Breaking Barriers: An Examination and Recommendations Regarding the Role of Clean Distributed Electricity Generation in Mexico

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Abstract

Through the 2013 Energy Reform, the Law of Energy Transition, and the General Law of Climate Change, the policy makers in Mexico have aimed to lower electricity tariffs, generate 35% of electricity from clean energy sources by 2024, and reduce greenhouse gas emissions by 30% in 2020 and 50% in 2050 compared to greenhouse gas emissions in 2000. Furthermore, the 2013 Energy Reform aims to promote economic development and reduce electricity subsidies. In an effort to achieve these goals, policy makers have tried to diversify the country's electricity generation profile, including the promotion of clean distributed generation (DG) technologies. A broad cross section of governmental and non-governmental stakeholders has publicly supported these objectives; however, low domestic electricity prices, high system acquisition costs, and a lack of financing have and will continue to limit the deployment of clean DG systems in Mexico. Furthermore, deep penetration of clean distributed generation under current net metering policies and electricity tariff structures may actually undercut the effective operation of Mexico's electricity market by increasing operation costs and adding technical complexities to the electricity network.

In this thesis, I make three short-term and one long-term recommendations to the Ministry of Energy and the Energy Regulatory Commission to promote the deployment of clean DG technologies beyond current barriers to entry and without adding economic and technical strain to the electricity industry. I recommend that these organizations (1) add clean DG to grid planning and develop a distributed energy resources strategy, (2) execute community-scale clean DG capacity auctions, (3) increase investment and financing opportunities for the public, and (4) modify electricity tariff structures and net metering policies. I hope these recommendations to the Ministry of Energy and the Energy Regulatory Commission will help the State achieve its energy policy and greenhouse gas emission reduction goals.

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Title: Ford Professor of Urban and Environmental Planning

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Chapter 1

Introduction

1.1 – Mission

I make recommendations to two client organizations[1] – the Ministry of Energy (SENER) and Energy Regulatory Commission (CRE) – regarding ways to incentivize the deployment of clean Distributed Electricity Generation[2] (DG) in a manner that overcomes current barriers to entry and contributes to achieving the State's energy policy and greenhouse gas (GHG) emission reduction goals. I analyze the status of clean DG in Mexico, including policies and regulation, deployment goals, barriers to entry, and its role in the overall scheme of the 2013 Energy Reform, and argue why SENER and CRE should promote the deployment of clean DG beyond its current level.

1.2 – Why this is Important

Achieving the 2013 Energy Reform, clean energy generation, and GHG emission reduction goals is crucial for Mexico to promote its economic development and contribute to global climate change mitigation efforts. At the same time, increasing penetration of Distributed Energy Resources (DER) is revolutionizing and disrupting electricity markets across the globe. Mexico's current negligible installed DG capacity puts policy makers in an ideal position to promote the deployment of DG in a manner that contributes rather than hinders the obtainment of the State's goals.[3]

1.3 – Context Summary

Mexico's 2013 Energy Reform brought drastic structural changes to the country's energy industry. These reforms were essential to modernizing Mexico's energy sector, opening up hydrocarbon and electricity markets to private investment and encouraging market competition. In the electricity sector, the 2013 Energy Reform seeks to lower the cost of electricity generation through

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[1] SENER and CRE are the two institutions responsible for Energy Policy making in Mexico.

[2] Mexico's Law of Energy Transition (LTE) defines clean DG as electricity that is (1) generated by a third party, (2) generated in an electricity plant that is interconnected to a distribution network with a high concentration of load centers, and (3) generated from clean energy sources as defined by the Law of Electricity Industry (LIE) (GoM 2015). While distributed electricity generation can refer to a number of different technologies, this thesis will look into clean DG as defined by the LIE and the LTE. Section 2.2 of this thesis lists technologies considered as clean DG.

[3] Beginning 2017, the Mexican electricity network had an installed capacity of 247 MW, equivalent to a 0.34% penetration of DG (CRE 2017a, SENER 2015a).

the creation of a Wholesale Electricity Market (WEM) and the reduction of energy losses throughout the transmission and distribution network (DOF 2013b). Furthermore, through the Law of Energy Transition (LTE) – a subsequent law of the 2013 Energy Reform – and the General Law of Climate Change (LGCC), the State has committed to achieving ambitious clean energy production and GHG emission reduction goals (GoM 2015, GoM 2016).[4]

Clean DG is becoming more prevalent in electricity systems across the globe. In recent years, the integration of intermittent DG technologies has had substantial economic and technical impact on electricity markets (MITEI 2016). While clean DG technologies can help reduce GHG emissions, reduce energy losses, lower the price of electricity generation, increase energy security, and empower communities by making them stakeholders in the electricity system, they can also add significant technical strain to the distribution system and increase costs to electricity markets (SENER 2016a). Current energy policy, along with favorable climate conditions, provide attractive incentives for potential adopters of clean DG technologies in Mexico.[5] Although current installed capacity of DG in Mexico is minimal, CRE expects significant deployment in the coming years (CRE 2017a).

Figure 1.1 - Expected Growth of DG in Mexico

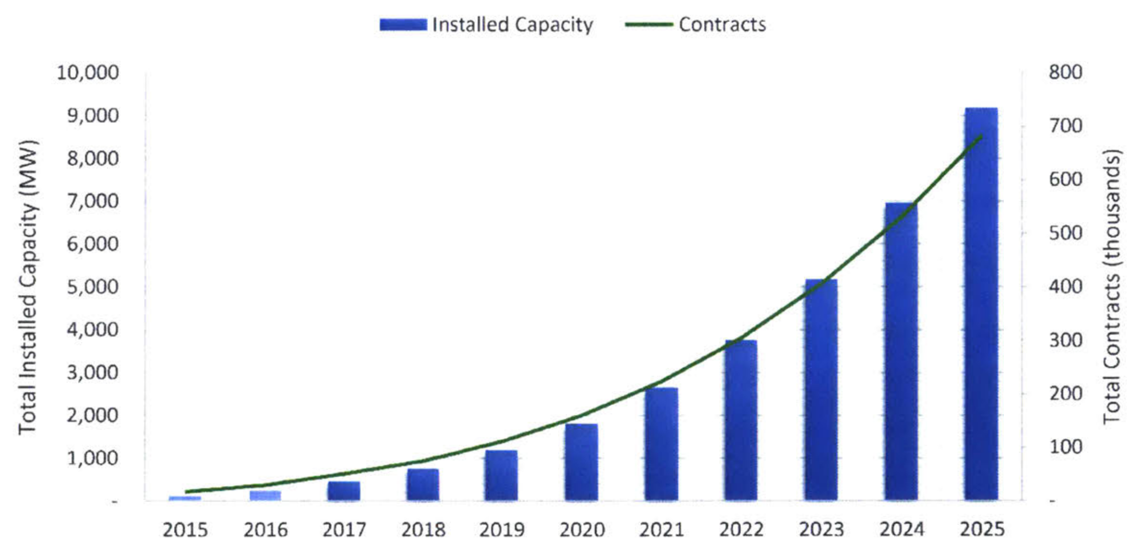

Figure 1.1 Source: CRE 2017a. Figure by author.

[4] The Ministry of the Environment (SEMARNAT), not SENER or CRE, oversees the implementation of the LGCC. Nonetheless, the scope of this thesis includes the reduction of GHG emissions and therefore references the LGCC.
[5] Clean DG systems have open and indiscriminate access to the country's distribution and transmission networks and receive generous benefits (e.g. 1:1 Net Metering policy). Furthermore, the LTE mandates SENER to promote clean DG.

Along with CRE, other organizations – SENER, IRENA, and BNEF – forecast significant integration of DG into the Mexican electricity system as well (SENER 2016a).

Figure 1.2 - Expected Growth of DG in Mexico up to 2030

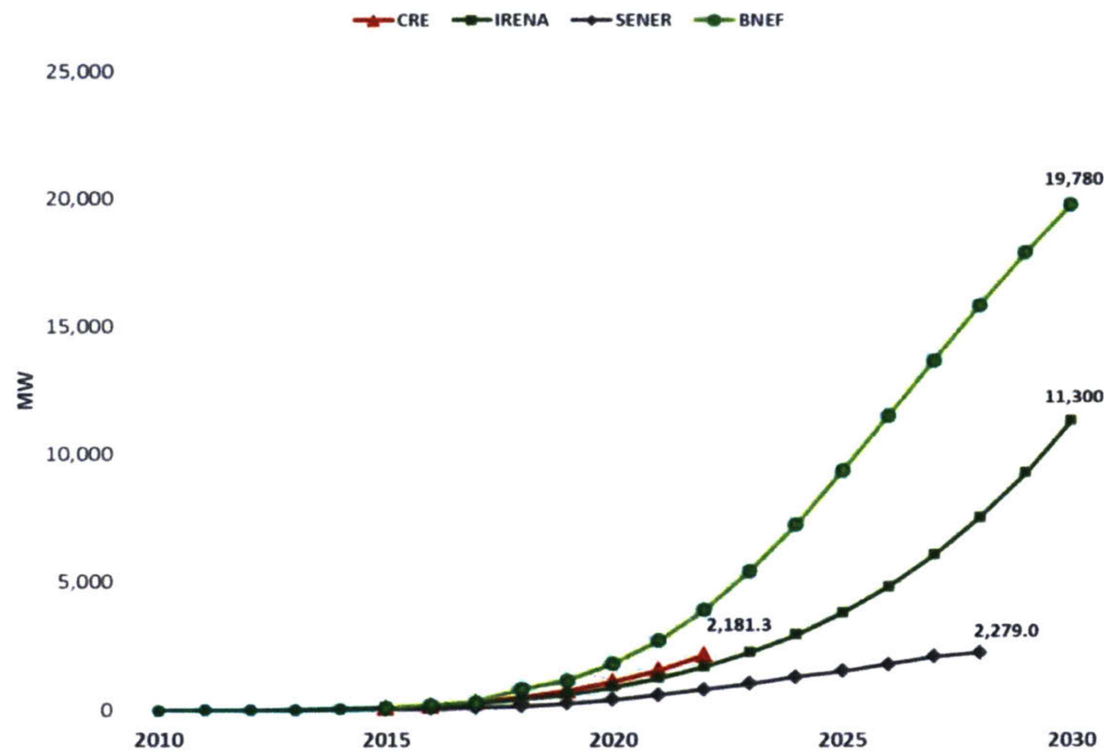

Figure 1.2 Source: SENER 2016a.

Regardless of CRE's forecast and the favorable climate that exists in Mexico for technologies such as Solar PV, considerable barriers to entry are preventing the adoption of clean DG technologies in the Mexican electricity sector. Clean DG technologies, such as Solar Photovoltaic (PV) energy systems, remain expensive and are economically unfeasible for the vast majority of the population that pay subsidized electricity tariffs (SENER 2017b). Current policies and conditions in the Mexican electricity market are likely to limit the deployment of clean DG to commercial electricity customers and the 1.2% of domestic electricity customers with unsubsidized electricity tariffs (SENER 2017b).[6] Therefore, in this thesis, I make recommendations to SENER and CRE to incentivize the deployment

[6] I designed my investigation around the concept of clean DG as a whole to be consistent with legislation and policy documents in Mexico; however, Solar PV systems make up ~98% of the total distributed electricity generation technologies (CRE 2017a) and residential customers consist of ~89% of electricity users in Mexico (SENER 2017b). Therefore, I naturally gravitated towards distributed solar energy in the residential sector.

of clean DG beyond current barriers to entry and provide reasons as to why it is in the best interest of policy makers to do so.

1.4 – Methodology and Structure Overview

In order to understand how clean DG will unfold in the Mexican electricity market under current conditions and how to promote its deployment in a manner that is aligned with the State's energy policy and GHG emissions reduction goals, I engaged existing scholarship, policy documents, and grey literature. Furthermore, I conducted a series of semi-structured interviews with stakeholders in government and solar energy groups in Mexico to identify and understand their position regarding clean DG.[7] I demonstrate the potential benefits that may exist with strategic deployment of clean DG by developing solar energy models using the Baja California Sur electricity transmission network as a reference.

The structure of this thesis is as follows: in Chapter 2, I explain the role that clean DG can play in achieving Mexico's electricity generation and GHG emission reduction goals. In Chapter 3, I present my argument as to why the Mexican electricity market is likely to fail to obtain the potential benefits of clean DG given current economic and policy conditions. In Chapter 4, I make recommendations to SENER and CRE to incentivize the deployment of clean DG and remove current barriers to entry in a manner that is aligned with the State's Energy Policy and GHG emissions reduction goals. Appendixes provide additional history, context, and statistics surrounding the Mexican electricity sector as well as a case study that analyzes the economic impact of different levels of Solar PV integration into the Baja California Sur Transmission system. My hope is that my recommendations to the agencies involved will lead to the development and implementation of clean DG systems in Mexico that take full advantage of the favorable geographic conditions that exist throughout Mexico, while reducing the technical and financial burdens facing the rapidly transforming electricity sector.[8]

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[7] Interviewed stakeholders in this process include the Independent Electricity System Operator (CENACE), the Electricity Utility (CFE), the Ministry of Energy (SENER), the Energy Regulatory Commission (CRE), solar energy associations, private companies that sell clean DG systems, renewable energy advocacy groups, and owners of clean DG systems.

[8] Currently, ~1.7 million people in Mexico live without electricity (GoM 2017a). There is tremendous potential for Solar PV systems to provide electricity to remote, isolated regions that are inaccessible with conventional electricity technologies. However, this thesis will focus solely on electricity generation units connected to the electricity distribution and transmission networks.

Chapter 2

The Role Clean Distributed Electricity Generation Can Play in Meeting Electricity Generation and Climate Change Goals

In this chapter, I examine Mexico's electricity generation and GHG emissions mitigation goals established in the 2013 Energy Reform, the Law of Energy Transition, and the General Law of Climate Change. I explain why and how clean DG can help to achieve these. I also provide additional context on energy losses and subsidies in the Mexican energy industry.

2.1 – Principal Goals within the Electricity Sector of the 2013 Energy Reform

The 2013 Energy Reform brought forth drastic constitutional changes in order to modernize and provide economic efficiency to the hydrocarbons and electricity industries in Mexico. Concerning matters of the electricity industry, the Energy Reform's principal goal is to lower electricity tariffs to promote economic development and significantly reduce electricity subsidies throughout the country. The principal manners the Energy Reform seeks to achieve these goals is through the creation of a competitive Wholesale Electricity Market (WEM) and the reduction of energy losses throughout the transmission and distribution networks.[9]

The 2013 Energy Reform Decree includes provisions to promote environmental protection and conservation through the following actions (DOF 2013b):

- Establishes Mexico's commitments to use energy and natural resources efficiently, reduce greenhouse gas and residue emissions, and lower the country's carbon footprint,
- Obliges participants in the electricity industry to reduce contaminating emissions,
- Mandates the SENER to develop a strategy to promote the use of clean technologies.

Through these actions, the Energy Reform seeks to:

- Reduce the carbon footprint of the electricity sector and country in general,

[9] Appendix A.1 and A.3.1 provides history of the evolution of the electricity industry in Mexico and the 2013 Energy Reform respectively.

- Diversify Mexico's electricity generation profile and integrate a large scale of low-carbon energy technologies,
- Optimize economic and technical efficiency in the electricity generation sector in order to lower the cost of electricity generation and promote competition and economic development in the country,
- Increase competitiveness, economic and operational efficiency, and the financial wellbeing of CFE,
- Significantly reduce technical and non-technical losses in the Transmission and Distribution networks,
- Ensure financial stability and certify investments from private parties, lowering the cost of project financing, and therefore, costs to electricity end consumers.

The 2013 Constitutional reform created Clean Energy Certificates (CELs) to promote larger and quicker integration of renewable technologies into the electricity system (DOF 2013b). The Law of the Electricity Industry (LIE) requires electricity market participants to generate a minimum amount of electricity from carbon free sources (GoM 2014b).[10] Generators that fail to meet said criteria need to purchase CELs from parties that have excess CELs or pay fines, therefore increasing the value of clean energy and fomenting the integration of renewable sources into the electricity market (1 CEL = 1 MWh of electricity from clean energy sources).[11]

2.1.1 – Energy Losses and Subsidies in Mexico

Reducing energy losses and subsidies are two of Mexican policy-maker's main objectives as these have been worth billions of dollars in recent years.[12] In 2015, the Mexican electricity system reported having 13.1% technical (network inefficiencies) and non-technical (electricity theft) losses worth USD ~\$2.7 billion,[13] almost double the average OECD country network losses (CFE 2015). Including losses from billing and collection process, in 2015, ~21% of the energy produced by CFE was not charged. CFE's goal is to reduce energy losses to between 10% and 11% by 2018 (CFE 2014, CFE 2015).

Electricity subsidies have increased at an average annual rate of 6.2% since the year 2000. Subsidies peaked in the 2008 with a total electricity subsidy of ~USD \$13.3 billion out of which ~67%

[10] Section A.3.3 in Appendix A provides an in-depth look into the CELs and the Law of the Electricity Industry (LIE).
[11] Section 2.2 defines "clean energy" under Mexican legislation.
[12] Section A.2 in Appendix A provides an in-depth look into the energy losses and subsidies.
[13] 2015 electricity losses were worth MXN \$42,246 million (CFE 2015). 2015 exchange rate: MXN \$15.88 for USD \$1 (Banco de México 2017b).

was destined to the residential sector, ~14% was destined to the industrial sector, and ~19% was destined to the agricultural sector (GoM 2017a).[14] In 2008, energy subsidies amassed to 3.2% of the country's GDP. The electricity subsidy by itself represented 1.2% of GDP (Scott 2013). From 2011 to 2014, the electricity subsidy destined to residential sector was on average ~86.3% of the total electricity subsidy. The remaining ~13.7% is given to the agricultural sector (GoM 2017a).[15]

Figure 2.1 - Electricity Subsidy in Mexico

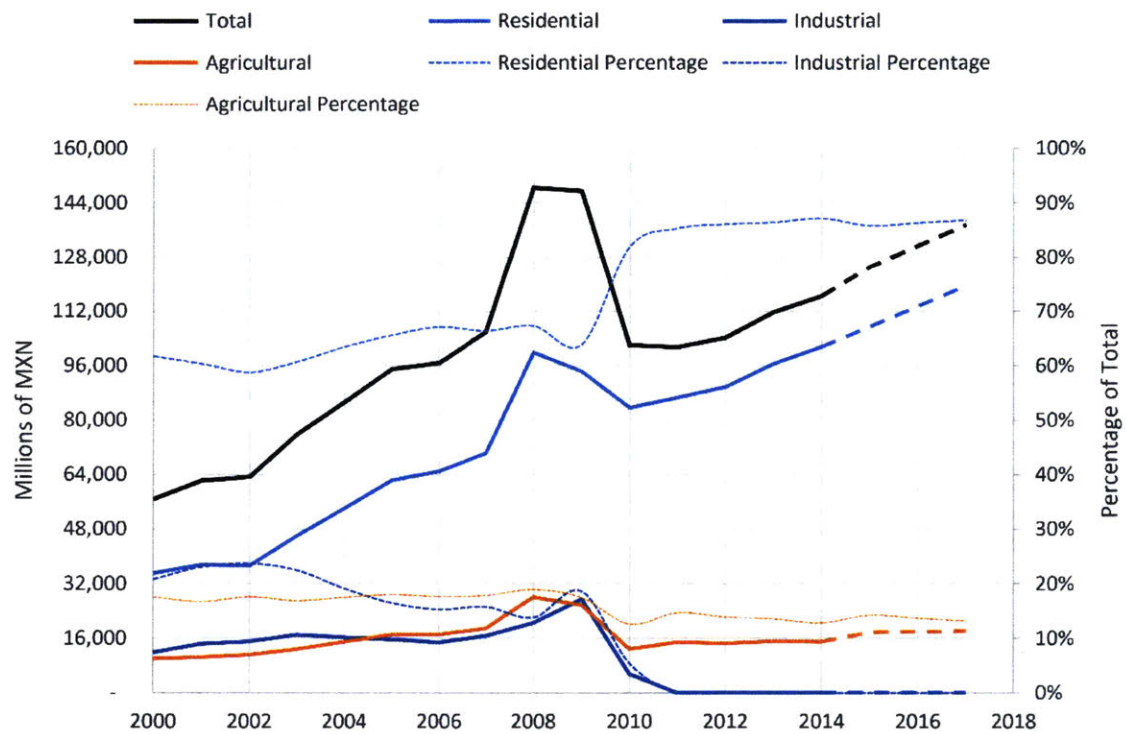

Figure 2.1 source: GoM 2017a. Figure by author.

2.2 – Clean Electricity Generation and GHG Emissions Reduction Goals

The Law of Energy Transition[16] (LTE) sets out to "regulate the sustainable use of energy as well as the obligations of clean energies and reduction of polluting emissions of the Electrical Industry,

[14] 2008 total, residential and industrial electricity subsidies were worth MXN $148,521 million, MXN $99,934 million, and MXN $20,522 million respectively (GoM 2017a). Average exchange rate in 2008 was MXN $11.14 for USD $1 (Banco de México 2017b).

[15] Figure 2.1 shows the evolution of electricity subsidies in Mexico reported by the Federal Government from 2000 to 2014 as well as projected subsidies from 2015 to 2017. The drop in electricity subsidies after 2009 is due to the closure of *Luz y Fuerza del Centro* which received ~38.6% and ~38.1% of the total electricity subsidies given out in 2008 and 2009 respectively.

[16] Published December 24, 2015 in the Official Gazette (GoM 2015).

maintaining the competitiveness of the productive sectors" (GoM 2015). The LTE states that "the Ministry of Energy will set as a goal a minimum participation of clean energy for the generation of electricity of 25% by the year 2018, 30% by the year 2021, and 35% by the year 2024" (GoM 2015).[17] In 2015, Mexico generated ~16.3% of its electricity from clean energy sources (GoM 2017a).[18]

The LIE's definition of clean energy differs slightly from the definition used by organizations like the International Energy Agency (IEA) or the International Renewable Energy Agency (IRENA). The LIE defines clean energy as sources and processes of electricity generation whose emissions or residues do not exceed certain established thresholds (GoM 2014b). This definition is inclusive to energy generated from wind, solar, oceanic, geothermal, biofuels (including bio-methane captured from waste streams), hydrogen, hydroelectric, and nuclear sources (GoM 2014b). However, unlike the IEA's (IEA 2017) or IRENA's (IRENA 2015) definition of clean energy, the LIE considers efficient cogeneration and any type of electricity generation using fossil fuels that have carbon capture and sequestration technologies as clean energy sources (GoM 2014b).

