). The country receives a top score for auctions due to their continued resounding success.

Chile - 5

Before the auction design in Chile was reformed in 2014, renewable projects only won 2% of the contracts, but since then the country has seen steady growth in NCRES especially solar PV (Nasirov et al., 2019). Some of the key changes made were longer contracts and lead times, changing the contract denomination to USD indexed to inflation, and introducing 8-hour time blocks for bidding (Nasirov et al., 2019). The breakdown of supply blocks into 8-hour segments really caters to the intermittency of solar as developers only have to bid on the daytime when systems produce (Nasirov et al., 2017). The change in currency denomination is seen as favorable to foreign investors evidenced by the fact that 100% of the developers are foreign companies and their local subsidiaries (Viscidi & Yepez, 2019). All auctions are technology neutral making Chile one of the few countries in the world where solar can compete with fossil fuels and other NCRES without subsidies (Agostini et al., 2016). Chile's utility scale capacity soared over the past five years at 3.128 GW, and the number of projects currently under

construction this year is more than the current installed capacity with 3.567 GW (CNE_b, 2020). One drawback is the extremely high rate of delays witnessed with only 8% of projects completed on time but this fact has not led to project abandonment (Viscidi & Yepez, 2019) The country scores a 5 in this category because these auctions are an essential factor to the market attractiveness in Chile especially after the reform and have contributed to a very attractive market.

Mexico - 2

The first three rounds of tenders were extremely effective and due to the short lead times, Mexico saw rapid growth in installed capacity (Diaz, 2018). Mexico set the world record for the lowest bid of $20.60/MWh in 2017, reflecting a very attractive market and the efficacy of the CEC being offered to bid winners (Mesbahi & Langone, 2019). More than half of the PPAs awarded went to PV, where wind in the other countries won more contracts (Viscidi & Yepez, 2019). The country receives a 2 in this category because of the indefinite suspension of the program and no signs that the current administration will schedule another auction.

Comparison

Brazil has the longest history of effective auctions (reaching 29 total) due to the higher frequency and a combination of technology specific and neutral auctions (FS-UNEP, 2020). Although tenders in Mexico currently puts the country in first place in terms of installed utility scale capacity at just under 4.5 GW, with no more auctions scheduled, Chile and Brazil will likely surpass the country within the next year. The auctions in Chile, and now Brazil with the entry of PV into the neutral auctions, reflect the efficacy of the tendering process and the true potential solar as a cost competitive alternative to traditional fuel sources. The lack of local content requirements in Chile and Mexico are seen as favorable to project developers due to the tendency of price increases for local equipment ($IRENA_b$, 2019). In the long run, however, the incentives for local content in Brazil and Argentina could become an advantage for the countries if they manage to establish a local supply chain and can not only avoid high import tariffs, but also export to countries in South America. Around two thirds of winning bids in Argentina and Brazil come from local companies (Viscidi & Yepez, 2019).

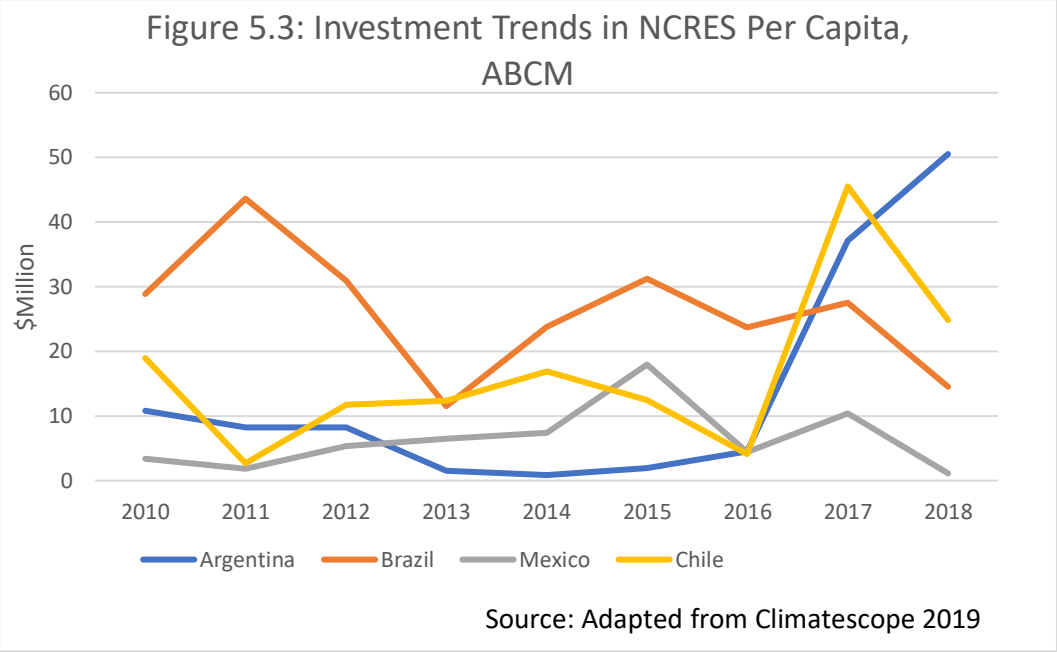
5.2.4. Economic and Political Stability

The level of risk is a factor project developers must consider when investing in large utility scale PV plants. Some of the political risks that are especially relevant in regard to renewable energy projects are transitions to new administrations, and changing laws or policies (BNEF, 2017). Economic risks are influenced by the stability of the economy, currency fluctuations and interest rate risk (BNEF, 2017). Moody's and Standard & Poor are two organizations that assess credit and assign a rating based on the risks involved when investing in countries. These ratings are countrywide and do not distinguish between industries, so they are not necessarily pertinent to the solar market specifically. Nonetheless they are included in Table 5.5 to provide an idea of the overall rating of each country. Figure 5.3 shows

investment trends in NCRES (not specifically solar) in order to provide another perspective on confidence in these markets.

Table 5. 5: Credit Rating	Moody's	S&P	Rank Significance
Argentina	Ca	CCC+	Non-Investment Grade (extremely speculative)
Brazil	Ba2	BB-	Non-Investment Grade (speculative)
Chile	A1	A+	Upper Medium Grade
Mexico	Baa1	BBB	Lower Medium Grade

Source: https://tradingeconomics.com/country-list/rating



Argentina – 2

Historically a bad place for investment with such economic turmoil and high rates of inflation (Recalde et al., 2015). This is reflected in the very low ratings from Moody's and S&P. As these ratings are country wide, they don't necessarily reflect the current situation in the market for solar. The World Bank and FODER providing guarantees for PPAs awarded during auctions has greatly reduced risk. The investment trends demonstrate the efficacy of the RenovAr program in inspiring investor confidence as

the auctions have attracted billions of dollars for investment in NCRES (see Figure 5.3). With the pandemic stressing the economy, more uncertainty about investments have arisen this year as well (Tayal, 2020). The country receives a score of 2 because even with investment guarantees and trends on the rise, the country on the whole is a risky place for investment making the solar market slightly unattractive in terms of economic stability.

Brazil - 4

According to Moody's and S&P, Brazil is also not considered the safest place for investment. Again, the NCRES investment trends show that Brazil has consistently invested heavily in the sector. In 2019 the country had a 30% increase in investment with $6.5 billion, of which $2.5 billion went to PV (FS-UNEP, 2020). The country also ranks high globally for investment in NCRES (REN 21, 2020). From a political standpoint, the government has continually supported the growth of NCRES. The Moody's and S&P rankings have some weight but in general the country is an attractive market for investment in NCRES and solar specifically which is why it receives a 4.

Chile - 5

The economy and political environment has always been seen as stable and the high scores given by Moody's and S&P reflect this. The country was the first to privatize the electricity sector and there is little oversight or regulations coming from the government, an environment favored by investors (Nasirov et al., 2019). The investment trends in NCRES in Chile have not been as stable but in 2019, the country received record investment totaling $4.9 billion, of which $2.2 billion went to PV (FS-UNEP, 2020). Based on the upper medium grade ratings from Moody's and S&P, along with the consistent political support, the country is rated 5.