The General Law of Climate Change[19] (LGCC) – implemented and overseen by the Ministry of the Environment (SEMARNAT) – was the first law to establish the clean energy generation target of 35% by 2024. In the LGCC, Mexican policy makers set an aspirational goal of 30% GHG emissions reductions by 2020 and 50% emissions reduction by 2050 with regards with GHG emissions in the year 2000 (GoM 2016). In 2015, Mexico's CO_2 emissions were 23% above the year 2000 baseline (WorldBank 2017a).[20]

2.3 – Assistance in Compliance of Electricity Generation and Climate Change Goals with Clean Distributed Electricity Generation

The LTE defines clean DG as electricity that is (1) generated by a third party, (2) generated in an electricity plant that is interconnected to a distribution network with a high concentration of load centers, and (3) generated from clean energy sources as defined by the LIE (GoM 2015). Clean DG can play an important role in Mexico's pursuit of lower electricity tariffs and GHG emissions. In its most recent publications concerning the role of renewable energy in Mexico, SENER has

[17] In the country's strategy of energy transition to promote the use of cleaner technologies and fuels, SENER has further committed to generate 40% of its electricity from clean energy sources by 2035, and 50% by 2050 (CONUEE 2016).
[18] Section A.1.2 in Appendix A provides an in-depth look into Mexico's electricity generation profile.
[19] Published June 6, 2012 in the Official Gazette. Updated on June 1, 2016 (GoM 2016).
[20] CO_2 emissions in 2000 were 383 $MtCO_2$. In 2015, CO_2 emissions were 472 $MtCO_2$ (WorldBank 2017a).

acknowledged the growing role and immense potential of clean DG, particularly Solar PV, recognizing diminished energy losses, lower GHG emissions, reduced public spending, and increased energy security as benefits it can provide to the Mexican electricity industry (SENER 2016a).[21] Addressing how clean DG can help with the State's electricity generation and climate change goals:

1. Lowering the Cost of Electricity Generation: Clean DG can lower the total cost of meeting electricity demand, including production, transmission, and distribution costs (Meehan et. al. 2006). By doing so, clean DG can be a significant contributor of the 2013 Energy Reform's goal concerning the electricity industry (DOF 2013b). Clean DG can help lower the cost of electricity generation through (1) reduction of energy losses and (2) reducing the demand from centralized power plants to meet electricity demand.

    a. Reduction of Energy Losses: Clean DG systems aid in the mitigation of electricity losses in both transmission and distribution networks by reducing the distance between points of production and consumption (Pillai et al. 2014). Multiple interviewed individuals for this thesis recognized the important role that clean DG can play in reducing energy losses. Quotes from these interviews include the following:

    "In a country with so many technical and non-technical transmission losses, DG systems help you reduce electricity theft. Households generate the electricity. What a household does not consume exits directly onto the grid. A neighboring home will consume that. Electricity doesn't travel much" (Interview, Roberto Capuano 2016).[22]

    "[Electricity] generation is very close to consumption point, reducing energy losses in the system" (Interview, Edmundo Gil Borja 2017).[23]

    "One of the main advantages is that by having to transmit less energy, there are less losses in the system" (Interview, Daniel Chacón 2017).[24]

    "[With DG] there are less energy losses" (Interview, Nemorio González 2017).[25]

    "DG helps us address one of our biggest issues, which is reducing energy losses throughout the distribution network" (Interview, Guillermo Zuñiga 2017).[26]

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[21] Section B.2 in Appendix B provides an in-depth look into the conditions for Solar Energy in Mexico.

[22] Roberto Capuano is the Co-founder and COO of Enlight, S.A. de C.V. and President of the Distributed Generation Committee in ASOLMEX (Mexican Association of Solar PV Energy).

[23] Edmundo Gil Borja is the Managing Director of Distribution and Commercialization of Electric Energy and Social Entailment at SENER.

[24] Daniel Chacón is an Official at Iniciativa Climática de México (ICM).

[25] Nemorio González is Director of System Operation and Planning at CENACE.

[26] Guillermo Zuñiga is a National Commissioner at CRE.

b. Reduced Demand from Centralized Grid: Adoption of clean DG systems reduces the need for centralized power plants to meet system electricity demand (Satchwell, Mills, and Barbose 2015). As generation from centralized plants decreases, marginal producers are no longer required to meet energy demand, lowering the overall cost of electricity generation in competitive markets (Pérez-Arriaga 2013). The reduction of centralized demand is particularly valuable when meeting peak electricity demand. Meeting peak demand is a costly endeavor for electricity utilities (Pérez-Arriaga 2013). Approximately 10% of installed capacity in the U.S. is built to meet around 1% of peak-demand hours throughout the year (Feldman et. al 2015). Reduction of peak electricity demand provides major electricity generation savings. In England, a 2 GW increase in installed residential DG capacity from 2014 to 2015 reduced peak electricity demand by 900 MWh (GoUK 2015).

2. Meeting Clean Energy Production Goals: Clean DG can be a major contributor to meeting the country's clean energy generation goals established in the LTE (GoM 2015). All clean DG technologies account for the country's clean energy generation profile (GoM 2014b, GoM 2015). Multiple interviewed individuals for this thesis recognized the important role that clean DG can play in helping the country achieve its 35% clean energy generation target by 2024. Quotes from these interviews include the following:

> "I believe we have no choice. We are hardly going to reach the goals without significant deployment of DG. We need to be generating 35% by 2024. [Complying with our targets] will require everything that can be done because it is a very ambitious goal" (Interview, Roberto Capuano 2016).

> "In order to reach our targets, evidently we need to do a good job on all fronts. This refers to installing clean generation, having greater efficiencies, clean distributed generation; they will all play an important role some way or another. Today, DG penetration is very low. Any percentage of DG that can help meet our goals is not only welcome, it's necessary" (Interview, Oliver Flores 2017).[27]

> "The proper development of clean DG will certainly help us reach our goals" (Interview, Edmundo Gil 2017).

> "That jump [from our current percentage of clean energy production] to 35% in such little years will require all the possible mechanisms and tools" (Interview, Diego Villarreal 2016).[28]

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[27] Oliver Flores is the Managing Director of Generation and Transmission of Electric Energy at SENER.

[28] Diego Villarreal is the Deputy Managing Director of Coordination of the Electricity Industry at SENER.

3. Reduction of GHG emissions: Clean DG can help reduce overall GHG emissions in electricity systems, making it a valuable contributor to meeting the LGCC goal of reducing GHG emissions in 2020 and 2050 as compared with emissions in the year 2000 (GoM 2016). Life cycle GHG emissions from electricity generated with renewable technologies is immensely lower than electricity generated with conventional fossil fuel technology, helping decarbonize the grid and mitigate climate change (Weisser 2007). Replacing electricity generated by power plants that use fossil fuels with clean DG technologies helps reduce overall GHG emissions in electricity systems (Gilmore, Lave, and Adams 2006). This issue is particularly valuable when the electricity generated by clean DG systems is substituting centralized power plants used to meet peak electricity demand. Meeting peak demand is a highly polluting endeavor for electricity utilities (Pérez-Arriaga 2013). In Mexico, CENACE relies on Turbogas and Internal Combustion plants that use diesel, fuel oil, and natural gas to meet peak electricity (SENER 2015a).

4. Additional Clean DG Benefits not Included in Official Policy: Additional to benefits that are directly linked to official State policy and goals but are also in SENER's and CRE's best interests, clean DG can (1) increase energy security, (2) defer system investments, and (3) provide social benefits.

    a. Increased Energy Security: With adoption of clean DG systems, customers produce their electricity on-site, reducing the need for centralized power plants to meet system electricity demand (Satchwell, Mills, and Barbose 2015). Renewable technologies like wind and solar energy operate with local resources, reducing the need to purchase fuels shipped from distant locations and increasing energy independence (Weisser 2007).

    b. Deferral of System Investments: Distributed energy resources can help defer planned grid investments, improve grid resiliency, and improve power quality by decentralizing power generation and providing voltage regulation (Eltawil and Zhao 2010).

    c. Social Benefits: Beyond economic and technical benefits, distributed electricity generation provides multiple social benefits as well. Ownership of a clean distributed electricity generation system empowers customers by giving them a direct stake in the transition to a low-carbon economy, assists the public take-up of carbon reduction measures, foster behavioral change in energy use, and helps develop local supply chains (GoUK 2015).

Chapter 3

Under Current Conditions Surrounding Clean DG in Mexico, the Electricity Industry Is Likely to Fail to Capture Potential Benefits and Potentially Hinder Achievement of its Electricity Generation and GHG Emission Reduction Goals

Government incentives, dropping prices, and improved technology has made the integration of clean distributed energy sources more prevalent across electricity markets, a trend that is expected to continue (MITEI 2016). However, electricity transmission and distribution networks were not designed to accommodate a high penetration of distributed energy sources (EPRI 2014). The increasing addition of intermittent renewable distributed generation technologies has caused significant economic and technical impacts on the operation of an industry originally designed to function with centralized power plants far from consumption load centers. Clean DG resources can provide substantial value to electricity markets and society and, at the same time, imperil grid reliability and increase the costs of operation.

In this chapter, I argue and demonstrate how under current conditions surrounding clean DG in Mexico, the electricity industry will fail to capture potential benefits and potentially hinder achievement of the State's Electricity Generation and GHG emission reduction goals. Despite the favorable conditions that exist in Mexico for the performance of clean DG technologies (particularly Solar PV),[29] barriers to entry will limit the deployment of clean DG. Furthermore, should significant customer-driven deployment of clean DG occur, current Net Metering[30] (NetM) policy and tariff structures could impede the lowering of electricity generation costs.[31]

[29] Section B.2 in Appendix B provides an in-depth look into the solar resources in Mexico.

[30] Section A.3.4 in Appendix A provides an in-depth look into current Net Metering policy in Mexico.

[31] In this Chapter, I run a series of solar energy models to support my argument. Appendix B contains the methodology and software used to develop these solar models. I use quotes from interviews conducted with various stakeholders of the electricity industry to support my argument. Figure D.1 in Appendix D provides a list of interviews developed in for this thesis.

3.1 – Under Current Conditions, Clean DG will have Minimal Impact on Meeting Clean Energy Generation and GHG Emission Reduction Goals

Opposition to renewable energy technologies has diminished in recent years. CRE forecasts an exponential integration of DG up to 2023 (CRE 2017a); however, current barriers to entry will significantly limit the deployment of clean DG technologies. Therefore, clean DG will have minimal impact on meeting the State's clean energy generation goals established in the LTE and GHG emission reduction goals established in the LGCC unless additional steps are taken. The principal barriers the will hinder the deployment of clean DG systems in Mexico are:

1. High costs of technology: Clean DG systems remain expensive and can only be afforded by a small portion of the population.
2. Domestic electricity tariff structures and subsidies: The acquisition of Solar PV modules is only economically feasible for households with high electricity consumption levels (DAC Tariffs) and commercial clients in Tariff 2.[32] Domestic electricity customers with DAC tariffs and commercial electricity customers in Tariff 2 represent around 10% of all domestic and commercial electricity clients (SENER 2017b).

3.1.1 – System Acquisition Challenges

The installation costs and performance of Solar PV systems have evolved drastically in recent years (IEA 2017).[33] Solar PV systems are now cheaper and more reliable. Information availability about renewable energy has improved dramatically, and utilities and regulators have significantly reduced the time it takes between the purchase and installment of rooftop Solar PV systems in various electricity markets (John 2015b). Nonetheless, the cost of solar PV systems and absence of adequate financial support are still significant barriers to the diffusion of technologies such as Solar PV systems (Rai, Reeves, and Margolis 2016). Potential adopters of Solar PV systems face high upfront costs.

Mexico is one of the largest economies in the world (15th highest GDP in 2016); however, the majority of wealth is concentrated in a small percentage of the population (CIA.gov 2017). The Standardized World Income Inequality Database indicates that Mexico is within the 25% of countries

[32] Section A.2.2 in Appendix A provides an in-depth look into Tariff Structures.

[33] Section B.1 in Appendix B provides an in-depth look at the evolution of Solar PV technology prices.

with the highest levels of inequality in the world (Solt 2017). In 2014, the wealthiest 10% of the population held ~40% of all income (WorldBank 2017b).[34]

3.1.2 – Limited Pool of Potential Customers due to Electricity Subsidies and Tariff Structure

As seen in Figure 1.1, CRE has ambitious goals for DG integration, aiming to increase the total installed capacity from 2016's 247 MW to ~9,177 MW in 2025. Out of the total expected installed DG capacity, ~4,400 MW is expected to come from small-scale Solar PV units in 2025 (CRE 2017a).[35] However, under current tariff structures, the acquisition of Solar PV modules is only economically feasible for the 1.2% of households with high electricity consumption levels (DAC Tariffs) and commercial clients in tariff structure 2.[36]

CFE's voluminous domestic subsidies discourage customers in non-DAC tariff classes to pursue aggressive forms of energy savings such as installing residential Solar PV systems. Diego Villarreal offers his perspective on this distortion:

> "Imagine you have two identical neighboring houses where the bimonthly limit for DAC consumption is 1,000 kWh. Both houses consume 1,001 kWh every two months. One of the houses installs some form of distributed generation system that drops its net consumption down to 999 kWh every two months. The value of energy that each house receives is completely different. They are identical consumers, they are obtaining the same service, in marginal terms they are receiving the same good; however, the value – or price – of energy of one is much higher than the other even though both agents are doing the exact same thing" (Interview, Diego Villarreal 2016).

Figure 3.1 illustrates Diego Villarreal's assessment in a region with 1D domestic electricity tariffs.

[34] Brazil is the only nation with a larger economy and higher inequality than Mexico (WorldBank 2017b).
[35] Section A.2.3 in Appendix A provides an in-depth look into DG statistics in Mexico.
[36] Section A.2.2 in Appendix A provides an in-depth look into electricity tariff structures in Mexico.

Figure 3.1 - Tariff 1D during Summertime

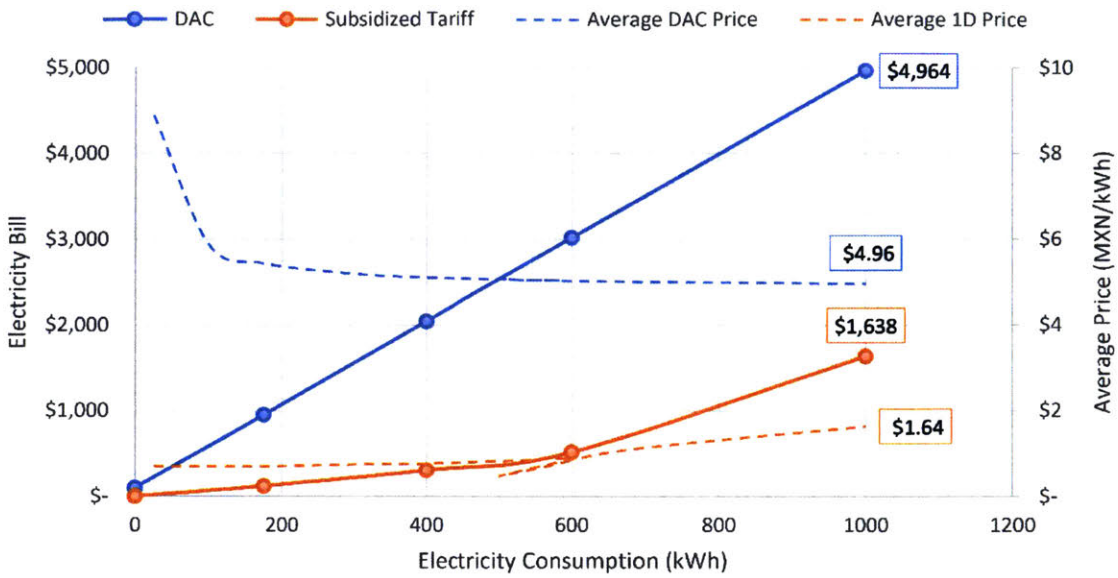

Figure 3.1 source: CFE 2017. Figure and calculations by author.

Diego Villarreal further elaborates on the need for SENER to address market distortion:

> "This is something that SENER will eventually have to address because it is an important market distortion, especially when the development of these technologies becomes much wider. It is something we cannot allow to endure. It is a massive distortion" (Interview, Diego Villarreal 2016).

Running the suggested scenario by Diego Villarreal for two households that consume 1,001 kWh/month and 999 kWh/month in Baja California Sur,[37] we can easily compare the difference in the value of installing a Solar PV system in households with and without subsidized electricity. If each household installed a 3.5 kW Solar PV system[38], and assuming they operate identically, both users would realize the same reduction in energy consumption; however, actual electricity bill savings would be drastically different.[39]

[37] Assuming electricity tariff class "1D" where the DAC threshold is 1000 kWh/month. The tariff class in the city of La Paz is 1D.

[38] As seen in Section A.2.3, the average small-scale Solar PV installation in Mexico currently has a capacity of ~3.5 kW.

[39] Model assumes an average installation price for a residential Solar PV system of USD $3/W, the 2017 exchange rate found in Figure D.4, an annual inflation rate of 3.5%, and abides by CRE's Net Metering policies.

Figure 3.2 - Energy Savings with Solar PV System in BCS

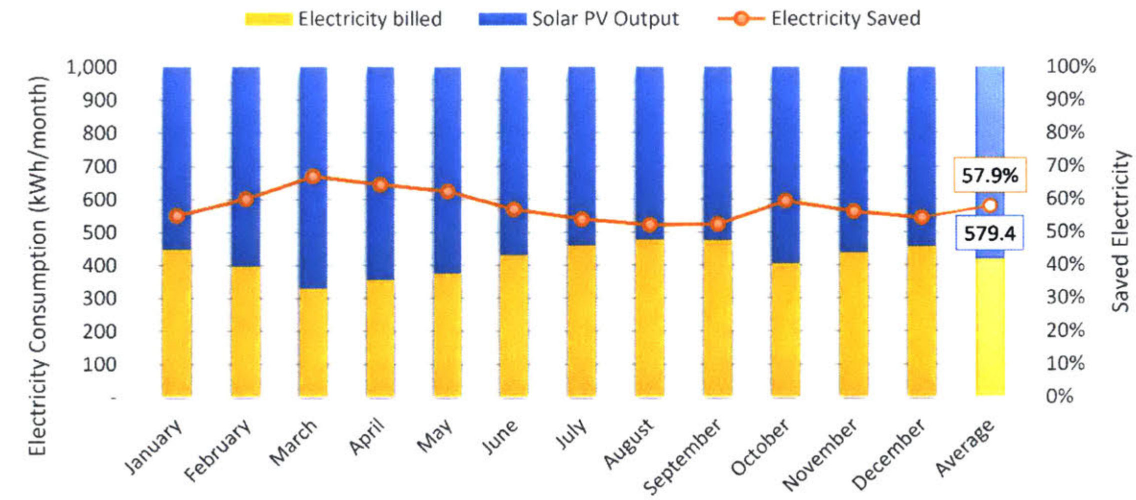

Figure 3.2 source: NSRDB 2017; PVPMC 2017. Figure and results by author.

The household that paid DAC tariffs would recover its investment in less than 4 years[40] by reducing its average consumption from 1,001 kWh/month to 421.6 kWh/month. Meanwhile, even though the household that paid Tariff 1D reduced its electricity bill by the same amount (average reduction from 999 kWh/month to 419.6 kWh/month), it would not recover its investment until the end of the 10th year of operation.[41]

Figure 3.3 - Cash Flow of Customer with DAC Tariffs in BCS

Figure 3.3 and results by author.

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[40] NPV of MXN ~$306 thousand; IRR of 25.7% considering 10 years.

[41] NPV of MXN ~-$26 thousand; IRR of 1.0% for 10 year period.

Figure 3.4 - Cash Flow of Customer in Tariff Class 1D

Figure 3.4 and results by author.

Though commercial tariffs are also unsubsidized, prices for commercial customers are lower than for households in DAC tariffs. The average DAC household pays almost twice as much as the average commercial customer in Tariff 2 while consuming around 66% more electricity. Commercial customers in Tariff 3 have lower tariffs than both Tariff 2 and DAC customers, but much greater levels of average electricity consumption and larger bills.

Figure 3.5 - 2016 Tariff Comparison

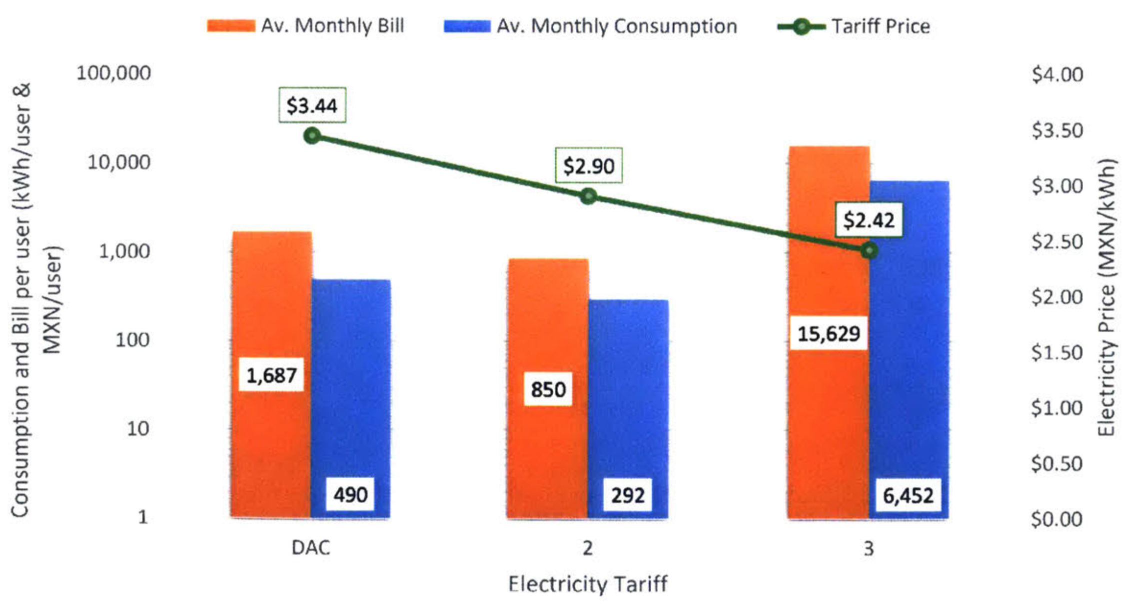

Figure 3.5 source: SENER 2017b. Figure by author.

Continuing the exercise of Figures 3.3 and 3.4, if a commercial customer in Baja California Sur under Tariff Structure 2 consumed an average of 1,000 kWh/month and installed an identical Solar PV system, the customer would recover their investment at the beginning of the 9th year of operation.[42]

Regarding commercial customers under Tariff 3, installing a Solar PV system is not attractive. Considering a Tariff 3 customer in Baja California Sur who consumes an average of 15,000 kWh/month and installs a 25 kW Solar PV system, in 10 years of operation, the customer will have only recovered around two thirds of their investment.[43] Additionally, a 25 kW Solar PV system would require around 125 m^2 of surface area (MITEI 2015), further complicating the acquisition and installment of a Solar PV system.

Figure 3.6 - Cash Flow of Commercial Customer Tariff 2

Figure 3.6 and results by author.

[42] Model assumes an average installation price for a residential Solar PV system of USD $3/W, the 2017 exchange rate found in Figure D.4, an annual inflation rate of 3.5%, and abides by CRE's Net Metering policies. NPV of MXN ~$11 thousand; IRR of 4.5% for 10 year period.

[43] Model assumes an average installation price for a residential Solar PV system of USD $3/W, the 2017 exchange rate found in Figure D.4, an annual inflation rate of 3.5%, and abides by CRE's Net Metering policies. NPV of MXN ~-$643 thousand; IRR of -6.2% for 10 year period.

Figure 3.7 - Cash Flow of Commercial Customer Tariff 3

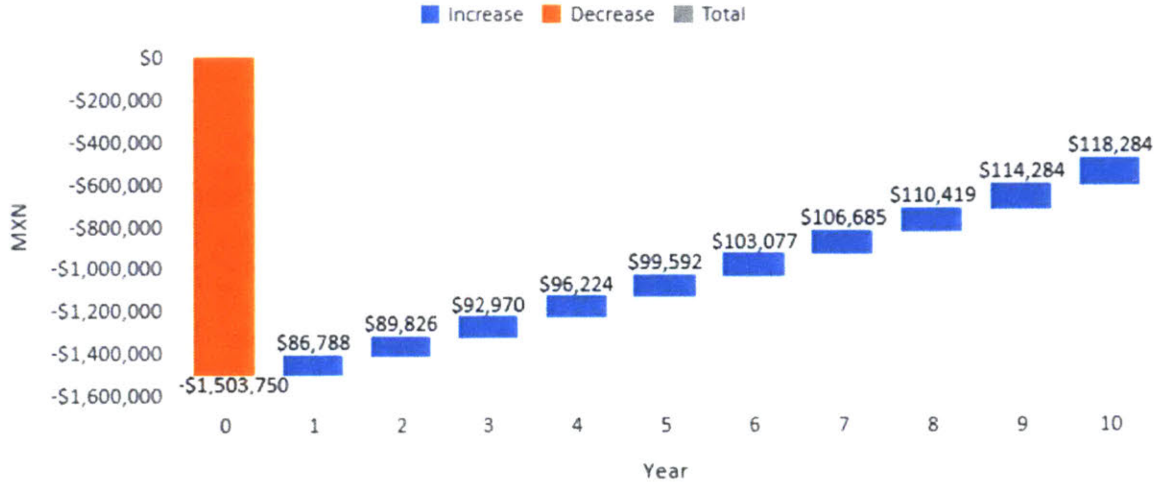

Figure 3.7 and results by author.