Mexico - 1

The country is seen overall as a decent place for investment according to the credit ratings from Moody's and S&P. While this may be true in certain sectors of the economy these assessments do not accurately reflect the political risk involved with investing in the solar industry. The Energy Reform was passed in 2013 in hopes of opening the electricity sector to private investment and reducing inefficiencies of the government owned monopoly (Robles, 2016). The current administration is working to undo these policy reforms and seeks to revert back to an electricity sector run by the government with more investment in fossil fuels (Cubillo, 2020). By flooding the CEC market and devaluing the credits, investors are deprived of a key factor in the profitability of their projects (Guevara, 2019). Also, this year the government tried to limit the number of permits available to wind and solar producers (Warren & Giovanni, 2020). The country scores a 1 due to the current administration's actions creating significant risk and a very unattractive environment for investment.

Comparison

Chile is seen as the best country overall in terms of investment risk and the solar industry is no exception. Brazil and Argentina may be rated low, but the continued investment in NCRES shows that these markets are more than speculative. Brazil has consistently led with huge investments in NCRES with

Mexico surpassing the country only once in the last ten years. Mexico is the least attractive market in terms of political risk.

5.2.5. Impact of Barriers

Argentina - 3

This country is the least mature market in the region and has limited experience in the industry. The largest barriers in the past were insufficient lines of funding and investor confidence in the country. These challenges are still present, but the country is taking steps to reduce them. Transmission remains a large barrier and is the greatest impediment to continued growth of the market as capacity additions for large-scale PV cannot occur without grid upgrades (Fenés & Gubinelli, 2019). The country plans to overcome this barrier in procuring transmission expansion in the next round of RenovAr. Argentina scores a 3 in this category as the impact of the barriers is still hindering market growth, but they are not inhibiting growth completely creating a moderately attractive environment for PV.

Brazil - 4

The lack of skilled workers is highlighted as a barrier in the industry for Brazil specifically (Carstens & Cunha, 2019). Some states have created training centers to help overcome this barrier (Bradshaw & Januzzi, 2019). Local content requirements can present barriers to investment due to higher prices, (IRENA$_b$, 2019) but it hasn't been much of an obstruction. Low-cost access to funding is one of the largest obstacles because even though the development bank BNDES offers favorable rates, it doesn't provide funding for smaller projects (Aquila et. al, 2017). Transmission capacity also remains a challenge for further expansion in the industry (IRENA, 2016). Brazil receives a score of 4 because the barriers are normal challenges countries face when developing a market and they are not inhibiting growth as the country has the highest installed capacity combining DG and centralized projects (ABSOLAR, 2020).

Chile - 4

Some of the specific challenges that Chile faces along with the other general barriers of an emerging market, are linked to the harsh conditions in the desert. The highest levels of radiation in the desert come with greater stress on panels due to extreme conditions and soiling coming from dust covering panels (Haas et al., 2018). Lack of water to clean the panels in these remote desert areas is another obstacle (Zurita et al., 2018). At this point, the industry is prohibitive to smaller companies and without any direct lines of financing or favorable lending rates for small companies or even residential owners (Haas et al., 2018). The country has made great progress in transmission, linking the northern and southern grids into one system and seeks to invest in transmission lines linking Chile with neighboring countries by 2035 (Diaz et al., 2020). The country receives a 4 because although the barriers are still present, they are not so inhibiting. These barriers are trending towards having less impact on the industry and mainly present areas for improvement.

Mexico - 2

Among the other common barriers such as an outdated grid system with lack of interconnection and sufficient transmission lines, land rights also were listed as a specific barrier (Robles, 2016). Much of the land best suited for solar coincides with indigenous communities, and community involvement is seen as an opportunity to overcome this challenge (Dobrotkva et al., 2018). Aside from these relatively common challenges, the main impediment standing in the industry's way is the current administration. The country was on track to be a leader in the region however the new administration put a halt to that progress. Due to the significance of this barrier, the country receives a score of 2 because it is not an attractive market currently.