While the acquisition of a Solar PV system may be attractive to some commercial customers under Tariff 2, current tariff structures provide the most favorable conditions and economic incentives to DAC households. With the acquisition of Solar PV modules being principally economically feasible for households in DAC tariffs, the adoption of residential clean DG systems is limited to ~1.2% of CFE's clients (SENER 2017b). If all current residential clients with DAC tariffs install a 3.5 kW Solar PV system, around 2.4 GW of rooftop Solar PV capacity would be deployed throughout Mexico. CRE currently expects to have close to 2.5 GW of small-scale Solar PV capacity installed by the end of 2023 (CRE 2017a).

CRE's forecast seems overly ambitious under current market conditions. Furthermore, these systems would be installed in limited areas with high income, concentrating the operational complexity and technical impact of DG systems in certain zones throughout the country. Such deployment of clean DG systems will probably have little effect on reducing non-technical energy losses. As written in section 2.2, non-technical electricity losses tend to be concentrated in low-income areas.

3.2.3 – Other Barriers to Entry

Moskovitz (1992) identifies a lack of reliable information, improper valuation of renewable energy, expensive equipment and lack of financing, and long adoption processes as the main barriers to entry of renewable energy. Beyond economic barriers, residential customers may also be resistant to technology adoption because of aesthetic impacts (Ek 2005). The general public has yet to fully embrace the possibility of owning Solar PV systems (Ek 2005). Potential customers generally gravitate towards third-party ownership due to operations and maintenance concerns (Rai, Reeves, and Margolis 2016). Furthermore, it is highly unlikely that electricity customers will install Solar PV systems in properties they do not own. This means that the vast majority of renters are excluded as potential technology adopters (Qureshi, Ullah, and Arentsen 2017).

3.2 – Under Current Conditions, Clean DG will fail to lower the Cost of Electricity Generation

In theory, clean DG can help reduce the cost of electricity generation by reducing energy losses (Pillai et al. 2014) and reducing the need for marginal centralized power plants to meet system electricity demand (Satchwell, Mills, and Barbose 2015). However, under current conditions, clean DG will probably fail to lower the costs of electricity generation in the Mexican electricity sector due to:

1. Minimal energy loss reduction: Current barriers to entry will limit deployment of clean DG to areas that already have reduced energy losses.
2. Added system costs: Deployment of clean DG under current NetM policies will increase and unevenly distribute electricity generation costs throughout the system.
3. Reduced overall DG value to system: Current customer driven deployment of Distributed Energy Resources is likely to miss opportunities for utilities to capture significant system value.

3.2.1 – Clean DG will not Reduce Energy Losses under Current Conditions

The Mexican electricity network suffers equally from technical and non-technical losses. Non-technical losses refers mostly to electricity theft. As seen in Section 3.1.2, under current conditions, adoption of clean DG systems is limited mainly to households with DAC tariffs, meaning households with high incomes. In 2015, around 52% of the country's electricity losses were due to non-technical losses (CFE 2015). Electricity losses are distributed unevenly among different states and tend to occur in areas with low incomes and higher crime rates (García 2016b). As seen in Section 2.3, multiple interviewed individuals identified the reduction of energy losses as one of the greatest benefits that clean DG can provide; however, current market conditions will significantly limit the electricity industry from obtaining this benefit.

3.2.2 – Current Net Metering Policies will Reduce CFE's Revenue and Increase Operational Costs throughout the System

In order to promote the adoption of clean DG technologies, CRE policy makers have implemented NetM policies that are highly advantageous to potential adopters by offering a 1:1 valuation of energy injected into the grid[44] (DOF 2017b). Roberto Capuano (Interview 2016) stated, "Mexico has one of the most benevolent Net Metering schemes for the user and [Solar Companies], probably worldwide." Tomás Gottfried[45] (Interview 2017) explained the importance that current NetM policy has on the viability of acquiring a clean DG system, stating that "...before Net Metering was available, distributed generation only made sense if you were on a mini grid."

Under NetM schemes, the integration of clean DG sources into the grid inevitably increases system costs[46] (Eltawil and Zhao 2010). The collection of revenue to cover such costs amplifies the inequality in surplus distribution among households. Residences that do not adopt clean DG technologies pay disproportionally more for the investment decisions taken by households that choose to install clean DG systems such as rooftop Solar PV (Boero, Backhaus, and Edwards 2016). While clean DG can lower the cost of electricity generation (Pérez-Arriaga 2013), customer-sited deployment of these technologies under NetM policies has generally reduced revenues collected by utilities more than it has reduced electricity generation costs, leading to a revenue erosion effect and lost future earning opportunities[47] (Satchwell, Mills, and Barbose 2015). Average retail rates increase as utility costs are spread over a reduced sales base (Eltawil and Zhao 2010). Wide deployment of clean DG systems leaves electricity utilities and regulators with diminished revenue streams to support and operate the distribution network (Brown and Bunyan 2014).

The value of energy produced by a clean DG is entirely dependent on its time of production (Brown and Bunyan 2014). Electricity prices are volatile over the course of the day and vary seasonally. A kWh injected from a clean DG system into the distribution network is most valuable during peak-

[44] Section A.3.4 in Appendix A provides an in-depth look at Net Metering benefits in Mexico.
[45] Tomás Gottfried is the Engineering Manager for *Potencia Industrial* and owner of a clean distributed electricity generation system.
[46] Network O&M, ancillary services.
[47] Electricity utilities tend to be the strongest adversaries of clean DG integration. Central-power-plant-reliant utilities in electricity markets with substantial penetration of DG sources (e.g. RWE in Germany) have lost billions of dollars from reduced income and increased operation costs (John 2015b). Members of CFE presented opposition to the Energy Reform, fearing that it would lose its biggest clients and be forced to operate with reduced revenues (Rodríguez 2017). Francisco Rojas, CEO of CFE prior to the Energy Reform, resigned from his position upon acceptance of the Reform (Expansión 2014).

demand and least valuable during lowest electricity demand. Nonetheless, rather than reflecting price volatility, NetM treats all energy injected by a clean DG system into the grid the same regardless of the time during which it is produced, failing to differentiate between energy produced on-peak and off-peak (Satchwell, Mills, and Barbose 2015).[48]

Though DAC households only account for ~1.2% of all customers, ~13% of CFE's domestic tariff income comes from DAC households[49] (SENER 2017b). As suggested by Satchwell, Mills, and Barbose (2016), under current NetM policy in Mexico, CFE is bound to lose its best clients and therefore operate with reduced revenue streams. As DAC households adopt Solar PV systems, the pool of subsidized customers will increase, hurting the industry's effort to eliminate electricity subsidies. According to Jesús Luis Suárez,[50] the structure of electricity tariffs influences the preferences and requests of prospective clients. He states:

> "Most of our potential clients are interested in dropping down from a DAC tariff to a subsidized tariff. They are not too concerned with becoming net zero consumers. We try to encourage them to be more aggressive with their energy savings goals, but once [a prospective customer] understands the structure of electricity tariffs, it's hard to get that idea out of their head" (Interview, Jesús Luis Suárez 2016).

The 2013 Energy Reform deemed CFE a Productive State Enterprise (DOF 2013b); meaning CFE may no longer operate at a loss, which has been the case during previous years (CFE 2014; CFE 2015). Current NetM policies and tariff structures in Mexico provide attractive incentives for CFE's few high-paying customers to purchase a clean DG system by providing the benefit of 1:1 energy valuation and granting subsidies for the net portion of electricity being charged (that is, if the user drops down from a DAC Tariff to a subsidized tariff). These policies will reduce CFE's revenue stream and constrain its ability to reach operational liquidity.[51]

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[48] Figure C.8 in Section C.2 in Appendix C compares average monthly electricity demand and Global Horizontal Irradiation in the BCS transmission network in 2016. Peak Solar PV performance would occur midday while peak electricity demand normally occurs once the sun has set. Nonetheless, current NetM policy values all energy injected into the grid equally, regardless of electricity demand.

[49] Section A.2.2 in Appendix A provides an in-depth look into electricity tariff structures in Mexico.

[50] Jesús Luis Suárez is the Executive Director of EVA México, a private company that sells and installs Solar PV systems.

[51] Model assumes a 3.5kW system in BCS (tariff 1D) in the summertime.

Figure 3.8 - Lost Revenue for CFE under current NetM Policy and Tariff Structure

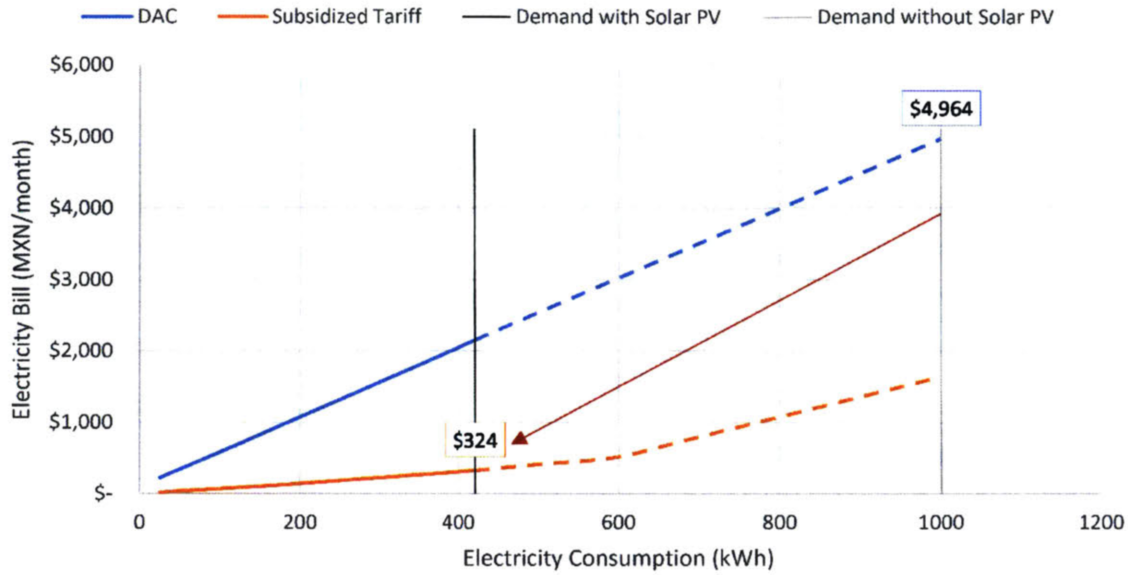

Figure 3.8 source: CFE 2017. Calculations and results by author.

Though households that adopt a Solar PV system rely heavily on, and add strain to, the distribution network, their use of the distribution network is not reflected on their bill once they drop down to a subsidized tariff class (CFE 2017). Since adoption of clean DG systems is only feasible for the wealthiest households, current policies provide regressive incentives. Socialized costs created by NetM policies are unevenly allocated to households that do not have the wherewithal to acquire a clean DG system.

The 2013 Energy Reform intends to reduce and concentrate electricity subsidies among the population with lowest incomes without increasing electricity prices by lowering the cost of electricity generation; however, electricity network costs in Mexico are bound to increase under current NetM policy and will be distributed among a reduced customer based that pays subsidized electricity tariffs. Though energy subsidies are a burden to the Mexican economy, increases in energy prices have a strong negative impact on presidential popularity[52] (Frankfort-Namichias and Leon Guerrero 2015) and disproportionately affect households with lower incomes more than wealthier households (Saari, Dietzenbacher, and Los 2016). Roberto Capuano argues that though electricity subsidies will inevitably

[52] President Peña-Nieto's popularity dropped to a record-low 12% after the liberalization of gasoline prices in early 2017 (Expansión 2017).

disappear, "…it is an incredibly important good. Everyone consumes electricity. There is no price elasticity." (Interview, Roberto Capuano 2016). He further adds:

> "[Eliminating subsidies] is a political atomic bomb. Talking about electricity tariffs in the government is a taboo subject, both in CRE and SENER" (Interview, Roberto Capuano 2016).

CRE and SENER have studied the impact that increasing levels of DG integration may have on the technical and economic operation of the grid by using California's electricity market as a reference point.[53] CRE has adopted CAISO's assessment, expecting negligible impact on the Mexican electricity industry prior to 5% integration of DG technologies.[54] The current small volume of DG in the Mexican electricity network minimizes the negative impact that NetM policy allots to CFE and its customers; however, if CRE's DG growth forecasts hold true, there will be a ~5% integration of DG sources into the electricity network by 2023.[55]

Figure 3.9 - Expected Integration of DG into SEN

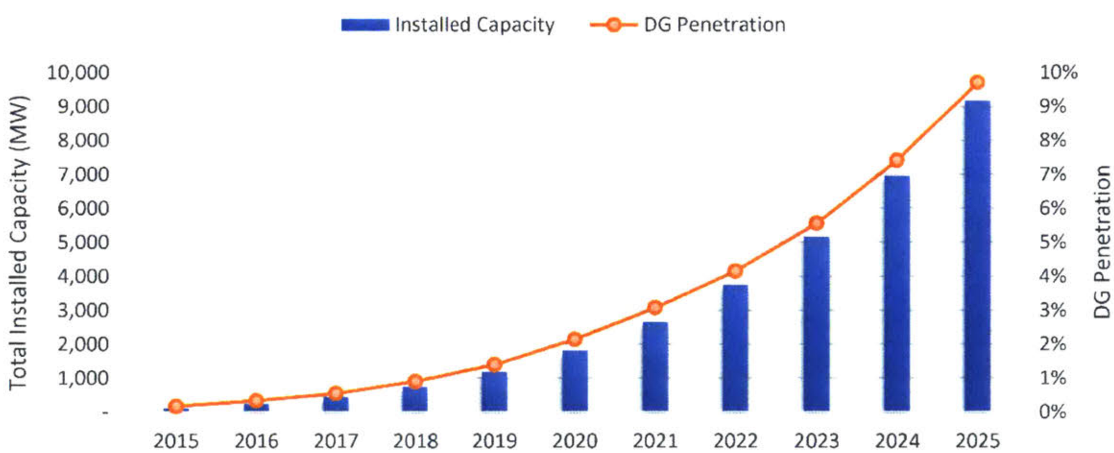

Figure 3.9 source: CRE 2017a; SENER 2015a. Figure and calculations by author.

[53] SENER and CRE have used the California electricity industry as a reference point for the Mexican electricity industry due to similar installed capacities and climatic conditions.

[54] Case studies in various electricity markets have shown different levels of resiliency towards integration of residential Solar PV. In 2012, the UK Electricity Utility *National Grid* accommodated a penetration of up to ~10% of households (~2.2 million households) or 10 GW of generation of Solar PV systems without hindering transmission and distribution network operation (GoUK 2012). Hawaii has reported grid reliability issues and operational challenges upon integration of ~20% renewable energy (Eber and Corbus 2013). The California Energy Commission (CEC) reported that grid reliability issues might arise with an integration of 5% of DG sources. Nonetheless, CEC set the ambitious goal of installing 12 GW (~20% penetration) of distributed generation sources into its network by 2020. Around 90% of installed capacity is expected to come from residential Solar PV systems (California Energy Commission 2017).

[55] Considering the expected addition of removal of power plants (SENER 2015a) and CRE's expected integration of DG into the SEN (CRE 2017a), a 5% and 10% integration of distributed energy sources into the grid would imply installed capacities of ~4.4 GW and ~9.2 GW by 2023 and 2025 respectively.

If policy makers continue to refuse to increase electricity prices, socialized costs caused by the integration of clean DG technologies under existing NetM policies will exacerbate problems that the Energy Reform is attempting to address. It will either increase CFE's operational costs or require increased subsidies. Therefore, under current policies, significant penetration of clean DG technologies – which is promoted by the 2013 Energy Reform – directly contradicts the Energy Reform's missions and goals.

3.2.3 – Customer-Driven Deployment of DG fails to Capture Potential Value for the System

The rapidly increasing volume of DERs[56] installed in random locations on the distribution network has forced electricity utilities to re-assess reliability across the grid (Eber and Corbus 2013). Current customer-driven deployment of DERs misses opportunities for electricity networks to capture significant system value (ICF 2016). Adopters of clean DG systems install their systems in a way that maximizes individual benefits rather than system benefits (ICF 2015). As I noted above, current NetM policies and tariff structures will continue to limit the deployment of clean DG to a small number of areas. Thus, clean DG in Mexico is bound to be deployed in a manner that will fail to provide maximum system value.

In Mexico and across electricity markets, the vast majority of clean DG technologies are intermittent Solar PV systems that currently cannot provide a reliable, steady supply of electricity into the grid or to households (CRE 2017a). Electricity utilities and system operators are unable to control power production from distributed Solar PV systems. This exposes the distribution network to excesses or shortages of energy fed into the grid, and therefore, voltage variations that can damage grid infrastructure (Eber and Corbus 2013).

The intermittent nature of Solar PV requires backup from conventional power plants. This is especially true in electricity markets with high integration of Solar PV and peak electricity demand occurring after the sun has set, requiring aggressive and costly ramp-ups from backup generators (Brown and Bunyan 2014). Growing integration of Solar PV in the state of California requires an increased ramp up from centralized plants to meet peak demand (John 2014).

[56] MITEI's (2016) *Utility of the Future Study* defines Distributed Energy Resources (DER) as "any resource capable of providing electricity services that is located in the distribution system." DERs include distributed generation, demand response, energy storage, and energy control devices that are located and function at the distribution level (MITEI 2016). DERs are expected to play a larger role in electricity networks across the globe (EPRI 2014).

Figure 3.10 - Prospective CAISO Load Profile with Increased Solar PV Integration

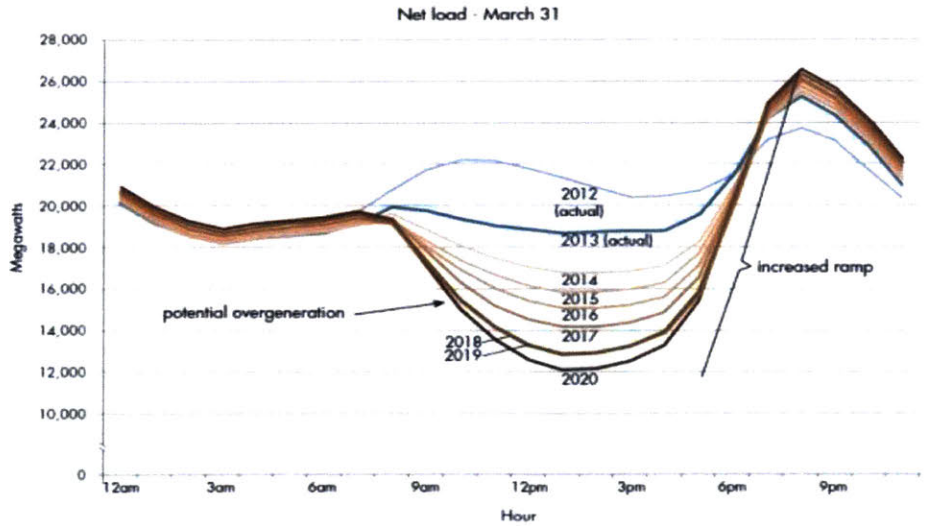

Figure 3.10 source: John 2014.

Significant integration of residential Solar PV will reduce the load demand during daylight hours; however, throughout a vast portion of the country, Solar PV will not be able to supply energy to meet peak demands on its own. Mexico's energy consumption profile, including peak electricity demand, varies by season, day, and region[57] (IEA 2014). Other than summer working days in the north of the country, peak demand hours tend to be late at night, usually after the sun has set (IEA 2014).[58]

Figure 3.11 - Typical Load Curves for 2014 Concerning Annual Peak Demand, Northern Mexico (left) and Southern Mexico (right)

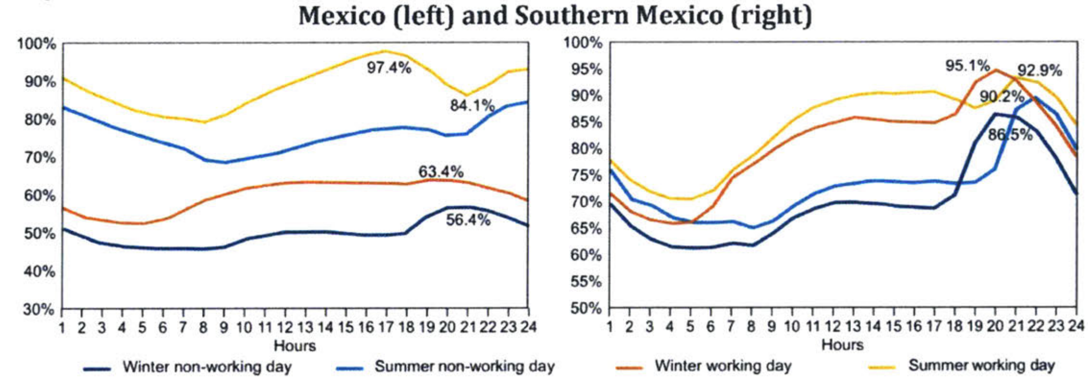

Figure 3.11 source: IEA 2014.

[57] In 2014, peak demand in Mexico generally occurred between 8 pm and 10 pm in southern states. Northern states experienced a wider variation of peak demand times. Summer working days in the north had peak demand at around 5 pm with peak demand during non-working days and winter seasons occurring closer to 8 pm and 9 pm (IEA 2014).

[58] Northern Mexico = Baja California, Baja California Sur, Sinaloa, Sonora, Coahuila, Chihuahua, Durango, Nuevo León, Tamaulipas; Southern Mexico = Distrito Federal, Hidalgo, Estado de México, Morelos, Puebla, Tlaxcala, Campeche, Chiapas, Guerrero, Oaxaca, Quintana Roo, Tabasco, Veracruz, Yucatán.

If CRE's expected integration of Solar PV systems are solely driven by customer preference, it is possible that Mexico will mirror the expected "duck-curve"[59] effect noted in California's electricity market (Figure 3.10), requiring aggressive ramp-ups from internal combustion power plants that currently use fuel oil and natural gas to meet peak electricity demand as the sun is setting (John 2014).[60] If Mexico does not address this issue properly, electricity generation costs and, most likely, CO_2 emissions may increase sharply due to the ramp-ups required to meet peak electricity demand. Both developments would go directly against the State's electricity and GHG emission reduction goals.

[59] The "duck curve" refers to the drop in net load during day light due to Solar Energy being injected into the grid. As solar energy fades, a steep ramp-up from centralized plants is required to meet peak electricity demand.

[60] In 2015, Mexico generated ~13% of its electricity with internal combustion power plants that use fuel oil, particularly to meet peak electricity demand (CFE 2015, SENER 2017a, SENER 2015a). SENER expects to replace fuel oil with natural gas and generate only ~1% of its electricity with fuel oil by 2025 (SENER 2015a, SENER 2016a). Section A.1.3 in Appendix A provides the prospective development of the electricity industry in Mexico.

Chapter 4

Recommendations to Promote and Deploy Clean DG in Mexico in a Manner that Will Surpass Current Barriers to Entry and Help Meet the State's Electricity Generation and GHG Emission Reduction Goals

With the 2013 Energy Reform, the Mexican electricity sector has undergone a revolutionizing overhaul. Policy makers are trying to lower electricity tariffs (and therefore, reduce electricity subsidies), generate 35% of all electricity from clean energy sources by 2024, and reduce GHG emissions by 30% and 50% by 2020 and 2050 respectively (as compared to GHG emissions in 2000). Meeting these ambitious goals will requires a more holistic approach, involving multiple technologies, a greater coordination of policies and regulations than we have seen thus far.

Clean DG technologies have the potential to provide tremendous value to the Mexican electricity system if deployed and planned-for correctly. While current economic conditions pose significant barriers that may prevent significant penetration of clean DG throughout the electricity grid, unplanned, customer-driven integration of clean DG systems in Mexico will potentially burden the electricity sector more than it may aid it in the achievement of electricity generation and GHG emission reduction goals.

Given the novelty of clean DG in Mexico, there is still time for regulators to modify existing policies and adopt new policies to help the country reap the potential benefits that clean DG can provide. In this chapter I present three short-term and one long-term recommendations for SENER and CRE to help promote the deployment of clean DG sources in a manner that can better meet the State's electricity generation and GHG emission reduction goals.[61] These recommendations are based on my analysis and modelling efforts presented in the earlier chapters.

[61] As was the case in Chapter 3, in order to support my claims, I develop solar models using the state of Baja California Sur as a case study. The methodology and process I use to develop these models can be found in Annex B of this thesis.

Recommendation 1 – Add Clean DG to Grid Planning and Develop a DER Strategy

To date, SENER has published three different Development Programs of the National Electricity System (PRODESEN).[62] In these publications, SENER has analyzed the development of electricity generation, transmission, and distribution infrastructure as well as what power plants they plan to decommission. Distributed electricity generation is currently not included in SENER's planning scope. Their reports fail to discuss distributed electricity generation at any level. While power markets around the world are evolving to accommodate the growing integration of clean DG, the current modernization of the Mexican electricity industry still focuses on the continued development of a centralized model. In order to obtain the potential benefits that distributed energy resources can provide, SENER must find a way to integrate DERs and overcome current barriers to entry.

R 1.1 – Importance and Benefits of Adding DG to Grid Planning as Part of DER's Strategy

Electricity markets across the globe are relying on the increasing integration of distributed energy resources. Random, customer-driven deployment of clean DG is not sufficient. Strategically deployed DERs can bring greater total economic benefits at lower costs, provide more affordable consumer choices, improve flexibility in grid planning and operations, and provide services that traditional centralized electricity networks cannot, all while facilitating the de-carbonization of the electricity grid (EPRI 2014). Mexico's minimal installed capacity of DG puts it in an ideal position to maximize the potential benefits the electricity network can receive from these technologies. There is still time. SENER and CRE can study other electricity markets with high levels of integration of clean DG and plan its strategic deployment in Mexico accordingly. With adequate policies and planning, the electricity industry in Mexico can avoid many of the obstacles that have hindered the operation of electricity markets that did not adequately prepare for heavy integration of DG.

SENER's current planning methodology ignores the opportunities that distributed energy can provide to meet certain grid needs. Outdated planning approaches rely on static assumptions about DER capabilities and focus primarily on mitigating potential integration challenges, rather than proactively harnessing these flexible assets (MITEI 2016). For DERs to truly become resources that add value to the system, they must be brought onto the grid as part of an overall planning strategy that leverages the locational benefits of DERs to support future grid planning and investments (ICF

[62] The first publication covered the 15-year period of 2015 – 2029, the second publication covered 2016 – 2030, and the third publication covered 2017 – 2031.

2016). A DER strategy can address distribution network needs, align compensation accordingly, and target location-specific or broader issues that maximize system benefits (MITEI 2016). Energy losses can be further reduced, voltage stabilization can be improved, and system reliability further enhanced by determining the optimal placement of DG sources. This must be planned centrally (or at least regionally) rather than relying on random client-based adoption (Haghighat 2015).

In order to take full advantage of clean DG, SENER and CENACE should adjust their approach to grid planning which currently has a strong bias towards traditional infrastructure. If grid-planning decisions are made before consideration of DER services, network investments will underutilize the potential of DERs to provide grid services that centralized, traditional infrastructure cannot. Clean DG can offer deferral and avoidance of planned grid investments, improved grid resiliency, and reduce GHG emissions. DERs, if deployed effectively and placed on an equal footing in the planning process with traditional grid investments, can ultimately lead to increased net benefits for the system (MITEI 2016). Strategically planned DERs can better help the State meet its electricity generation and GHG emission reduction goals by:

1. Maximizing system benefits: Strategic deployment of clean DG, rather than random, customer-driven deployment of clean DG, can better address system needs. Increased operational efficiency translates into lower electricity generating costs.
2. Reducing infrastructure investment: Well-planned infrastructure investments will be reflected in reduced electricity tariffs.
3. Increasing energy security: Reducing the demand for imported fossil fuels by relying more heavily on renewable energy, will reduce GHG emissions.

R 1.1.1 – Maximize Overall System Value

Strategic deployment of distributed energy resources (e.g., clean DG) can be arranged to provide maximum value to the electricity system overall rather than to individual load centers (e.g., households or businesses). By developing a DER strategy, SENER and CENACE can jointly decide the locations and set-up through which clean DG will provide the maximum value to the overall network. The manner in which clean DG is currently being deployed in Mexico has minimal impact on reduction of energy losses (i.e., one of the key goals of national energy policy).[63] With strategic

[63] The reduction of energy losses is one of the main goals of the 2013 Energy Reform. Interviewed stakeholders identified energy losses as one of the main virtues of clean DG systems. Issue covered in Chapter 2 and Chapter 3.

deployment of DERs, SENER can plan for clean DG technologies to be placed close to locations with high energy losses. Solar PV panels perform differently depending on the position they are facing. Solar PV panels in the northern hemisphere perform optimally when facing south; however, when Solar PV panels in the northern hemisphere face west, they provide higher peak demand energy savings (EnergySage 2017). Electricity utilities prefer having Solar PV panels facing in a direction that helps reduce peak electricity demand (EPRI 2014). Current random, customer-driven deployment of clean DG in Mexico will continue to miss this potential benefit and potentially aggravate the "duck-curve" effect that has already been noted in the Californian electricity market.

It is in SENER's best interest that clean DG be deployed in a manner that maximizes economic and operational efficiency for the system as a whole, therefore reducing overall costs and helping to achieve the 2013 Energy Reform goals. Figure 4.1 shows the normalized electricity demand profile that centralized power plants need to meet in the BCS transmission network with a 5% integration of distributed Solar PV in June 2016 when panels are facing different directions at different tilts.[64] While the highest production of solar energy occurs when panels face south at a 25° angle, peak demand is better reduced when panels face west either at a 30° angle or a 45° angle. Figure 4.2 demonstrates the normalized total and peak-hour savings that the BCS electricity system would receive throughout 2016 with a 5% penetration of distributed Solar PV at different positions. Reducing peak electricity demand would have important impact on lowering electricity generation costs. Peak hour savings are significantly higher when panels face west rather than south.[65]

R 1.1.2 – Reducing Required Infrastructure Investment

Electricity tariffs include the cost of electricity generation as well as the cost of infrastructure investment (i.e. transmission and distribution lines) (CRE 2017b). SENER forecasts investments of USD ~$85 billion, USD ~$11 billion, and USD ~$8.5 billion in electricity generation, transmission, and distribution infrastructure from 2017 through 2031 (SENER 2017c). By developing a DER strategy, SENER can reduce the sum it will need to invest in grid infrastructure (Eltawil and Zhao 2010). Furthermore, by reducing total infrastructure investment, technologies like clean DG can lower the cost of electricity tariffs, therefore helping comply with the 2013 Energy Reform's goal.

[64] "S25" means panels are facing south at a 25° angle. "W30" means panels are facing west at a 30° angle. "W45" means panels are facing west at a 45° angle. Section C.2 in Appendix C provides the methodology for development of this solar model.
[65] Section C.2 in Appendix C provides the methodology used to calculate results in Figure 4.2.

Using estimates of the prospective development and electricity demand in the BCS transmission system from 2016 to 2030, I compared the total investment required to install a 5% integration of Solar PV energy in centralized and distributed formats. I determined that the NPV of electricity generation savings from centralized Solar PV systems is USD ~$43.7 million more than with distributed Solar PV systems.[66] These savings could construct ~45.6 miles of 230 kV Single Circuit transmission lines or ~28.5 miles of 230 kV Double Circuit transmission lines, equivalent to 41% or 26% respectively of the 230 kV transmission lines that SENER expects to build in BCS between 2018 and 2024 (SENER 2015a). By constructing a portion of the estimated installed capacity that will be required on a distributed basis, the system would require less infrastructure investment, and therefore lower electricity tariffs.

R 1.1.3 – Increased Energy Security

SENER expects the country's electricity demand to grow by around 50% from 2017 to 2031, with Natural Gas consumption expected to increase at a rate of 2.7% annually (SENER 2017c). At the same time, local natural gas production has declined continuously since 2010 and natural gas imports have increased aggressively. As seen in Figure 4.3, in 2016, Mexico imported more natural gas than it produced locally for the first time (SENER 2017d).

With a liberalized electricity market, low natural gas prices, increasing energy demand, and ambitious GHG emission reduction goals, demand for natural gas will continue to increase and phase-out diesel and fuel oil; however, even though the country is investing heavily in natural gas pipeline infrastructure, Mexico is currently at maximum natural gas importation capacity (NGI 2017). The country is experiencing a shortage of natural gas that is forcing generators in isolated regions of the country[67] to rely on diesel and fuel oil once again (NGI 2017, SENER 2017b). The increased use of diesel and fuel oil in recent months is translating into higher electricity prices and GHG emissions, directly contradicting the 2013 Energy Reform goal and the LGCC.

The strategic deployment of clean DG would increase energy security and reduce the demand for fossil fuels. As electricity demand increases, natural gas will inevitably play a large role in Mexico's electricity production profile in coming years (SENER 2017d). Growing pipeline infrastructure and

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[66] Section C.2 in Appendix C provides methodology for this exercise. The model considers the planned installed capacity and transmission line investments for the BCS network from 2016 to 2030 (SENER 2015a) as well as the 5% DG integration threshold identified by CRE.

[67] Particularly the Peninsular Region that holds the states of Campeche, Quintana Roo, and Yucatán.

the most recent exploration contract bids that target local conventional and non-conventional gas production will undoubtedly help mitigate natural gas supply scarcities; however, the development of a DER strategy could compensate for shortages, therefore eliminating the need for expensive and polluting fuels like diesel and fuel oil. In this sense, the development of a DER strategy could help reduce electricity generation prices (2013 Energy Reform goal) and reduce the amount of electricity generated by fossil fuels (LTE and LGCC goals).

R 1.2 – What are the Obstacles to implementing this Recommendation?

The development of a DER strategy and the inclusion of clean DG into systematic grid planning would be a novel concept for SENER. Since policy-makers are just now beginning to come to grips with the need to establish the rules of operation of the new electricity industry, they will surely be hesitant to integrate DG into the planning process until all facets of the new Wholesale Electricity Market have been developed. SENER's activities for the remainder of the current presidential term (2012 – 2018) are well delineated and will probably not be altered.

Further opposition may come from CENACE and CFE Distribution. Both groups are still getting used to the operation of the new electricity market. The adoption of a DER strategy emphasizing the inclusion of clean DG into systematic grid planning will increase the complexity of the system's operation. The current shortage of natural gas is creating an unstable operation of the WEM (NGI 2017). Meeting reliability standards and electricity demand with an uncertain fuel supply is a challenge for CENACE. The added intermittency that increasing levels of clean DG would add, would certainly increase the difficulty of operating the system. CFE Distribution may oppose the addition of significant amounts of distributed energy sources to the distribution network, as these will require additional investment and maintenance (EPRI 2014).

R 1.3 – How to Overcome These Obstacles

The LTE requires CENACE to develop and propose a smart grid program to the SENER every three years to modernize the transmission and distribution network. The smart-grid program must facilitate the incorporation of new technologies that lower the costs of the electricity sector and promote the development of clean DG (SENER 2016b). The development and inclusion of a DER strategy into systematic planning could originate from the smart grid program and be gradually eased-in by policy makers. The smart grid program would need to broaden its scope and establish a timeline concerning the progress and integration of more strategically planned DERs. Policy makers could target locations on the grid where DERs would provide the greatest value and develop pilot projects at these sites. Pilot projects are a good way of discovering potential problems with innovative programs and new approaches.

The PRODESEN spans a 15-year period. Distributed energy resources should start to be included in upcoming planning processes in small but increasing amounts in order to ensure that the Mexican electricity industry does not lag behind other electricity markets as it has done in past decades. Various electricity utilities are incorporating distributed Solar PV into their integrated resource planning and system capacity expansion (to improve overall grid hosting capacity and performance) (von Appen, J., Braun, M., and Stetz, T. 2012). The integration of distributed energy sources into the grid is inevitable. The sooner SENER comes to terms with the idea, and embraces the need to incorporate novel distributed technologies, the more policy makers will be able to align these technologies with the industry's electricity generation and GHG emission reduction goals.

Figure 4.1 - BCS Normalized Demand Profile with Solar PV - June 2016

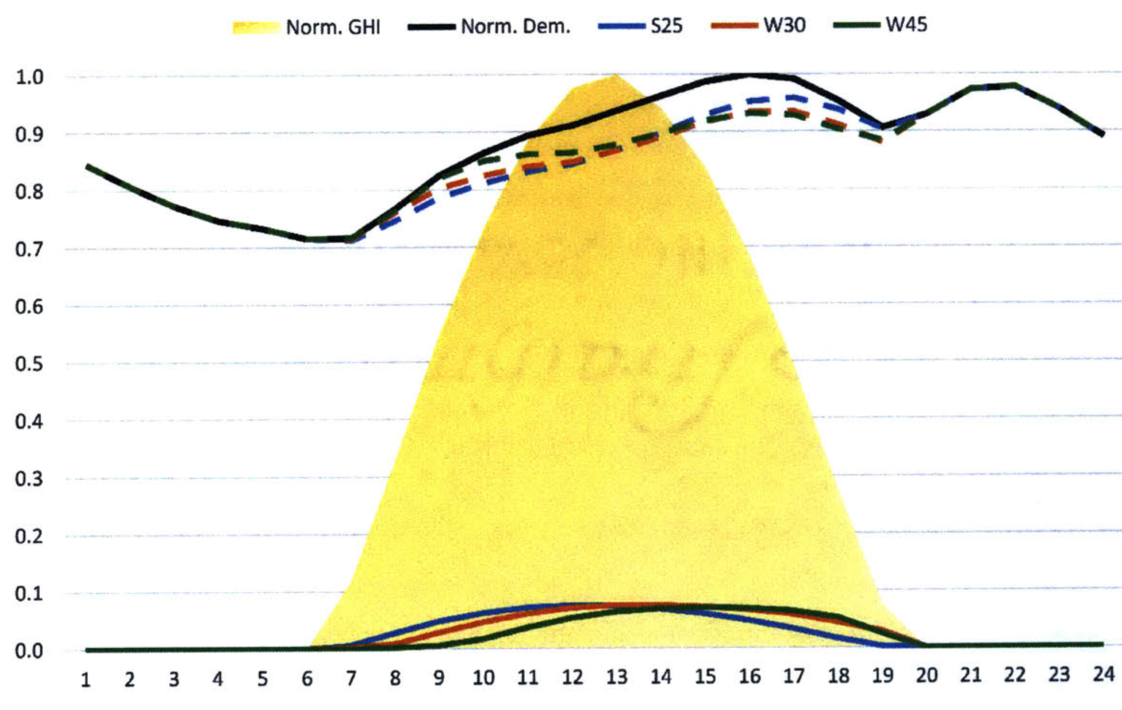


Figure 4.1 source: NSRDB 2017; CENACE 2017b; PVPMC 2017. Figure and results by author.

Figure 4.2 - 2016 BCS Network Normalized Total and Peak-Hour Savings with 5% Distributed Solar PV Penetration

	S25	W30	W45
Savings (MXN)	1.00	0.94	0.80
Peak Hour Savings (MXN)	0.59	0.94	1.00

Figure 4.2 results by author.

Figure 4.3 - Natural Gas Consumption 1997 - 2016

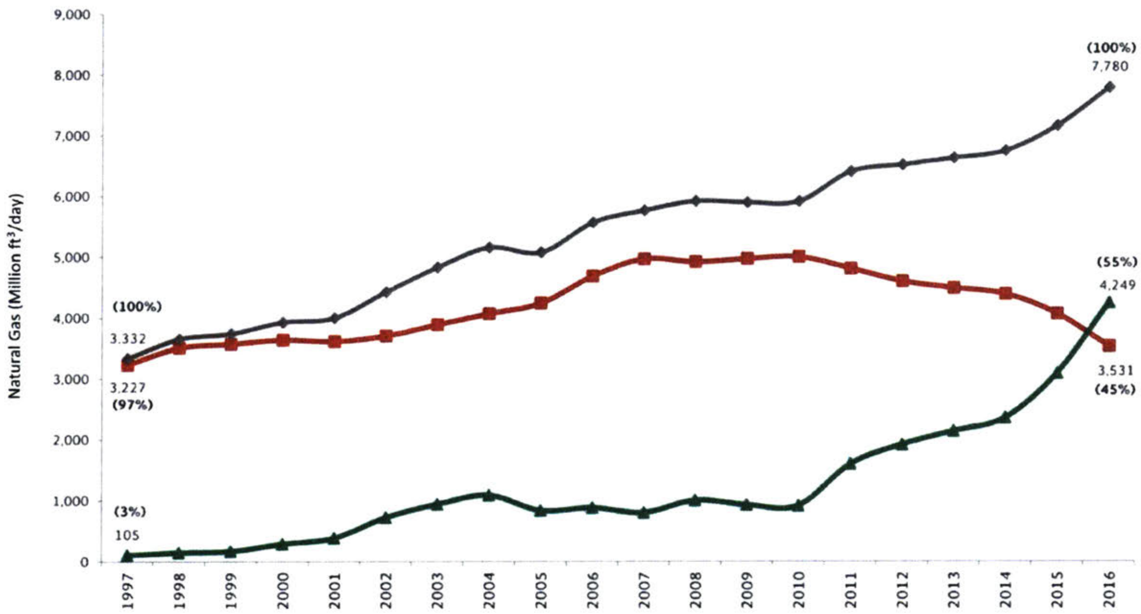


Figure 4.3 source: SENER 2017d.

Recommendation 2 – Organize Community-scale Clean DG Capacity Auctions

The deployment and adoption of clean DG technologies in Mexico is currently limited to households with DAC tariffs and commercial customers under Tariff 2 structures. DAC customers represent only 1.2% of all domestic electricity customers (SENER 2017b). Current system prices, electricity subsidies, and tariff structures make the acquisition of a clean DG system economically unfeasible for ~90% of CFE's commercial and domestic clients (SENER 2017b). Nonetheless, CRE expects an exponential penetration of DG technologies in coming years (CRE 2017a).[68]

[68] Refer to Figure 1.1 in Chapter 1.

The LTE obligates SENER to study how DG and other technologies can help them comply with the State's electricity generation and GHG emission reduction goals (GoM 2015). In order to incentivize the deployment of clean DG beyond current barriers to entry, policy makers must develop mechanisms that adapt to Mexico's unique electricity market structure and conditions.

Since the adoption of the LIE, Mexico has implemented two long-term energy, capacity, and CEL auctions.[69] The second auction, executed in July 2016, delivered record low energy prices for utility-scale wind and solar energy, demonstrating the advantageous conditions that exist in Mexico for renewable energy technologies. In order to promote optimal deployment of clean distributed electricity sources, Mexico should implement clean DG capacity auctions targeted for strategic locations identified by the SENER, CENACE, and CRE.

R 2.1 – Importance and Benefits of Community-Scale clean DG Capacity Auctions

The development of community-scale[70] clean DG capacity auctions would promote the deployment of distributed energy resources. SENER, along with input from CENACE, should be able to determine the best locations (at the current time) where clean DG systems (as well as other forms of DERs[71]) would provide the largest benefits to the network. Furthermore, auction systems fit the Mexican political paradigm since they are transparent and ensure a competitive, fair, open, and timely procurement process. Auctions reduce opportunities for corruption and avoid post-auction delays (Maurer and Barroso 2011).

Clean DG capacity auctions could be technology and site specific, with SENER defining the auction's goals but permitting flexibility in the proposals submitted by auction participants. Under this format, SENER would determine auction winners by the overall value they provide to the system. For example:

[69] Section A.3.3 in Appendix A provides an in-depth look into CELs.
[70] The community solar market is becoming a mainstream driver of U.S. solar market growth. Starting in 2017, community solar is expected to consistently drive 20% – 25% of annual non-residential PV market and become a half-gigawatt per year market by 2019 (GTM 2017). Community Solar tend to be mid-size systems that range from a few hundred kilowatts up to 5 MW in capacity. To comply with the LIE, installations would have to be of less than 500 kW in capacity to be considered "distributed generation" (DOF 2014). Given the larger average size of community scale installations as compared to residential Solar PV systems, BOS prices tend to mirror that of utility scale installations rather than residential scale Solar PV systems, providing more attractive forms of investment (RMI 2017).
[71] Given the current conditions of the Mexican electricity industry, Demand-Response and Energy Efficiency programs may provide significant value in the obtainment of the Energy Reform's goals.

- Distributed Solar PV energy installations with a storage system whose principal purpose is to inject electricity into the grid during peak demand hours,
- Distributed Solar PV or wind energy installations with smart meters in areas with high electricity losses whose principal purpose is to reduce energy losses.
- Distributed wind energy in areas where significant transmission line investment is expected (e.g., BC transmission network, BCS transmission network, or the peninsular section of the national transmission network).

By following this format, market participants would install community-scale clean DG on sites that maximize the benefits for the electricity system as a whole at highly competitive prices. The development of community-scale clean DG capacity auctions would increase the amount of clean generation available through the grid (helping meet the LTE goal of 35% clean energy generation by 2024), reduce GHG emissions (helping meet GHG emission reduction goals), reduce energy losses and electricity demand from centralized power plants (helping meet the Energy Reform's goal by lowering the cost of electricity generation and electricity subsidies), and meet CRE's DG penetration target.

The development and deployment of community-scale clean DG capacity auctions could be particularly beneficial for municipalities and communities eager to pay lower electricity bills for the services they provide. Municipalities pay high electricity rates for services such as street lighting and water pumping. Between January 2007 and January 2017, service electricity tariffs have increased at a higher rate than CFE's other electricity tariffs[72] and are only lower than domestic DAC tariffs and commercial tariffs. Public lighting tariffs in Mexico City, Monterrey, and Guadalajara in particular have been higher than commercial tariffs since July 2013 and are comparable to DAC tariffs (SENER 2017b).[73] While service electricity customers conform the second smallest group of CFE's electricity customers and consume the smallest amount of total electricity,[74] their average electricity bill is only lower than the average electricity bill of industrial customers. Municipalities and communities with high service electricity bills would be strong supporters of community-scale clean DG capacity auctions as they would be principal beneficiaries.

[72] Other electricity tariffs being domestic, commercial, agricultural, and industrial.
[73] Section A.2.2.3 in Appendix A provides an in-depth look in Service Industry Tariffs.
[74] Agricultural customers are the smallest group of customers but consume more electricity overall than service clients. Section A.2.3 in Appendix A provides an in-depth look into electricity tariffs.

R 2.2 – What are the Obstacles to implementing this recommendation?

Community-scale clean DG capacity auctions are a novel concept. Designing these auctions will require sophisticated technical capacity and extensive knowledge of how the whole system works. Proper valuation of the services being provided may be challenging. Furthermore, community-scale clean DG installations are significantly smaller than utility-scale installations. Therefore, given the higher level of complexity and the smaller scale, community-scale clean DG capacity auctions might have less traction than recent long-term auctions.

The involvement of CENACE in the designation of sites where community-scale clean DG installations can provide the highest value is imperative. CENACE is the most appropriate organization to determine where clean DG can provide the highest benefits. The successful execution of auctions of this kind will require intensive research and deep understanding of how community-scale clean DG installations interact with the electricity network and market. CENACE has to be fully committed and convinced of the value that these auctions will bring.

R 2.3 – How to Overcome these Obstacles

As with recommendation 1, prior to organizing a distributed clean DG auction, SENER should develop pilot projects to study the impact and effect that distributed community-scale energy installations have on the operation of the distribution network and market. Pilot projects would help SENER determine how to promote, design and execute auctions of this kind.