Comparison

Transmission is the most prevalent challenge represented in all four countries however Brazil and Chile are taking greater strides in upgrading their grids (REN21, 2020). Both of these countries could benefit from stronger funding for solar projects. ABCM all have land permitting right issues whether being indigenous land, environmental impact issues, or other reasons but it has more impact in Mexico than in the other countries (Robles, 2016). Large international developers do not have significant trouble securing finance, but the industries could benefit from more funds for smaller companies (Carstens & Cunha, 2019). As they are being addressed, these are not insurmountable challenges, they just need continued attention, foresight and planning for as project developers.

5.3. Discussion of Results

5.3.1. Overall Ratings

Argentina – 3.6

The country is the least mature out of the four countries but has shown true promise in the past few years. The high levels GHI, various support mechanisms, along with well-designed auctions and backing from the World Bank are the most attractive features paving the way for continued growth in the solar market. The country has a long history of economic turmoil, high inflation, and a volatile currency (Recalde et al., 2015), and there is still a level of risk due to this economic instability. The biggest barrier the country faces is lack of transmission and the next RenovAr auction is uncertain due to these grid constraints. Argentina is an attractive market with an overall score of 3.6 due to uncertainties in the nascent market, but the solid base of policies in place sets the country up to be an industry leader in Latin America as the solar industry continues to progress.

Brazil – 4.6

The strength and breadth of policies to support the solar industry, including very effective DG laws and a long history of successful auctions are the greatest strengths in Brazil. The DG laws set the country apart from the others and this sector of the industry will continue to create a higher contribution of solar to the electricity matrix. Solar PV's ability to effectively compete in the A6 technology neutral auction

is very promising for continued success of the technology in future auctions. The existing barriers affecting the attractiveness of the market should continue to be addressed in order to enhance further growth of the solar industry. Key opportunities for improvement include establishing better lines of finance for smaller solar projects and creating training programs to generate a more skilled workforce, and continued upgrades to the grid. Receiving an overall score of 4.6, the current state of the solar market in Brazil is leaning towards a very attractive market.

Chile – 4.6

The country's excellent solar radiation and ambitious RPS are very promising for the future of PV. The projects currently in the pipeline will continue to increase the capacity for years to come. An auction scheduled for next spring with over 2GWh of energy and storage offered will reinforce the current trajectory of the industry (Sully, 2020). The strongest aspects of the Chilean solar market are some of the highest levels of GHI in the world, well-designed auctions and economic and political stability creating a very attractive market for solar. The challenges that the country still needs to overcome is stimulating the DG sector of the solar industry, providing better lines of finance, and continuing to expand the grid. These obstacles are by no means insurmountable and the market is trending towards a very attractive market with a high score of 4.6.

Mexico – 2.6

The Energy Reform law set the base for development of the solar industry through liberalization of the energy sector and several policies to stimulate growth including CECs, net metering laws, and auctions. The decisive success of the auctions and the high levels of GHI in Mexico reflect the potential of the solar PV industry. Since the current President Andrés Manuel López Obrador was elected, the administration has worked to dismantle these policies and attempted to revert back to a government owned and operated electricity sector. With four more years of this administration and continued attacks on NCRES development, there is a lot of risk regarding the future of the solar industry. Given the political environment, Mexico scores an overall rating 2.6 indicating a moderately unattractive market.