Distributed Solar PV can help reduce the cost of electricity generation and lower the subsidies required nation-wide if installed in the optimal places. Some of the regions with the highest average temperatures during summertime – and therefore, the highest electricity subsidies[75] – also have the best solar resource in Mexico. Using the methodology described in Section C.4 in Appendix C, I have identified five of the most appropriate cities for pilot projects of distributed Solar PV energy systems. These are Mexicali, Hermosillo, Ciudad Obregón, Los Mochis, and Guasave. Figures 4.5 and 4.6 demonstrate how in 2013 these cities were classified in Domestic Tariff Class 1F, meaning they receive the highest domestic electricity subsidies.[76]

[75] Section A.2.2 in Appendix A provides an in-depth look into electricity tariffs.

[76] In Recommendation 3, I demonstrate how distributed Solar PV can help reduce electricity subsidies.

Electricity produced from winning auction installations would receive CELs based on the clean electricity they are producing. Nonetheless, in order to further generate interest and incentivize participation in these auctions, SENER should consider awarding installations that provide added services to the grid beyond CELs. If a winning participant is, for example, helping reduce electricity losses or helping to reduce peak electricity demand, SENER should reward these facilities in a way that reflects the services they are providing. This reward could take the form of bonus CELs. Furthermore, SENER and other units of government could recognize, publicize, and reward cities and municipalities which produce a portion of their electricity locally from clean energy sources, similar to Mexico's "Magic Towns" program (SECTUR 2016).[77] By doing this, SENER would be incentivizing auction participants to develop projects that maximize the value they provide to the system.

Figure 4.4 - Recommended Cities for Distributed Solar PV Pilot Projects

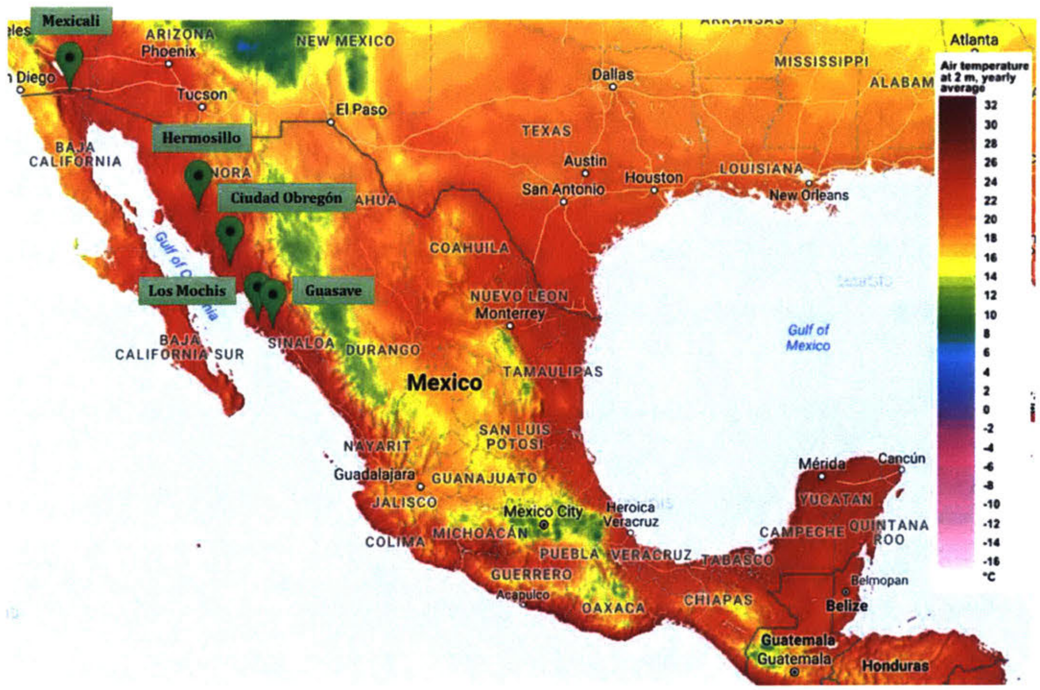


Figure 4.4 source: SolarGIS 2017; GoM 2017b. Figure by author.

[77] The "Magic Towns" contributes to revalue a set of populations of the country that have always been in collective imagination of the nation as a whole and which represent fresh and different alternatives for national and foreign visitors (SECTUR 2016).

Figure 4.5 - 2013 Tariff Class of Recommended Cities for Distributed Solar PV Pilot Projects

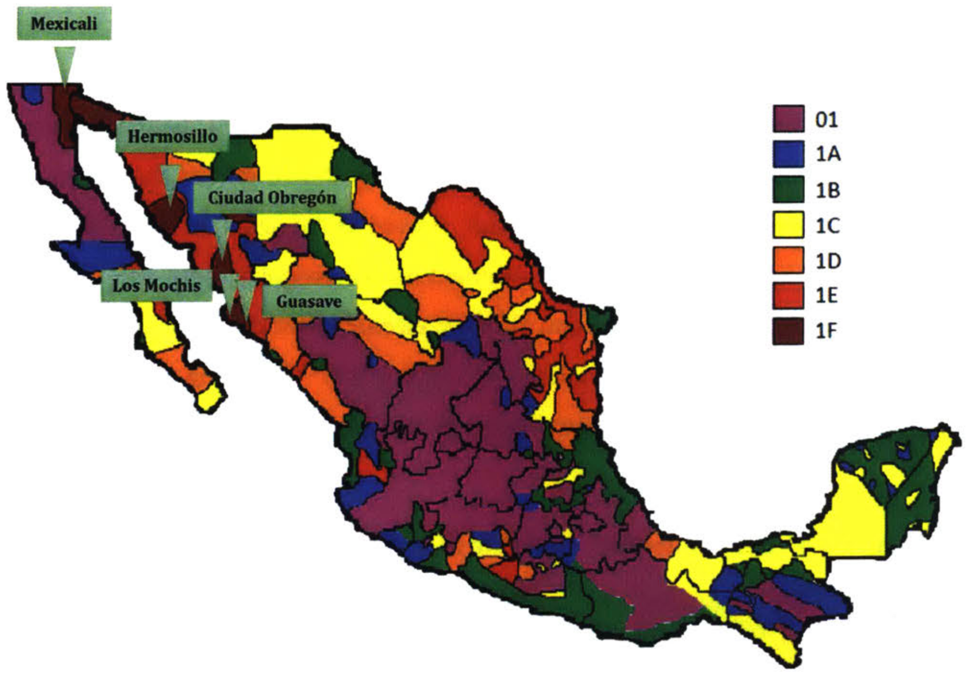


Figure 4.5 source: SolarGIS 2017; GoM 2014a; GoM 2017b. Figure by author.

Recommendation 3 – Increase Investment and Financing Opportunities for the Public

Following Recommendation 2, acquiring a clean DG system is only economically feasible for a small percentage of the population (SENER 2017b). SENER, CRE, and CFE[78] should increase access to clean DG systems by enabling electricity customers to receive savings in their electricity bills through investments in clean DG projects not installed on their property. Furthermore, SENER, CRE, and the Ministry of Finance and Public Credit (SHCP) should consider creating programs that cover a portion of the costs of installation of Solar PV systems (or other clean DG technologies) for interested users. These funds could come from repurposed electricity subsidies.[79] Customers would cover the remaining portion of costs through "soft credits", meaning the government might have to incur some of the initial costs involved in deploying clean DG systems.

[78] Strictly referring the retailing portion of CFE.

[79] This recommendation strictly suggests using a portion of the current subsidies to fund the deployment of clean DG technologies. The volume of subsidies will diminish. This recommendation does not suggest to create financing mechanisms additional to current subsidies, but rather reduce and repurpose subsidies.

R 3.1 – Importance and Benefits of Increasing Investment Opportunities for the Public

Providing more investment and financing opportunities for the public would spur the deployment of clean DG systems, thereby increasing the amount of clean generation on the grid, reducing GHG emissions, reducing the demand from centralized power plants (lowering the cost of electricity generation and electricity subsidies), and helping meet CRE's DG penetration forecast.

SENER should consider creating investment tools through which interested domestic, commercial, and service electricity customers can invest in clean DG stations in locations other than their own homes or businesses. A large portion of CFE's customers are renters, or live in apartments where installing Solar PV systems is either technically or economically impossible. Ek (2005) claims that the public is predominantly in favor of adopting renewable energy technologies; however, a NIMBY sentiment concerning technologies such as Solar PV has been sparked by fear of an unknown technology or negative aesthetic impact on households. The general public has yet to fully embrace the possibility of owning a Solar PV system (Ek 2005). Community-based renewable energy projects, with high levels of public participation, could be a means of increasing public acceptance (Rogers et al. 2008). By allowing domestic, commercial, and service customers to invest in clean DG sites other than their own properties, the market for prospective clients would increase significantly.

The deployment of clean DG can help reduce electricity subsidies. By repurposing and transforming a portion of electricity subsidies into financing mechanisms, SENER could instruct beneficiaries to install clean DG systems in a manner that maximizes system benefits rather than individual benefits. Doing so could make an important contribution to meeting the 2013 Energy Reform's goal of reducing electricity subsidies. Furthermore, local governments of municipalities with high domestic electricity subsidies could access these funds to deploy community-scale clean DG sites.

In continuation with recommendation 2, municipalities and communities that pay high prices for electricity services would be some of the principal beneficiaries from community-scale clean DG sites. Though subsidies are concentrated among domestic and agricultural electricity clients, Municipalities with high electricity consumption levels should be able to access funds to deploy clean DG projects that help reduce their electricity consumption and bills.

R 3.1.1 – Increased Community Awareness and Involvement

Community Solar PV sites have the benefit of lower unit installation costs as compared to residential Solar PV (RMI 2016). Clients investing in Community Solar PV projects could receive a discount on their electricity bill corresponding to the benefits that their investment provides to the grid, regardless of their electricity tariff. Customers would not be required to incur the large down payment necessary to acquire, for example, a large Solar PV system.

R 3.1.2 – Distributed Solar PV to Reduce Electricity Subsidies

Domestic electricity subsidies are determined by average summertime temperatures (CFE 2017).[80] Coincidently, as demonstrated in Figure 4.6, due to extensive sunlight, various regions with the hottest summers (and therefore, highest domestic electricity subsidies) also have abundant solar irradiation (Solargis 2017). SENER, CRE, and SHCP could repurpose a portion of the available electricity subsidies to install distributed Solar PV energy systems in municipalities that have high electricity subsidies and favorable conditions for Solar PV energy performance.[81] Policy makers should prioritize this form of financing to households that currently have subsidized electricity tariffs. I would discourage policy makers to grant this form of financing to DAC households since, as seen in Section 3.1.2, acquiring a Solar PV system is economically feasible and attractive for consumers with DAC tariffs. Figure 4.7 shows the value that can be obtained by repurposing subsidies to install clean DG systems. Figures 4.8, 4.9, 4.10, and 4.11 demonstrate the annual and accumulated cost savings that this program could generate in the BCS transmission network.[82]

R 3.2 – What are the Obstacles to implement this Recommendation?

Both issues covered in this recommendation suggest a drastic shift away from the current approach to electricity sector operations, and therefore, will inevitably face substantial obstacles. Getting permission for electricity customers to receive savings on their electricity bills by investments in clean DG installations that they do not own will be challenging. SENER, CRE, and CFE will have to quantify the savings that small, individual investments generate. This program will not have a low cost of compliance since CFE might have to interact with hundreds of thousands of customers. Furthermore, for energy savings to be reflected in a customer's electricity bill, their investment will have to be made in a clean DG site that is owned by the customer's electricity utility (currently only CFE). If customers invest on sites foreign to CFE, their return on investment, or electricity savings,

[80] The hotter the average summertime temperature, the higher domestic electricity subsidies granted to municipalities. The Ministry of Finance and Public Credit designates subsidies granted to domestic and agricultural electricity customers.
[81] Section C.4 in Appendix C contains methodology and recommendations of municipalities that have high domestic electricity subsidies and optimal conditions for Solar PV energy.
[82] I base results on the Baja California Sur case study presented in section C.2 in Appendix C.

will be difficult to direct to their electricity bill. An additional intermediary may be required for SENER to promote this policy. Besides, even if customers are allowed to invest in clean DG sites owned and operated by CFE, there may be an excess of demand for the opportunity to save on electricity bills with a shortage of projects to invest in.

Concerning the repurposing of electricity subsidies, as explained in Chapter 2, energy subsidies are a highly delicate issue in Mexico. Repurposing a portion of electricity subsidies to fund the deployment of Solar PV systems is sure to encounter political resistance. SHCP and all involved parties will have to be convinced of the return on investment these projects will provide. Furthermore, policy makers will have to decide if this program should prioritize households and municipalities that currently receive higher subsidies and have optimal conditions for Solar PV energy performance.

R 3.3 – How to Overcome these Obstacles

Implementing my recommendations in a way that maximizes social welfare will be difficult, even though proper execution can deliver substantial value. At least in their inception, the policy changes I am suggesting should be implemented regionally. SENER should deploy these new ideas in municipalities with the highest electricity subsidies and optimal conditions for Solar PV. The program should be limited to households with subsidized tariffs who will be investing in community solar projects rather than residential installations. Under a scheme of this sort, installation costs will be lower and SENER and CFE will be able to show that such installations provide the most benefit to the system rather than to individuals.

SENER will have to study the effect that community-scale Solar PV installations will have on electricity subsidies. If SENER presents convincing arguments that this program can help substantially reduce electricity subsidies, therefore helping comply with the 2013 Energy Reform (as seen in Figures 4.7 through 4.11), the program could be a tremendous success. CFE will not oppose this program, since the total revenue it receives will not be reduced. Under a subsidized tariff system, the reduction in electricity demand diminishes total subsidies, not CFE's sales. This effect is shown in Figure 4.12.

To avoid an overwhelming amount of interest from electricity customers in the beginning, investment should be limited to projects within a customer's own municipality or metropolitan area. The electricity utility in these municipalities – CFE – should be the owner and intermediary of the Solar PV installations. Nonetheless, CFE should execute tenders and competitions among private companies to ensure competitive prices. CRE and SHCP will have to define how much an individual can invest and what their savings will be.

As is the case with recommendations 1 and 2, the development of pilot projects as a first step should help to identify the feasibility and attractiveness of this recommendation.[83] Again, SENER and other units of government should recognize, publicize, and reward cities and municipalities which produce a portion of their electricity locally from clean energy sources, similar to Mexico's "Magic Towns" program (SECTUR 2016).

With smart, targeted deployment of Community Solar PV systems, the cost of electricity generation could be drastically reduced, contributing to the reduction of electricity subsidies and assisting in achieving the State's electricity generation and GHG emission reduction targets. CFE and SENER should inform investors regularly of the value their investments is providing (probably with each electricity bill). It is important that these customers become more aware of the consequences of their behavior as electrical energy consumers. CELs would be an attractive and efficient tool for community scale solar projects. Unlike customer-driven rooftop Solar PV, strategically deployed community solar projects could inject the vast majority of the electricity they generate into the distribution network.

Figure 4.6 - Accumulated Annual GHI vs Average Annual Temperature

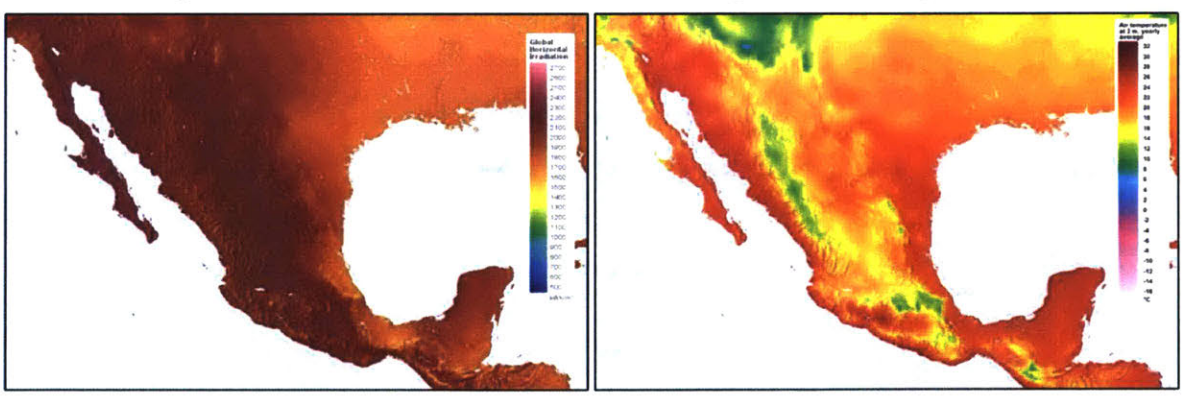


Figure 4.6 source: SolarGIS 2017.

[83] I have made a recommendation of these municipalities in recommendation 2 and section C.4 in Appendix C.

Figure 4.7 - Electricity Generation Savings

	NPV (millions USD)			IRR		
	S25	W30	W45	S25	W30	W45
Increasing Penetration	$622	$564	$370	23.1%	21.7%	16.4%
5% Penetration	$361	$330	$255	26.7%	25.5%	21.5%
10% Penetration	$693	$644	$496	25.0%	24.2%	20.4%
20% Penetration	$1,277	$1,234	$950	21.3%	21.0%	17.8%

Figure 4.7 and results by author.

Figure 4.8 - Electricity Generation Savings with Annually Increasing Integration of Distributed Solar PV in BCS

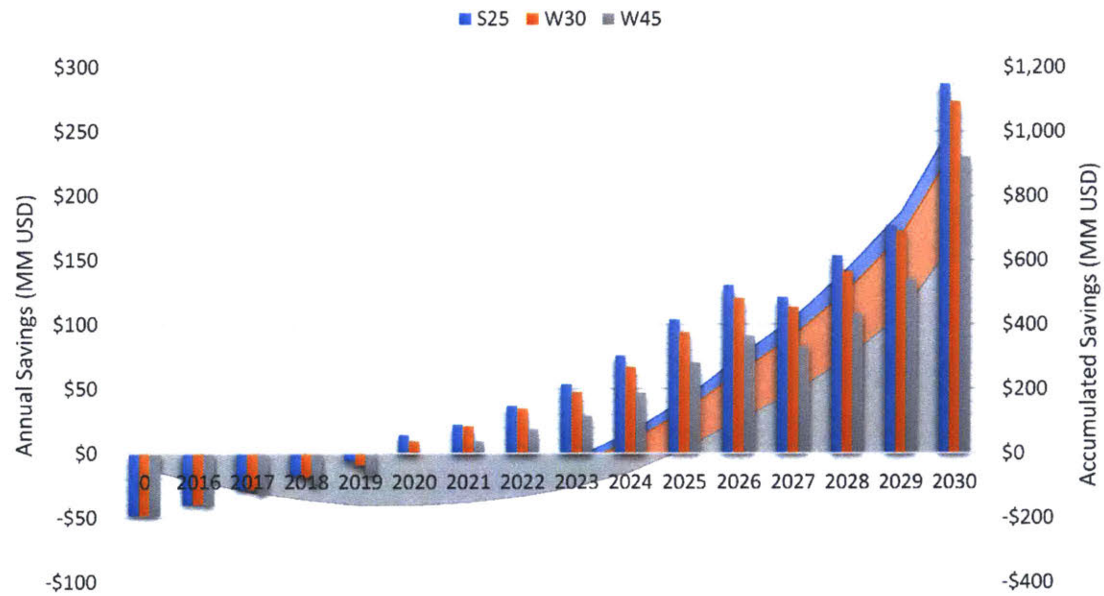


Figure 4.8 and results by author.

Figure 4.9 - Electricity Generation Savings with 5% Integration of Distributed Solar PV in BCS

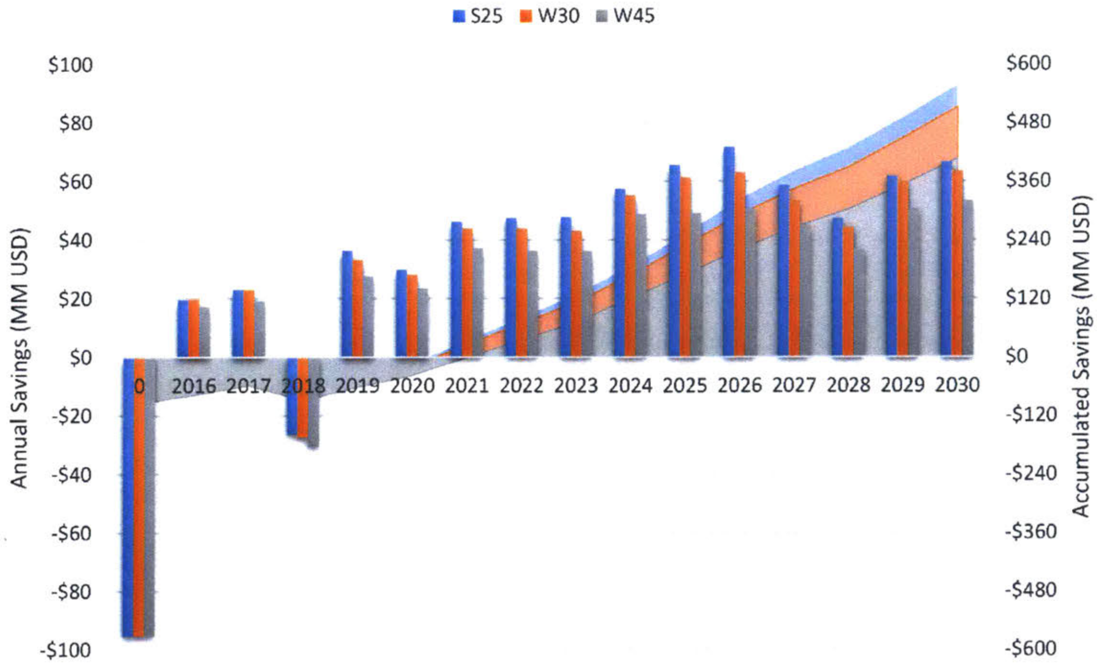


Figure 4.9 and results by author.

Figure 4.10 - Electricity Generation Savings with 10% Integration of Distributed Solar PV in BCS

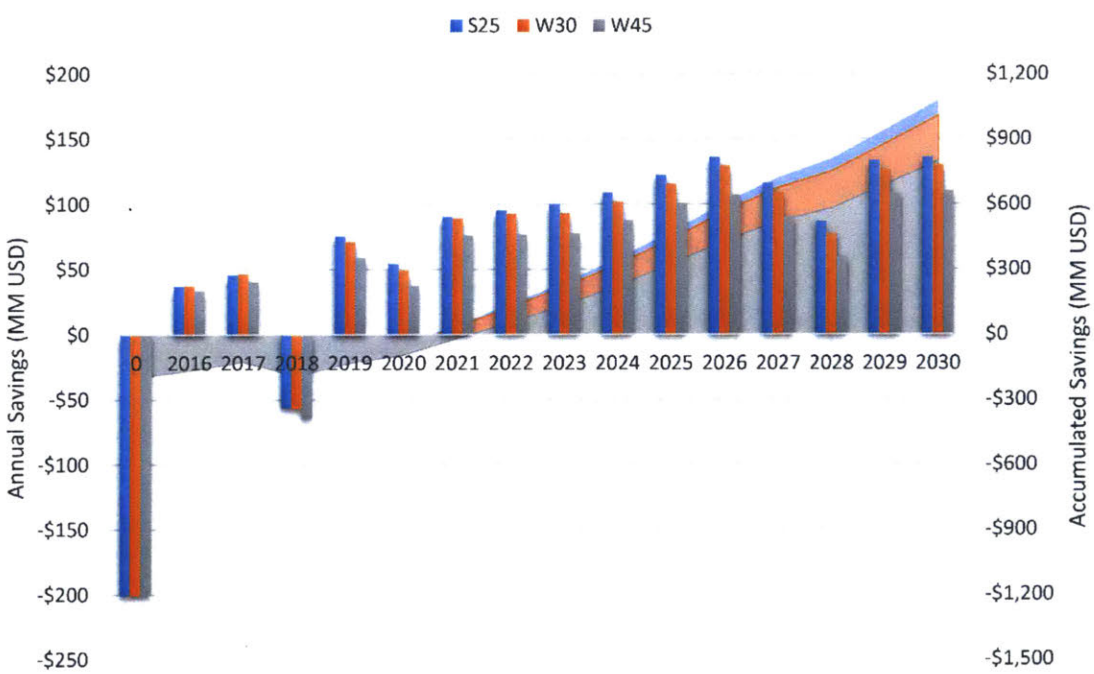


Figure 4.10 and results by author.