5.3.2. Final Observations

Unlike the conclusions made in the EY and Climatescope studies, the results of this analysis do not provide ranks due to the qualitative nature and limited scope of this rating system. Instead the categories of the methodology provide a foundation which can be used to highlight relative advantages or strengths in the factors falling under each category. The relatively higher ratings attributed to Brazil and Chile indicating more attractive markets, and the lower ratings of Argentina and Mexico signifying reasonably attractive and slightly unattractive markets respectively, correlate with the rankings for these countries assigned by Climatescope and EY. Brazil, Chile and Argentina all scored higher ratings (and ranks) than Mexico, and both Brazil and Chile scored higher than Argentina (Climatescope, 2019; Warren & Giovanni, 2020). In the Climatescope results, Chile was ranked 2nd with a rating of 2.85, Brazil 3rd rated 2.76, Argentina 7th and 2.49, and finally Mexico 24th at 2.17 (Climatescope, 2019). In the EY results,

Chile was ranked 11th, Brazil 15th, Argentina 19th, and Mexico 33rd (Warren & Giovanni, 2020). Recall that these studies did not distinguish between the various NCRES technologies when assessing the countries, and they also covered different groups of countries with Climatescope focusing on emerging markets and EY providing ranks for the top 40 markets.

Chapter 6

Conclusion

Climate change represents one of the greatest existential threats to civilization. Rapid decarbonization of the world's economy is essential to reduce the risk of irreversible damage to climate systems. Replacing fossil fuels with renewable energy sources for electricity generation is an important step to achieve necessary emission reductions (IRENA$_a$, 2020). The LCOE of technologies like wind and solar energy fell 77% between 2010 and 2018 (IRENA, 2018) making these viable options to spark an energetic transition. These technologies are the most cost-effective option for investment in new electricity generation in many parts of the world including Latin America (BNEF, 2019). The current work demonstrates the potential for ABCM to capitalize on the high levels of GHI and low costs of solar energy. The technology is relatively underutilized accounting for very small shares in electricity generation, ranging from less than 1% in Argentina to the highest contribution in the region in Chile with 8% (BP, 2020; CNE$_a$, 2020).

The work seeks to provide a broad overview of the solar industry in ABCM through an examination of the electricity sectors, highlighting the most valuable techniques employed, along with other market drivers and barriers affecting growth, and finally analyzing relative strengths and weaknesses. The most essential policies outlined in this work that directly stimulated significant capacity additions were auctions and net metering schemes. All four countries benefited from well-designed auctions. Chile stands out for its fully liberalized electricity sector, economic and political stability, and extremely high solar radiation, allowing solar to compete in auctions without subsidies. The net metering policies in Brazil have enabled record growth in DG. Argentina has been historically inhibited by an unstable economy, creating a risky environment for investment. Nonetheless, recent investment trends show new confidence in the market from project developers and show the potential the country has to emerge as a real leader as the market matures. Mexico's market is currently at a standstill, confronted with challenges and uncertainty due to the current administration.

The unique contribution of this work is a synthesis of data from a multitude of resources to present a study that examines and compares the four largest markets in the nascent solar industry in LAC. Most existing studies provide data for a single country, the entire region, or elaborate on all NCRES technologies instead of focusing solely on solar PV. Finding reports detailing the most up to date accurate data can be challenging, as it is still an emerging and dynamic market. With greater access to key market data, future studies could offer a quantitative analysis of the solar industry in these four countries, provide rankings and perform a more extensive review.

The pandemic had some negative effects on the solar industry as production slowed all around the world; however, renewables grew in demand due to priority access to distribution systems and low operating costs (IEA, 2020). Governments all around the world are talking about a green recovery. If

the chance is not taken, it could be even more difficult to transition, especially if the growth after the recession causes another surge in emissions (FS-UNEF, 2020). Mexico's government used the pandemic as an excuse to put a halt to renewable progress in favor of state-owned generation. Chile is not letting the pandemic slow the market down. The government still managed to follow through with an auction this year and already has another planned for May, with a huge offering of 2,310 GWh (Sully, 2020). Although the pandemic put auctions on hold, Bolsonaro's administration seeks to issue green bonds, in hopes of boosting solar by 8GW (Martín, 2020). Argentina is dealing with added stress on the fragile economy and delayed progress for renewables due to high debt levels exacerbated by the crisis (Tayal, 2020). Brazil and Chile are leading the way, but Mexico and Argentina still have potential to grow in the long term while other countries in the region take notice and begin to follow suit.

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