Figure 4.11 - Electricity Generation Savings with 20% Integration of Distributed Solar PV in BCS

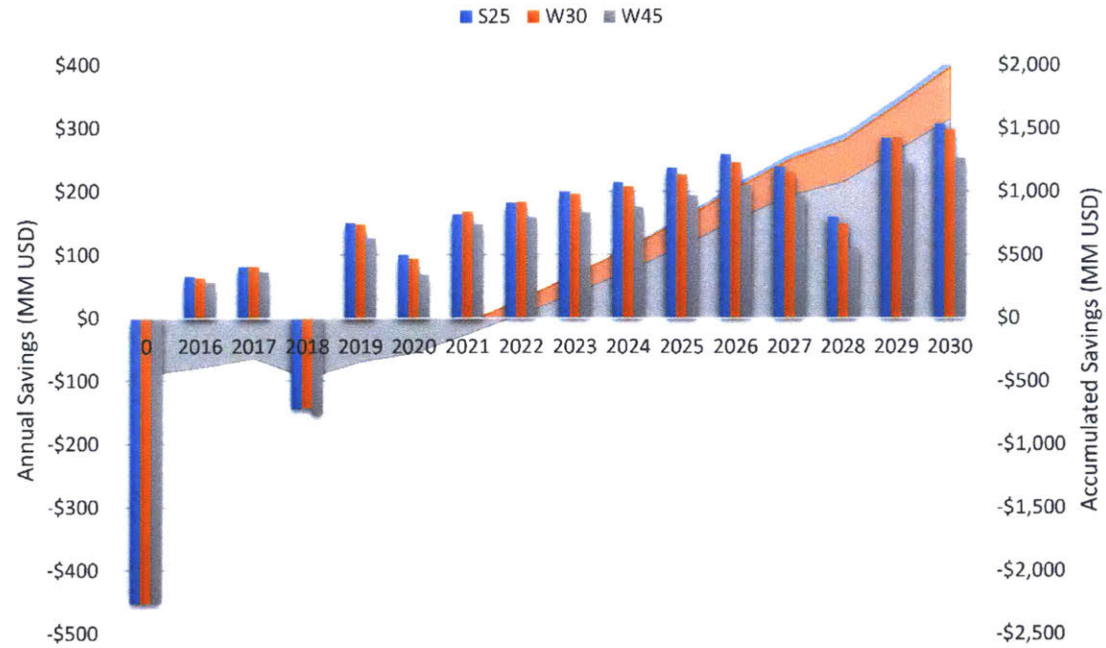


Figure 4.11 and results by author.

Figure 4.12 - Reduction of Subsidies with Solar PV

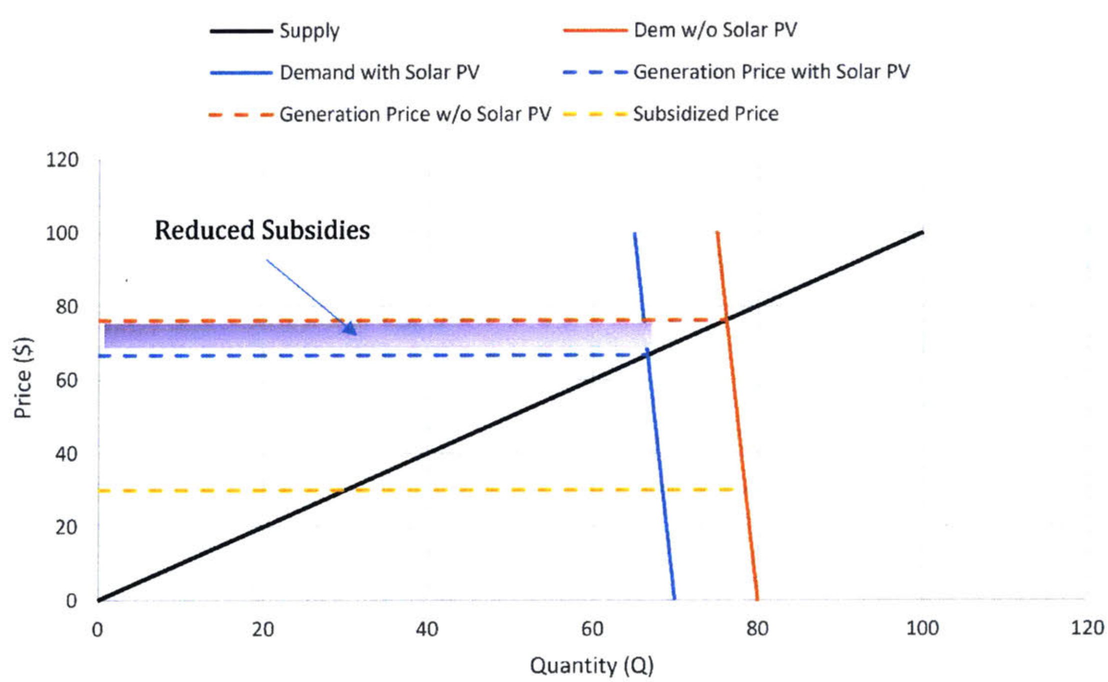


Figure 4.12 by author.

Recommendation 4 – Modify Electricity Tariff Structures and Net Metering Policy While There is Still Time

To promote the deployment of clean DG, CRE has established NetM policies that favor potential adopters (DOF 2017b); however, equitable valuation of grid-connected clean DG systems is practically impossible under current tariff structures and standard NetM conditions. Owners of these technologies forego the payments of services provided by the distribution and transmission networks (Boero, Backhaus, and Edwards 2016) and – in the case of residential DAC customers – are provided electricity subsidies once they drop down to their corresponding subsidized tariff (CFE 2017).

The current minimal integration of DG into the Mexican grid means that DG has negligible economic and technical impact on the electricity network.[84] As seen in Section 3.2.1, CRE has determined that the impact on the grid prior will be negligible until a 5% integration of DG is achieved. Figure 4.13 shows how CRE's and SENER's projections target a 5% integration of DG by 2023 (CRE 2017a, SENER 2015a). Should current tariff structures and NetM policies endure by this point, the electricity system is bound to incur added costs, directly in conflict with the 2013 Energy Reform's mission to lower electricity generation costs and reduce subsidies.[85]

R 4.1 – Importance and Benefits of Modifying Net-Metering Policies and Tariff Structures

The Mexican electricity sector's effort to comply with national electricity generation and GHG emission reduction goals could be burdened with the same negative side effects that have afflicted other electricity markets with aggressive deployment of intermittent DG technologies under current tariff structure and standard NetM policies (Nikolaidis and Charalambous 2017; Darghouth, Barbose, and Wiser 2011). In order to avoid further distorting existing electricity tariffs and increase revenue for CFE, CRE must restructure electricity tariffs in the following way:

1. Grid-connected clean DG owners must not forego paying for their use of the distribution network (MITEI 2016).
2. Modify the subsidies that currently go to households that install Solar PV systems and drop down from DAC consumption to the corresponding subsidized tariff class.

[84] At the beginning of 2017, DG integration into the grid was ~0.34% (CRE 2017a, SENER 2015a).
[85] Given this timeframe, unlike Recommendations 1 through 3, this Recommendation is designed for longer term.

R 4.1.1 – Adding Distribution Network Costs to Electricity Tariffs

CFE's current domestic electricity tariffs only charge customers for the volume of energy they consume. Electricity bills do not explicitly reflect the cost of transporting electricity from generation to consumption points (CFE 2017); however, flat, volumetric tariffs are not adequate for power systems with increasing integration of clean DG (MITEI 2016). One of the biggest economic virtues of clean DG systems under current policy in Mexico is their 1:1 valuation of energy injected into the grid (DOF 2017b). Grid-connected, intermittent clean DG technologies and are reliant upon the distribution network during the many hours of the day when they do not produce electricity. Current NetM policy excuses clean DG producers from paying their share of the costs of the distribution system when energy is being produced on the premises. Distribution costs are fixed, and do not vary with energy production or consumption. Thus, excusing clean DG customers from paying for their own distribution costs when their units are producing energy has no policy or economic justification (Brown and Bunyan 2014). Owners of clean DG systems must pay for their use of the distribution network.

R 4.1.2 – Modify Subsidies Given to Owners of Clean DG Systems

Wide deployment of clean DG systems leaves electricity utilities and regulators with diminished revenue streams to support and operate the distribution network (Brown and Bunyan 2014). When a DAC electricity customer reduces consumption below its corresponding DAC-threshold[86] with the adoption of a clean DG system, they enter the subsidized tariff bracket, substantially reducing CFE's revenue.[87] Reducing domestic electricity subsidies to households with clean DG sources would increase producer surplus (Figure 4.14). This issue is of high importance to CFE since under current policies and tariff structures CFE is bound to lose its highest paying clients and operate with reduced budget. Though consumer surplus would diminish if my recommendations are implemented, the attractive solar resource in various regions of the country would still make investing in Solar PV modules a viable option for consumers.

[86] Section A.2.2 in Appendix A provides an in-depth look into electricity tariff structures in Mexico.

[87] In the example depicted in Figure 3.8, CFE can lose over 93% of revenue collected from a domestic customer in DAC tariff upon acquisition of a Solar PV system.

R 4.2 – What are the Obstacles to implementing this Recommendation?

Modifying or increasing electricity tariffs and prices is a sensitive issue since it has a substantial impact on the public. Policy-makers will most certainly hesitate to pursue the idea. I suspect that the strongest resistance is likely to come from owners of clean DG systems, private solar energy companies and renewable energy advocacy groups, as these policy modifications will decrease their return on investment. Tariff modifications will directly affect the economic performance of their products.[88]

R 4.3 – How to Overcome these Obstacles

Though it might be unpopular, modifying electricity tariffs as I have suggested would better fit the goals of the 2013 Energy Reform. Continuing Chapter 3's example of the household that consumes 1,001 kWh/month of electricity in Baja California Sur,[89] in Figure 4.15 I demonstrate the financial performance of a 3.5 kW rooftop Solar PV system if the household continues to pay DAC tariffs under current NetM policy.[90] If a DAC household continues to pay DAC tariffs after installing a Solar PV system on their rooftop, the Net Present Value (NPV) and Internal Rate of Return (IRR) of the project diminish significantly.[91] The household would only realize a return on their investment in the middle of the 6th year of operation rather than after the 4th year. While not ideal, the new tariff structure I propose could incentivize prospective customers to pursue more aggressive energy savings rather than moving to their corresponding subsidized tariff class. If the same household sought to become a Net Zero energy consumer,[92] for example, the household would still recover its investment in the 6th year of operation but with higher future savings as well as a higher net present value (see Figure 4.16).[93]

While charging DAC tariffs to households that install rooftop Solar PV systems would be a strong disincentive to install clean DG technologies (particularly in a market that already presents high economic barriers to the majority of the population), it is important that establishments with grid-

[88] Demonstration of this in following section.
[89] Example assumes the same conditions: 3.5 kW Solar PV unit in Baja California Sur with an installation cost of USD $3/W and an inflation of 3.5%.
[90] Model assumes an average installation price for a residential Solar PV system of USD $3/W, the 2017 exchange rate found in Figure D.4 in Appendix D, an annual inflation rate of 3.5%, and abides by CRE's Net Metering policies.
[91] In 10 year period, NPV is reduced from MXN ~$306 to ~$108. IRR is reduced from 25.7% to 12.4%
[92] Customer in this example would achieve net zero electricity consumption with a 5.94 kW Solar PV system rather than having a 3.5 kW system.
[93] NPV of MXN ~$180 thousand; IRR of 12.5% in 10 year period.

connected DG systems do not forego paying for distribution network services. CRE should modify electricity tariffs in a way that either explicitly includes distribution network services or implicitly contains distribution network services in the electricity tariff.

As shown in Section A.2.2 in Appendix A, current tariff structures charge DAC households more than the cost of electricity generation. A possibility would be for CRE to remove surplus DAC charges for households with rooftop Solar PV systems, simply charging electricity tariffs that reflect the full cost of electricity generation.[94] CRE should at least consider finding an electricity price that is mid-point between the corresponding subsidized and DAC tariffs.

Along with adjusting tariff structures and NetM policy, CFE Distribution and CENACE will have to prepare for the technical impact on the distribution network that comes with increasing penetration of intermittent clean DG technologies. Electricity utilities in other power markets have mitigated the impact of high integration of intermittent distributed energy resources with updates and reinforcement of substations, transformers, and power lines as well as installing transformers that are capable of managing reverse flows (Energiewende 2015). Load tap changers, voltage regulators, capacitor banks, grid-tied sensors, and smart meters are becoming commonly used tools for electromechanically changing voltages at the substation and feeder levels (John 2015a). As these devices become more automated and networked, they are getting more useful for solving challenges that come with increased integration of clean DG technologies in the grid.

CRE and other stakeholders in the electricity industry in Mexico have determined that DG technologies will have negligible economic and technical impact on the electricity network prior to reaching 5% integration. I suspect policy makers will hesitate to alter current tariff structures and NetM prior to reaching the established 5% DG penetration threshold. The prospective administration is better suited to address tariff structures and NetM policy. Nonetheless, it is imperative that policy-makers, particularly CRE, be ready with the tariff scheme they will implement upon obtainment of 5% integration of DG technologies onto the electricity grid.

[94] Since electricity generation cost data was not available during the development of this thesis, I did not elaborate a model to demonstrate the IRR and NPV of a household that installs a Solar PV system under this tariff structure.

Figure 4.13 - Expected Integration of DG into SEN

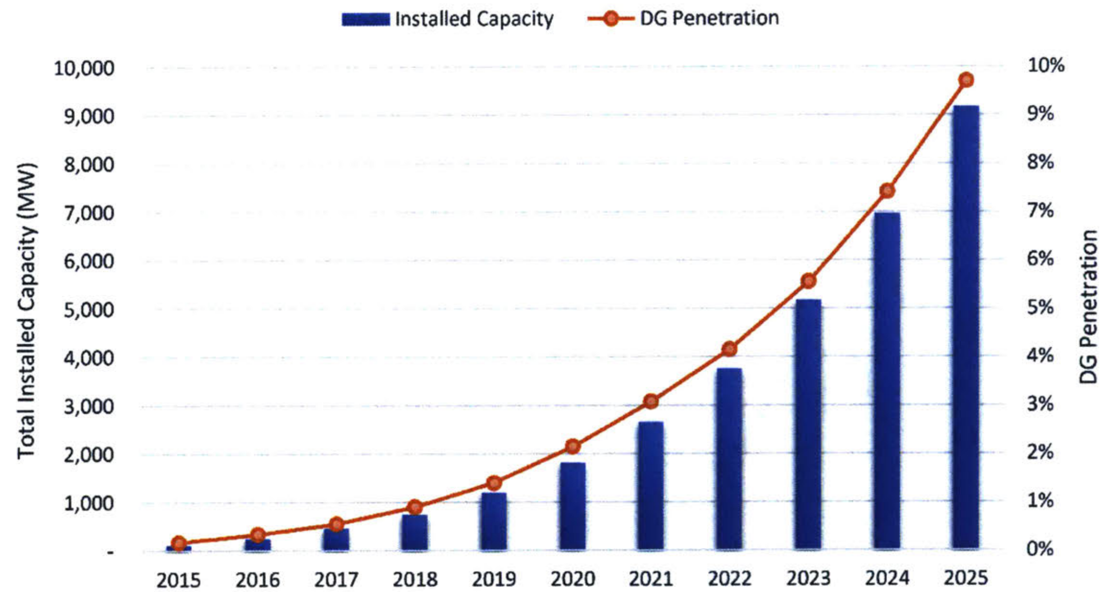


Figure 4.13 source: CRE 2017a; SENER 2015a. Figure by author.

Figure 4.14 - Producer Surplus under Proposed Tariff Structure

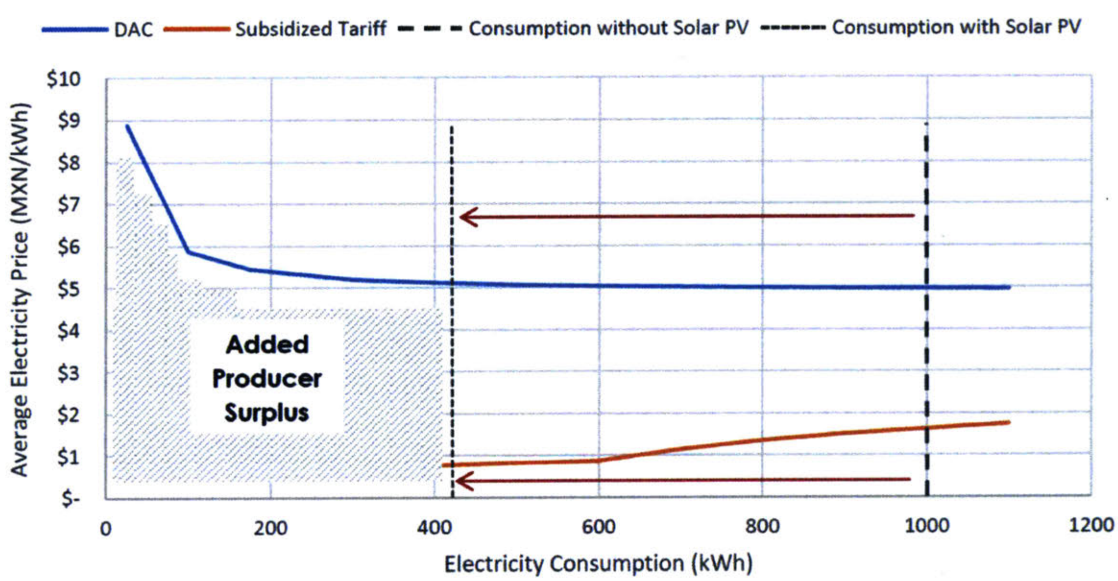


Figure 4.14 by author.

Figure 4.15 - Cash flow of Customer in BCS under Proposed Tariff Structure

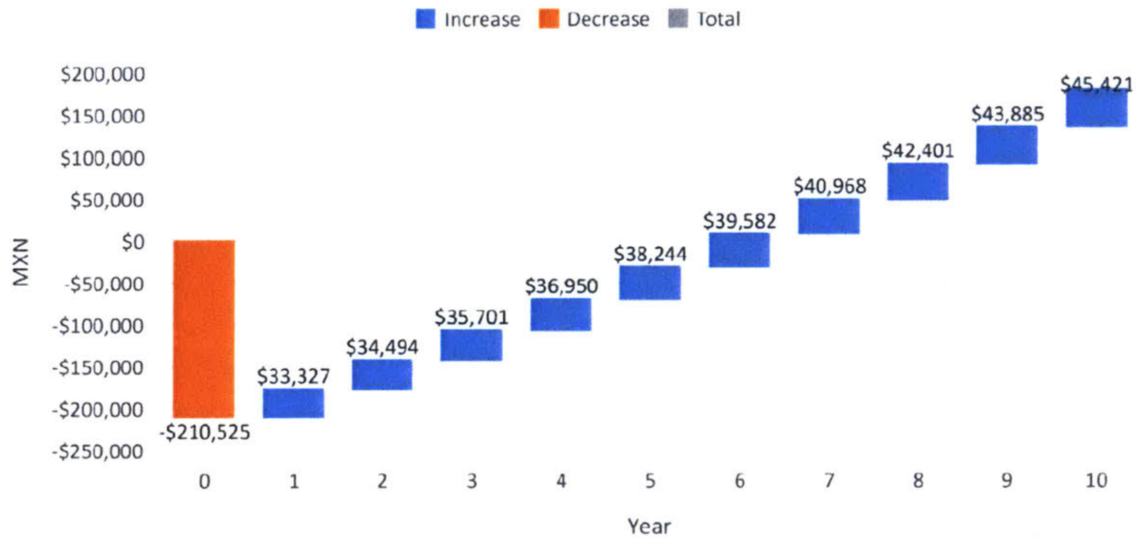


Figure 4.15 and results by author.

Figure 4.16 - Cash Flow of Customer in BCS with 5.94 kW System

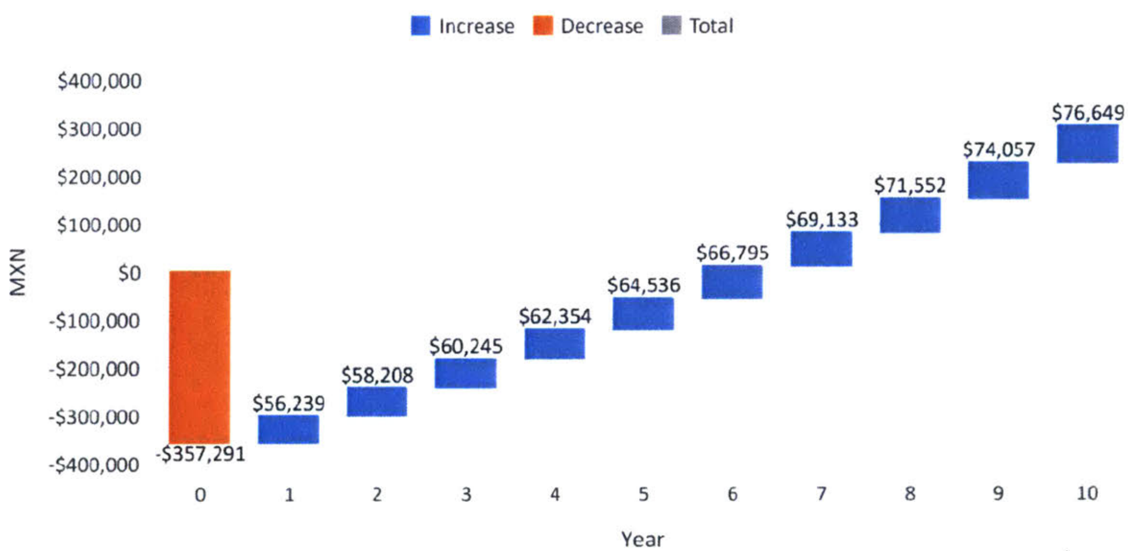


Figure 4.16 and results by author.

Recommendations Conclusion

The 2013 Energy Reform brought drastic policy and market operation changes for the electricity sector in Mexico. Policy makers in SENER and CRE continue to implement regulation on a rapidly changing sector. Policy will hardly be altered for the remainder of the presidential term. Nonetheless, distributed energy resources are becoming more prevalent in power markets across the world. I expect policy makers in SENER and CRE to be hesitant to modify current electricity market structure in Mexico; however, distributed energy resources like clean DG can provide services that centralized power systems fail to deliver, helping meet the State's electricity generation and GHG emission reduction goals through the series of recommendations I have developed in this thesis. Through the development of the pilot programs recommended in this thesis, SENER and CRE may be able to manage and deploy clean DG technologies in Mexico in a manner that avoids the negative technical and economic implications that other electricity markets have experienced and maximize its aggregate system value.

Appendix A – Overview of the Mexican Electricity Sector

A.1 – Development

A.1.1 – History

Electricity came to Mexico in the late 19th century. The first efforts to organize the Mexican electricity industry came in the early 20th century with the creation of the National Commission for the Promotion and Control of the Power and Generation Industry. The Mexican electricity industry developed under a model of open competition that enabled the country's industrialization. In 1930, 70% of the country's installed electricity capacity belonged to privately owned foreign companies that operated throughout different regions of the country (CFE 2014a, Ortega Lomelín 2016).

In the early 1930's, Mexico had 18.3 million inhabitants of which only 7 million had electricity. The private companies that provided electricity had serious operational difficulties. Interruptions were constant and prices were high. Companies targeted the more profitable urban markets, disregarding the rural population that constituted ~65% of the nation. In 1933, the federal government decreed that the generation and distribution of electricity would be public utility activities and, on August 14, 1937, the Federal Electricity Commission (CFE) was created to organize and manage a national system of electricity generation, transmission, and distribution across the country (CFE 2014a, Ortega Lomelín 2016).

In 1960, when private parties were responsible for just under 50% of the country's electricity generation, the government nationalized the electricity industry with the intent to ambitiously expand coverage throughout the country and interconnect the separate electric grids that existed throughout different regions. In 1976, the National Electricity System (SEN) became fully interconnected with the exception of the isolated electricity transmission and distribution networks in the states of Baja California and Baja California Sur, an arrangement that continues today (SEN 2017).

CFE became a state-owned, vertically integrated, non-profit monopoly responsible for electricity generation, transmission, distribution, and retail services. The company sought to obtain the highest performance possible that would benefit general interests at minimal cost. Along with CFE, a second company, *Luz y Fuerza del Centro*, distributed and had retail electricity services throughout the central region of the country (CFE 2014a, Ortega Lomelín 2016).

Figure A.1 - Development of Mexico's Electricity Grid Destined for Public Services

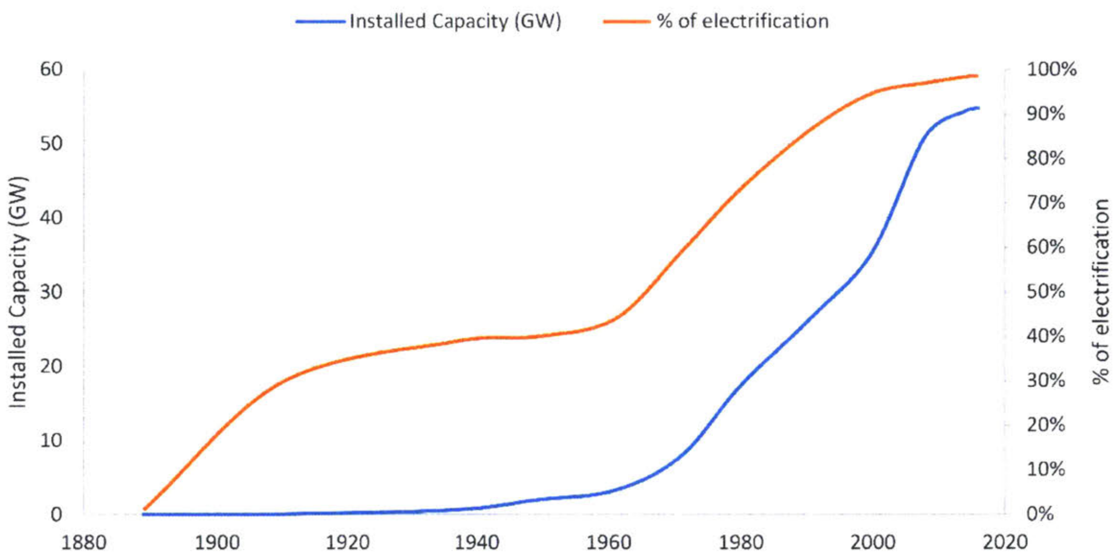


Figure A.1 Source: CFE 2014a. Graph by author.

In the early 1990's, the SEN started to show significant signs of fatigue. Severe operational inefficiencies and high costs of electricity generation stagnated and hindered the country's economic development. On December 1992, the Chamber of Deputies modified the Law of Public Service of Electric Energy to allow the participation of private parties in activities not deemed as *Public Service*, including (GoM 2017):

- Generation of electricity by independent power producers (IPPs) for direct sale to CFE,
- Generation of electricity for self-sufficiency, cogeneration, and small production.

Despite the 1992 reforms that enabled the entry of IPPs and self-sufficiency into the electricity sector, Mexico's electricity industry was still quite inflexible and had difficulties meeting growing demands. CFE had little incentive to improve its performance and inefficient operation. The industry failed to address increasing electricity distribution losses and generation costs. The federal government dissolved *Luz y Fuerza del Centro* in 2009 due to tremendously high recurrent financial operating deficits. CFE presented a financial deficit of USD ~$5.84 billion[95] in 2012 and USD ~$5.9 billion[96] in 2015 (Ortega Lomelín 2016, GoM 2017a, García 2016b).

A.1.2 – Current Operation and Profile

In December 2015, Mexico had an electrical installed capacity of 65.94 GW out of which 54.85 GW (~81.7%) are destined for public services and 12.3 GW (~18.3%) are owned and operated by private parties for self-sufficiency purposes. Out of the installed capacity destined for public services, CFE controlled 41.9 GW (~76.4%), leaving IPPs with 12.95 GW of installed capacity. CFE provides electricity to 99.53% of the urban population and 95.03% of the rural population, for a total national coverage of 98.53% of the population (SENER 2017c, GoM 2017a).

Figure A.2 - Installed Capacity for Public Service in 2015 by Source

Generator	Technology Type	Installed Capacity (MW)	Units	Share
CFE	Hydroelectric	12,027.80	176	21.9%
	Steam (fuel-oil and gas)	11,398.60	72	20.8%
	NGCC	7,578.30	68	13.8%
	Coal	5,378.40	15	9.8%
	Turbo gas	2,736.50	94	5.0%
	Geothermal	873.60	40	1.6%
	Internal Combustion	303.90	56	0.6%
	Wind	86.3	8	0.2%
	Solar PV	6	2	0.01%
	Nuclear	1,510	2	2.8%
	Total CFE	41,899.40	533	76.4%
IPP	NGCC	12,339.90	77	22.5%
	Wind	612.90	410	1.1%
	Total IPP	12,952.80	487	23.6%
	TOTAL	**54,852.20**	**1,020**	**100%**

Figure A.2 source: CFE 2015. Figure by author.

Mexico relies heavily on fossil fuels to generate its electricity. Figure A.3 and Figure A.4 show the country's breakdown of total electricity generation by source from the year 2000 to 2015. "Renewables" includes geothermal, biomass, wind, and solar energy installations (IEA 2017, GoM 2017a, SENER 2017c):

95 CFE's 2012 losses were MXN $77 billion (GoM 2017a).

96 CFE's 2015 losses MXN $93.9 billion (García 2016b).

Figure A.3 - Electricity Generation in Mexico by Source

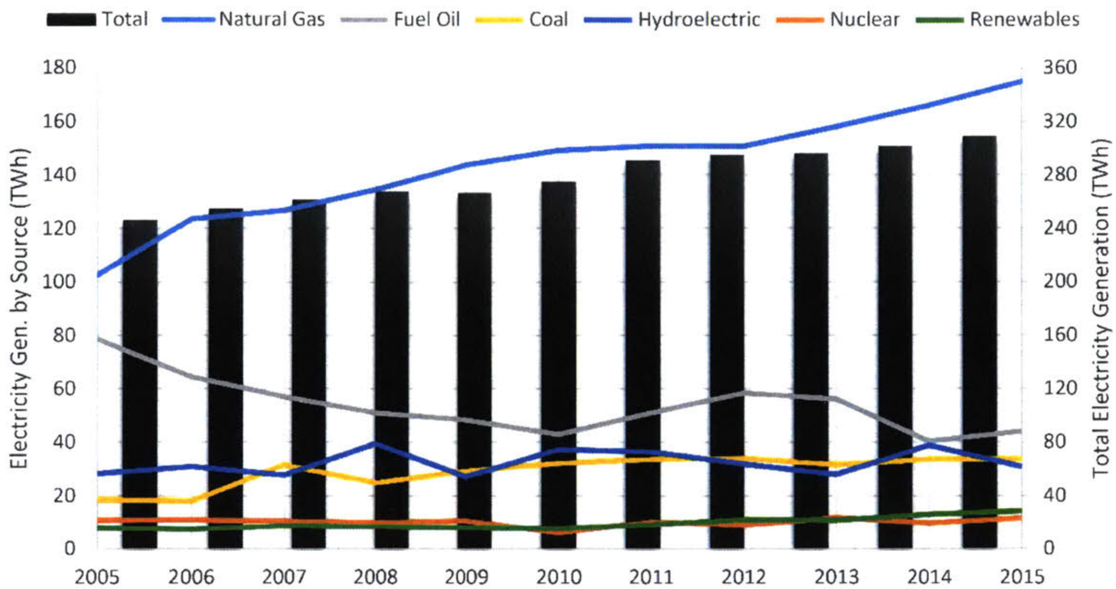
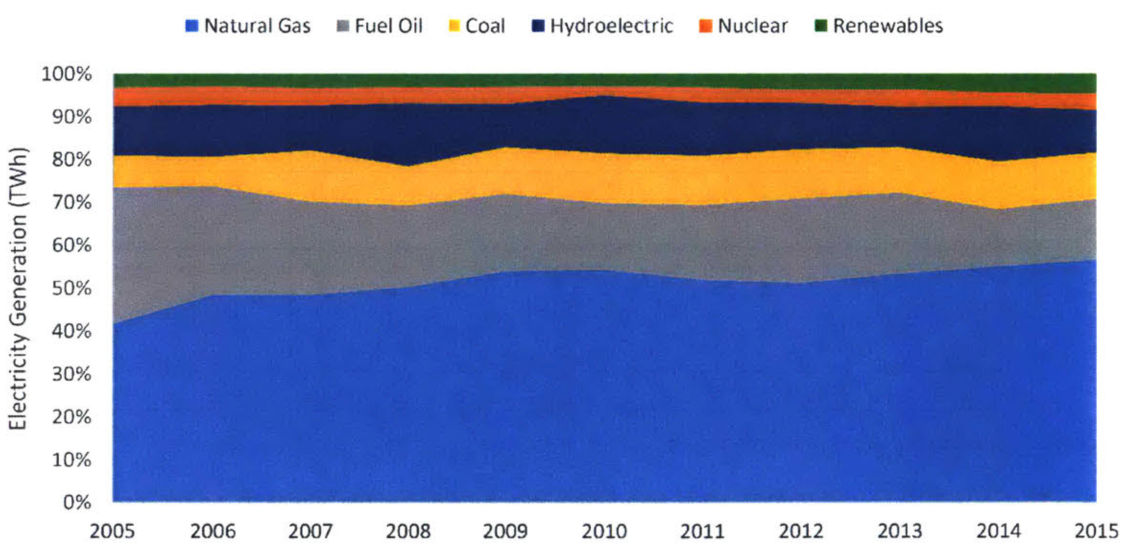


Figure A.4 - Share of Electricity Generation in Mexico by Source



Figures A.3 & A.4 sources: IEA 2017; SENER 2017a; SENER 2015a; GoM 2017a. Figures by author.

Figures A.3 and A.4 show how fossil fuels generated ~80% of the Mexico's electricity in 2015. The country has significantly increased its dependency on natural gas in order to phase-out the use of fuel oil to generate electricity. In 2015, CFE generated ~164.5 TWh of electricity (~54.6%), IPPs generated ~88.8 TWh (~29.5%), and private parties generated ~47.9 TWh (~15.9%) of electricity for self-sufficiency. Around 90% of the electricity generated by private parties came from Natural Gas (GoM 2017a; CFE 2015).

Figure A.5 - Public Service Electricity Generation in 2015 by Source

Generator	Technology Type	Generation (GWh)	Share
CFE	Hydroelectric	29,772.6	11.8%
	NGCC	46,275.1	18.3%
	Coal	31,188.1	12.3%
	Wind	202.0	0.1%
	Solar PV	12.5	0.0%
	Geothermal	5,862.1	2.3%
	Internal Combustion	1,646.6	0.7%
	Turbo gas	4,911.9	1.9%
	Steam (fuel-oil and gas)	33,017.2	13.0%
	Nuclear	11,176.5	4.4%
	Other	401.3	0.2%
Total CFE		164,465.9	64.9%
Independent Producers	NGCC	86,653.2	34.2%
	Wind	2,128.0	0.8%
Total Ind. Prod.		88,781.2	35.1%
TOTAL		**253,247.1**	**100%**

Figure A.5 source: CFE 2015. Figure by author.

Figure A.6 - Share of Public Service Electricity Generation in 2015

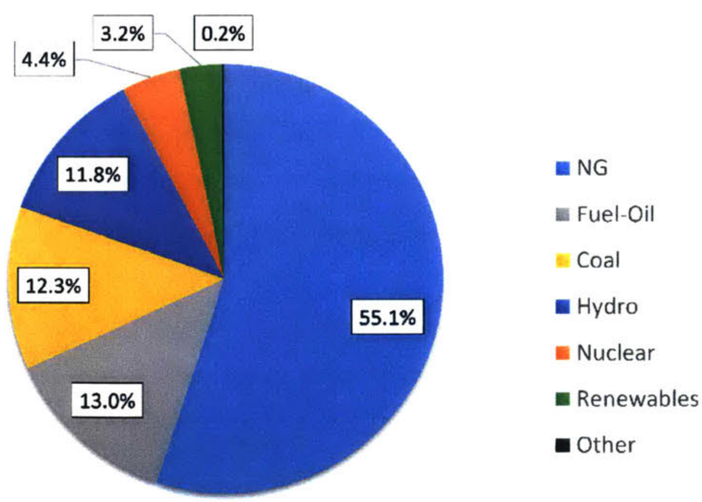


Figure A.6 source: CFE 2015. Figure by author.

A.1.3 – Prospective Development of Mexico's Electricity Industry

Mexico intends to lower electricity tariffs and achieve the established clean energy generation and GHG emission reduction targets through the creation of a competitive electricity generation market and the reduction of energy losses. Furthermore, the country's strategy includes the replacement of fuel oil with natural gas as a fuel source, the expansion of natural gas production and transportation networks, and the modernization and expansion of the electricity transmission and distribution network.

CFE reports that around ~80% of electricity prices in Mexico are tied to fuel costs (CFE 2015). The production of electricity using fuel oil is partially responsible for high electricity prices. Prior to the Energy Reform, CFE's parastatal status obligated the company to generate electricity using fuel oil provided by PEMEX. As seen in Figures A.4 and A.6, though decreasing in recent years, 13% of Mexico's 2015 electricity destined for public service was generated using fuel oil.

In its Development Program of the SEN, SENER plans to expand the transmission network 24,194 kilometers, requiring an investment of USD ~$6.9 billion[97] between 2015 and 2024. Furthermore, the SENER projected an investment of USD ~$5.6 billion[98] for the extension and modernization of distribution networks between 2015 and 2019 (SENER 2017e).

SENER has approved twelve natural gas pipeline projects that will expand the country's network by 5,159kms by 2029. The projects require an estimated investment of USD $9.74 billion (SENER 2017e). SENER expects total natural gas demand to grow by 20.3% from 2015 to 2030, equivalent to a 1.2% annual increase. In 2015, natural gas imports constituted around 46% of the country's consumption. SENER forecasts imports to supply over 61% of the country's total consumption in the early 2020's (SENER 2015a).

[97] Estimated investment of MXN $138.054 billion (SENER 2017e).
[98] Estimated investment of MXN $111.945 billion (SENER 2017e).

Figure A.7 - Forecasted Natural Gas Demand

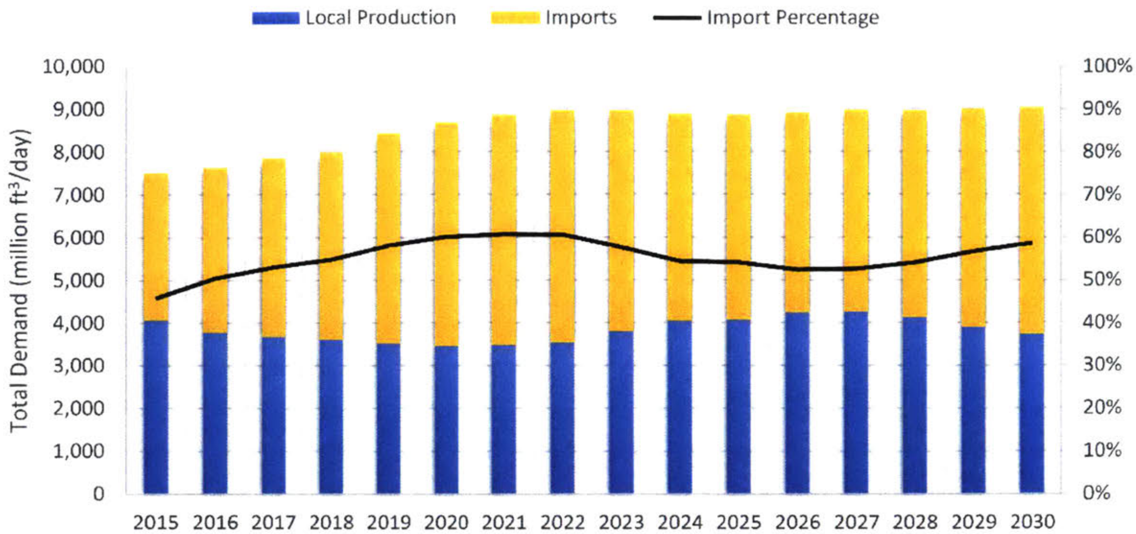


Figure A.7 source: SENER 2015a. Figure by author.

While renewable energies are expected to play a major role in the production of electricity in coming years, projections expect natural gas to continue being the main source of electricity generation, responsible for over half of the country's electricity production (IEA 2016; GoM 2017a; SENER 2017a).

Figure A.8 - Projection of Electricity Production Profile in Mexico

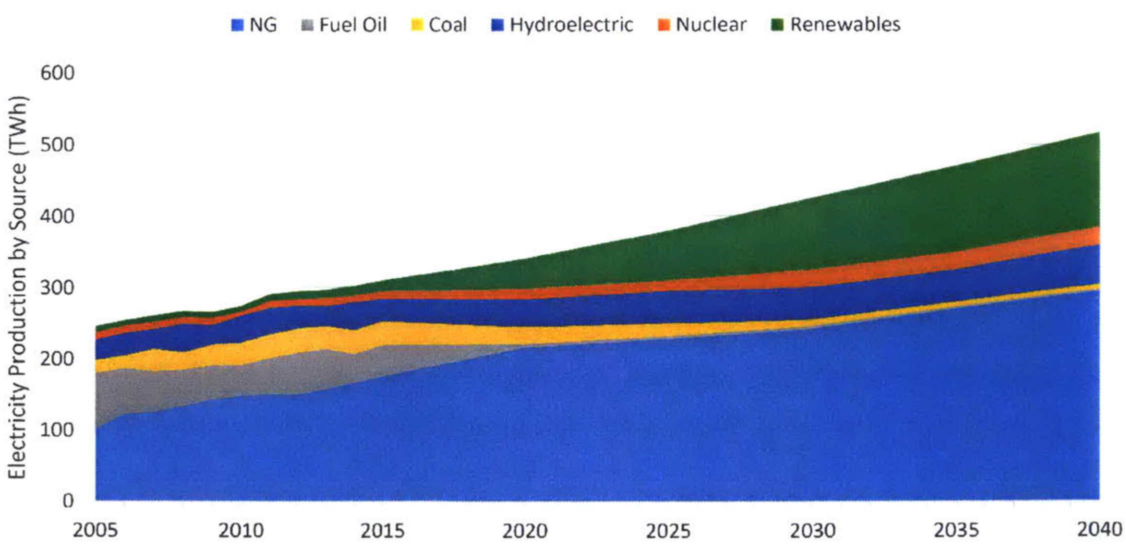


Figure A.8 sources: IEA 2016; GoM 2017a; SENER 2017ª. Figure by author

Figure A.9 - Expected Electricity Generation Profile 2015 - 2040

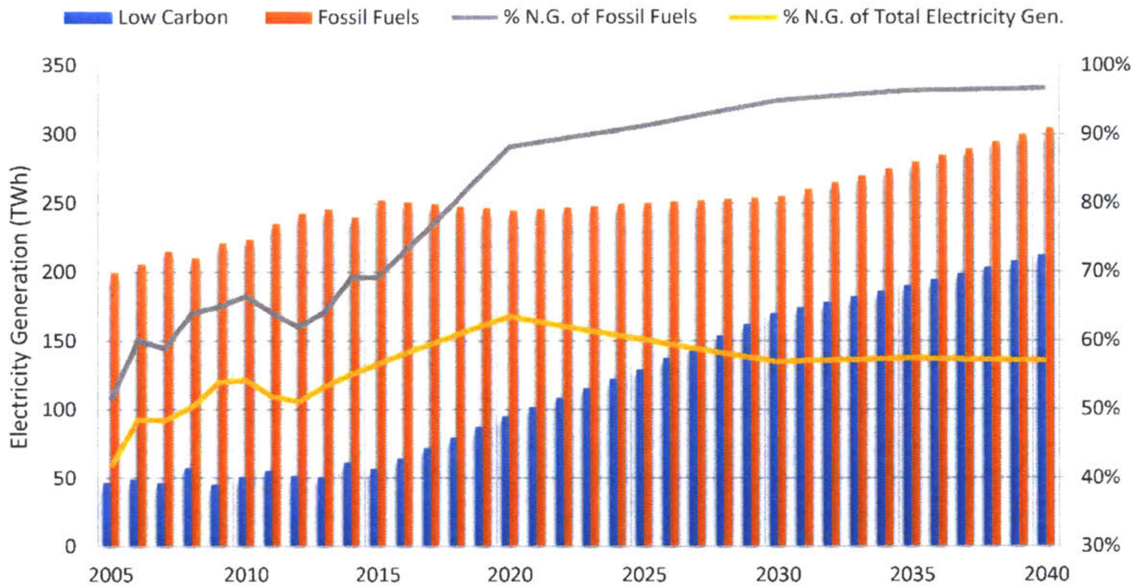


Figure A.9 source: IEA 2016; GoM 2017a. Figure by author

A.2 – Statistics

A.2.1 – Energy Losses

In 2012, Mexico reported having 16% network losses worth ~USD $3.95 billion.[99] This is almost three times higher than the 2012 average OECD country network loss of 6%, with some countries like South Korea having distribution electricity losses as low as 3%. Electricity losses in Mexico were reduced to 15% in 2013, 14% in 2014 (equivalent to 37.2 million MWh), and 13.1% in 2015 (worth USD ~$2.66 billion in 2015)[100] (CFE 2014, CFE 2015).

The Mexican electricity network suffers equally from technical and non-technical losses. Non-technical losses refers mostly to electricity theft. In 2015, around 52% of the country's electricity losses were due to non-technical losses. Electricity losses are distributed unevenly among the country's states and tend to occur in areas with low incomes and higher crime rates (García 2016b).

[99] 2012 electricity losses were worth MXN $52 million (CFE 2015). Average exchange rate in 2012 was MXN $13.17 for USD $1 (Banco de México 2017b).

[100] 2015 electricity losses were worth MXN $42,246 million. Average exchange rate in 2015 was MXN $15.88 for USD $1 (Banco de México 2017b).

Figure A.10 - 2015 Energy Losses by State

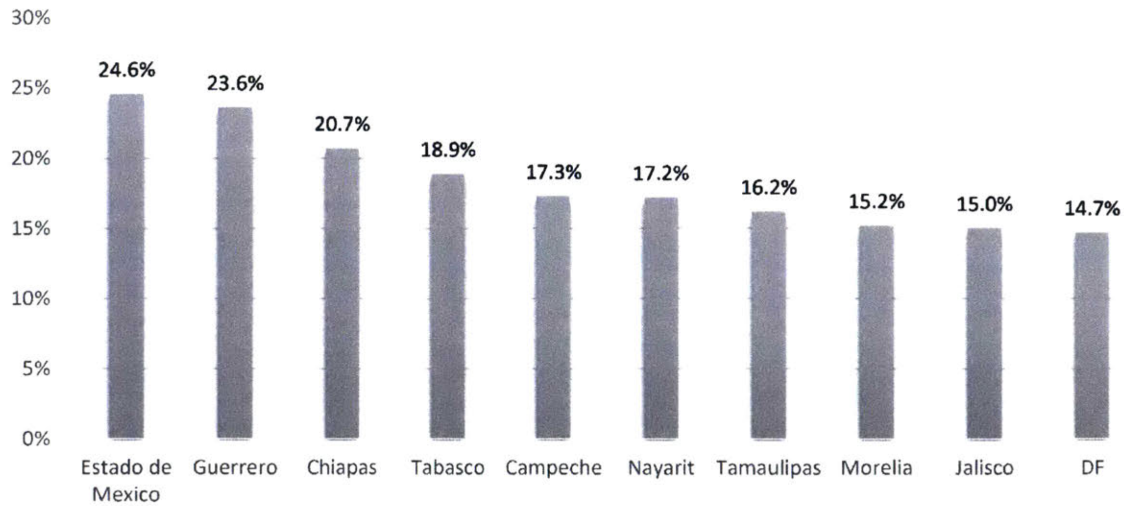


Figure A.10 source: García 2016b. Figure by author.

Electricity losses within the greater Mexico City metropolitan area are disproportionately higher than in the rest of the country.

Figure A.11 - Distributed Network Energy Losses outside Mexico City

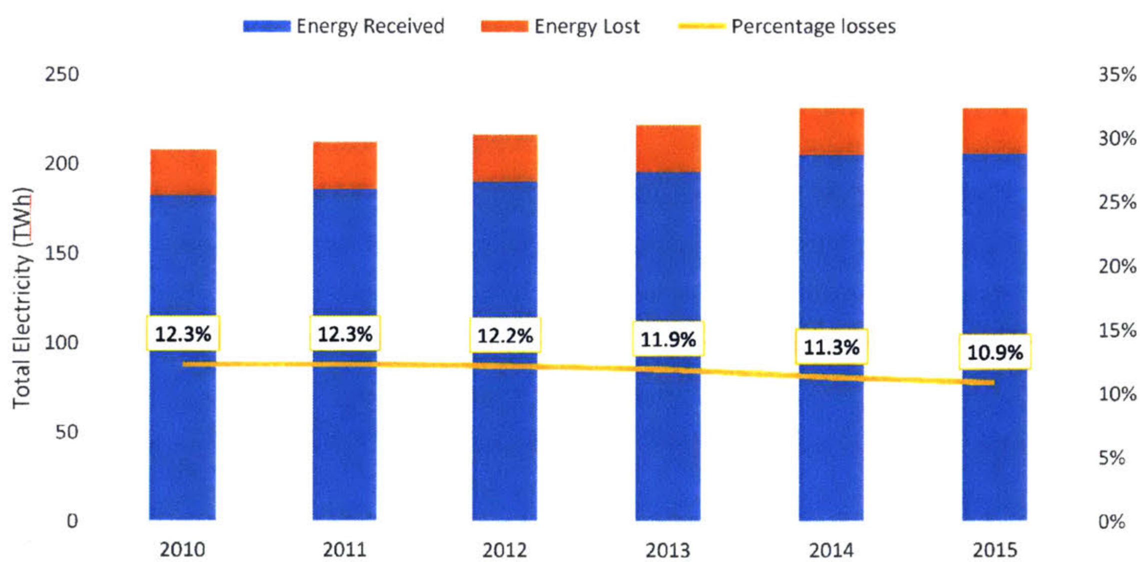


Figure A.11 source: SENER 2016b. Figure by author.

Figure A.12 - Distribution Network Losses in Metropolitan Mexico City

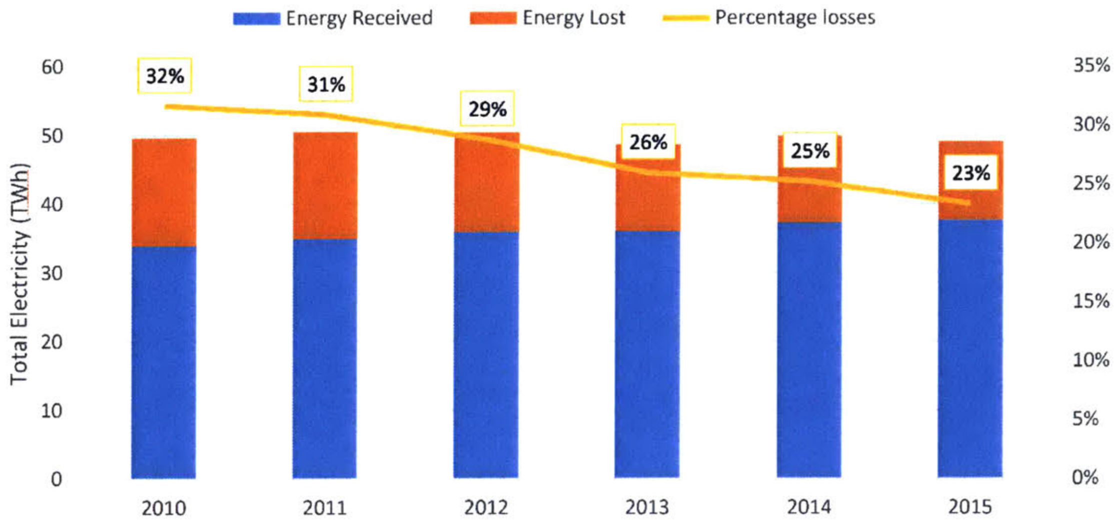


Figure A.12 source: SENER 2016b. Figure by author.

Including losses from billing and collection process, in 2015, ~21% of the energy produced by the CFE was not charged. CFE's goal is to reduce energy losses to between 10% and 11% by 2018 (CFE 2014, CFE 2015).

A.2.2 – Electricity Tariffs, Subsidies, and Customers

Though CFE incurs high operational losses, Mexico offers the lowest residential electricity prices out of all OECD nations. In 2016, Mexico's average residential and industrial electricity prices were USD $75.30/MWh and USD $81.70/MWh respectively (IEA 2016b); however, the average price of industrial electricity in Mexico is higher than the average price of industrial electricity in the United States, an important competitive disadvantage for economic development. In the same year, the USA's average residential and industrial electricity prices were USD $126.70/MWh and USD $69.00/MWh respectively. Mexico has the highest industrial electricity prices in North American (Canada's industrial electricity price in 2016 was $75.70/MWh) and is the only OECD nation that has higher industrial electricity prices than residential electricity prices (IEA 2016b).[101]

[101] Full data for Australia, Italy, Korea, New Zealand, and Spain was not available.

Figure A.13 – 2016 Electricity Prices in OECD Countries

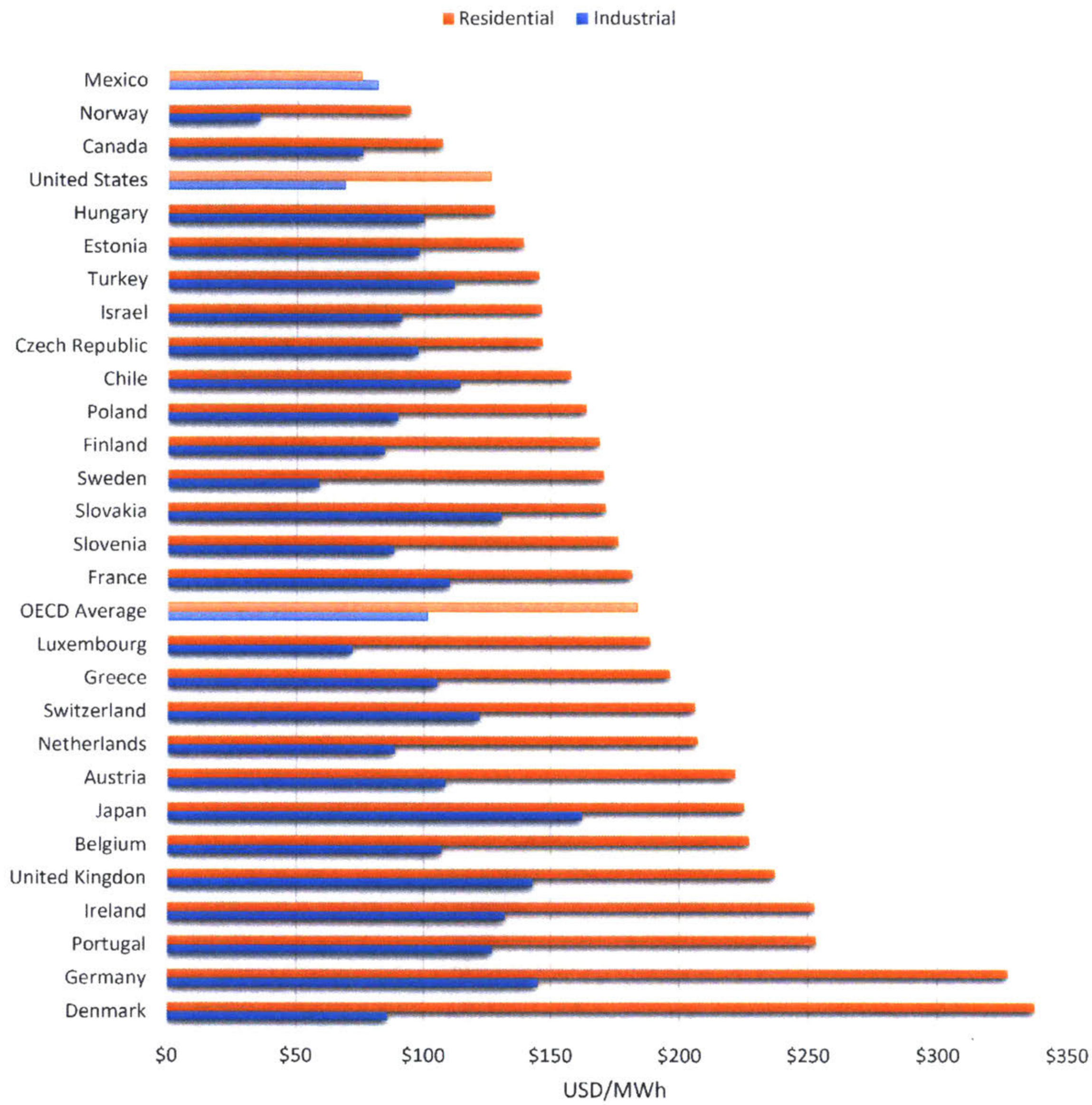


Figure A.13 source: IEA 2016b. Figure by author.

One of the principal reasons behind Mexico's low residential electricity prices compared to other OECD nations is the large subsidies in place. Electricity subsidies have increased at an average annual rate of 6.2% since the year 2000. CFE's total electricity subsidy increased at an average annual rate of 9.1% from 2000 to 2014. Subsidies peaked in the 2008 with a total electricity subsidy of ~USD $13.3 billion (GoM 2017a).

Figure A.14 - Electricity Subsidy in Mexico

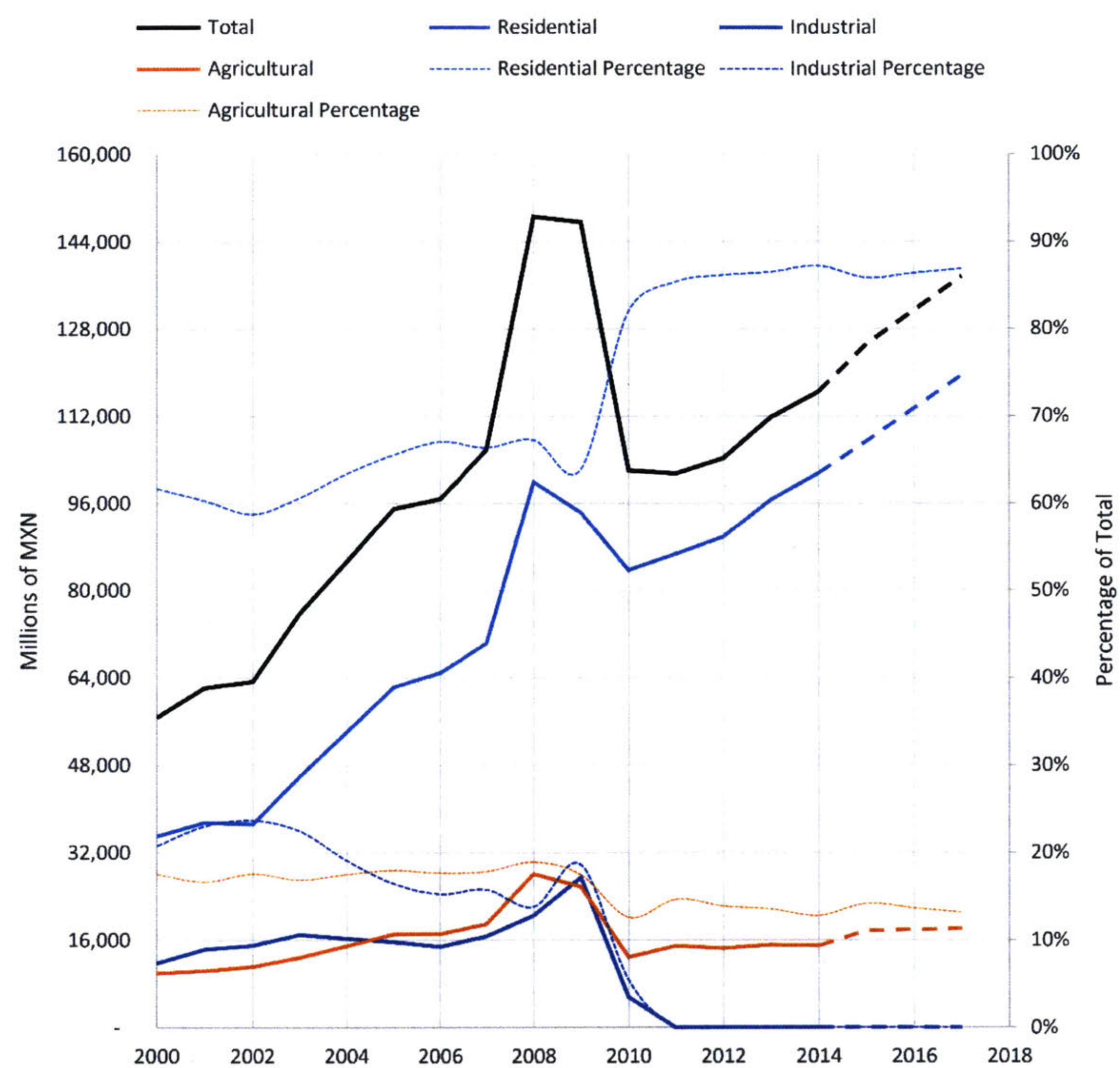


Figure A.14 source: GoM 2017a. Figure by author.

CFE divides its client pool into 5 different categories: (1) domestic, (2) commercial, (3) services, (4) agriculture, and (5) industrial. At the beginning of 2017, CFE had 40.76 million customers, with close to 88.6% of these being domestic customers and ~9.8% being commercial customers.[102] Nonetheless, the residential and commercial sectors consumed around 33.8% of CFE's energy and paid 36.9% of CFE's sales in 2016 (SENER 2017b).

[102] 98.4% of CFE customers are either domestic or commercial clients (SENER 2017b).

Figure A.15 - 2016 CFE Clients up to December 31, 2016

	Users	Energy (TWh)	Sales (Billions MXN)	Average Bill (MXN/user)
Domestic	36,113,943	58.4	68.5	1,897
Commercial	3,988,320	15.3	43.9	11,007
Services	209,387	8.6	23.1	110,332
Agriculture	128,565	11.3	6.6	51,336
Industrial	325,958	124.4	163.0	500,064
Total	**40,766,173**	**218.1**	**305.2**	**7,487**

Figure A.15 source: SENER 2017b. Figure by author.

Figure A.16 - 2016 CFE Clients up to December 31, 2016

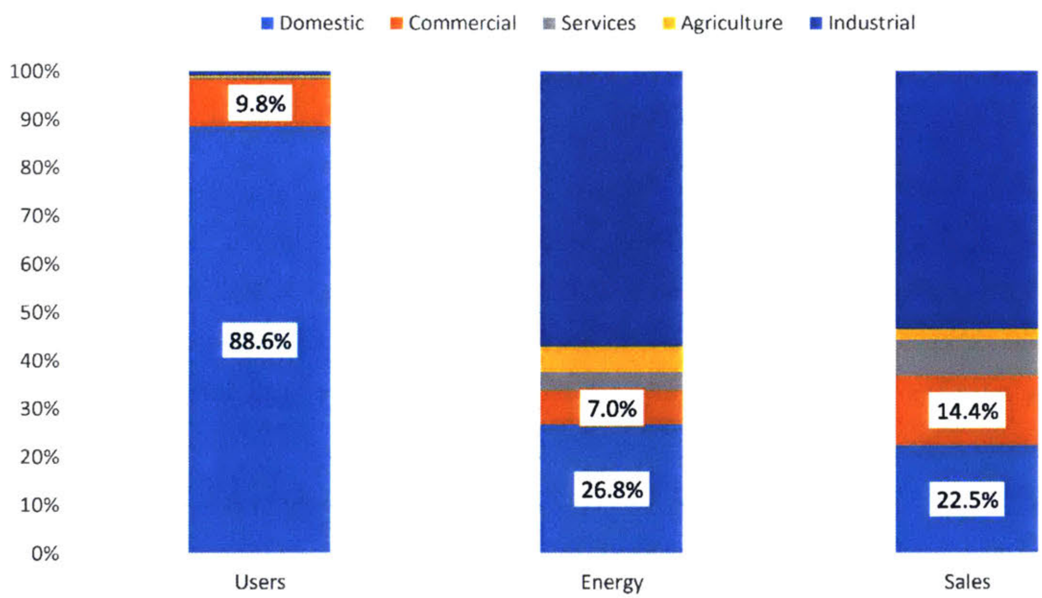


Figure A.16 source: SENER 2017b. Figure by author.

Figure A.17 - Evolution of Electricity Prices by Sector

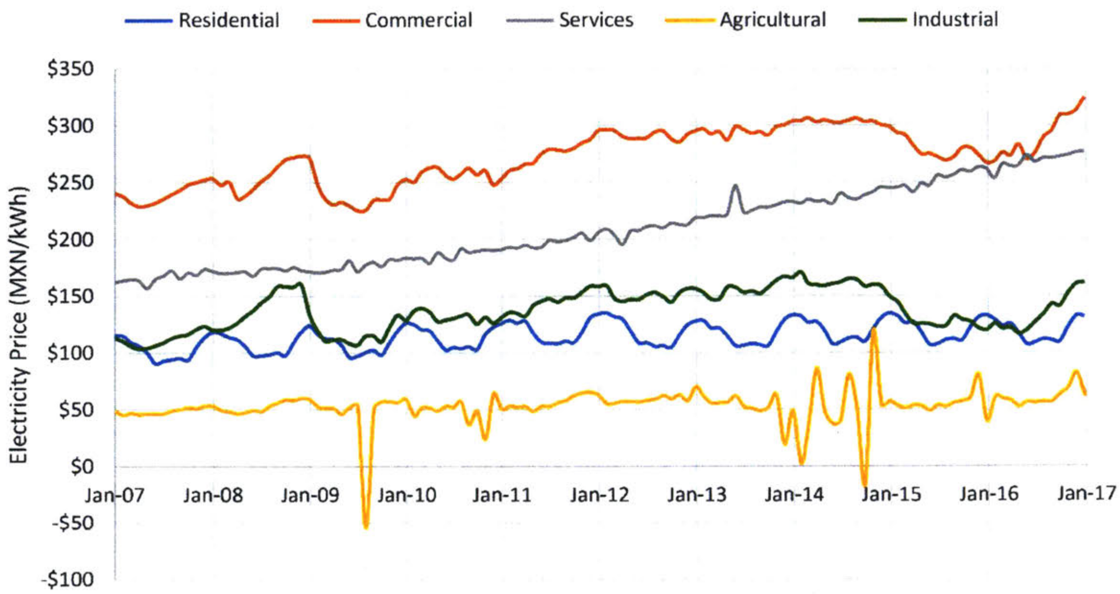


Figure A.17 source: SENER 2017b. Figure by author.

A.2.2.1 – Domestic Tariffs

CFE's domestic electricity prices rise as consumption increases; however, the vast majority of CFE's residential customers receive electricity subsidies. In the beginning of 2017, out of CFE's 36.1 million residential customers, only ~1.2% (434,193 customers) did not receive electricity subsidies. In some cases, subsidies cover up to 90% of a residential customer's electricity bill (Quintana 2014, SENER 2017b).

Tariffs across the country vary depending on the average monthly temperatures recorded during the six hottest months of the year.[103] Every tariff class has two structures: one for the six hottest months of the year (summertime) and another for the remaining six months (non-summertime). Domestic electricity subsidies are substantially higher in the summertime and are larger in regions with higher average monthly temperatures.[104] Customers with a 12-month average consumption that exceeds a determined threshold are placed in the unsubsidized tariff called "DAC Tariff" (meaning 'Domestic High Consumption') (CFE 2017).

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[103] Residential electricity tariffs are determined by the average monthly temperatures recorded in two or more consecutive months in three of the most recent five years (CFE 2017).

[104] The hotter the region, the larger electricity subsidies given to domestic customers.

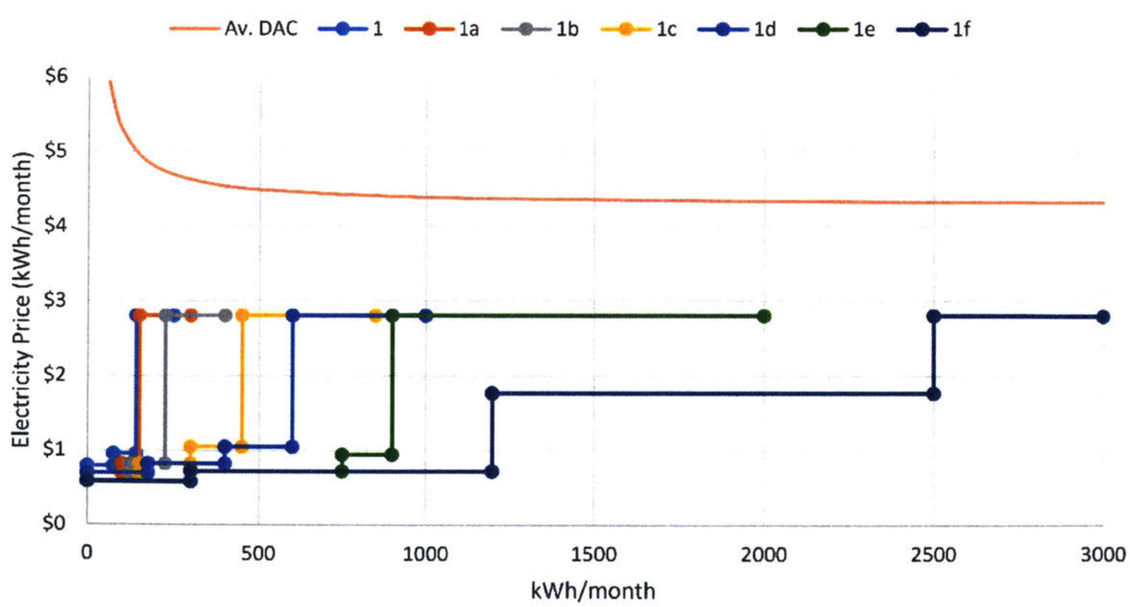
Subsidized tariffs are fixed throughout a calendar year and only charge for energy consumption. Meanwhile, DAC tariffs fluctuate on a monthly basis and charge a fixed price and a uniform price for energy consumption. DAC tariffs charge the full amount of electricity generation costs plus an added amount, making them significantly more costly than subsidized tariffs. DAC customers are placed in their corresponding subsidized tariff when their 12-month average consumption drops below the DAC threshold (CFE 2017).[105]

Figure A.18 - Domestic Tariffs by Temperature

Tariff Class	Minimum average monthly temperature (C°)	DAC Tariff Threshold (kWh/month)
1		250
1A	25	300
1B	28	400
1C	30	850
1D	31	1,000
1E	32	2,000
1F	33	2,500

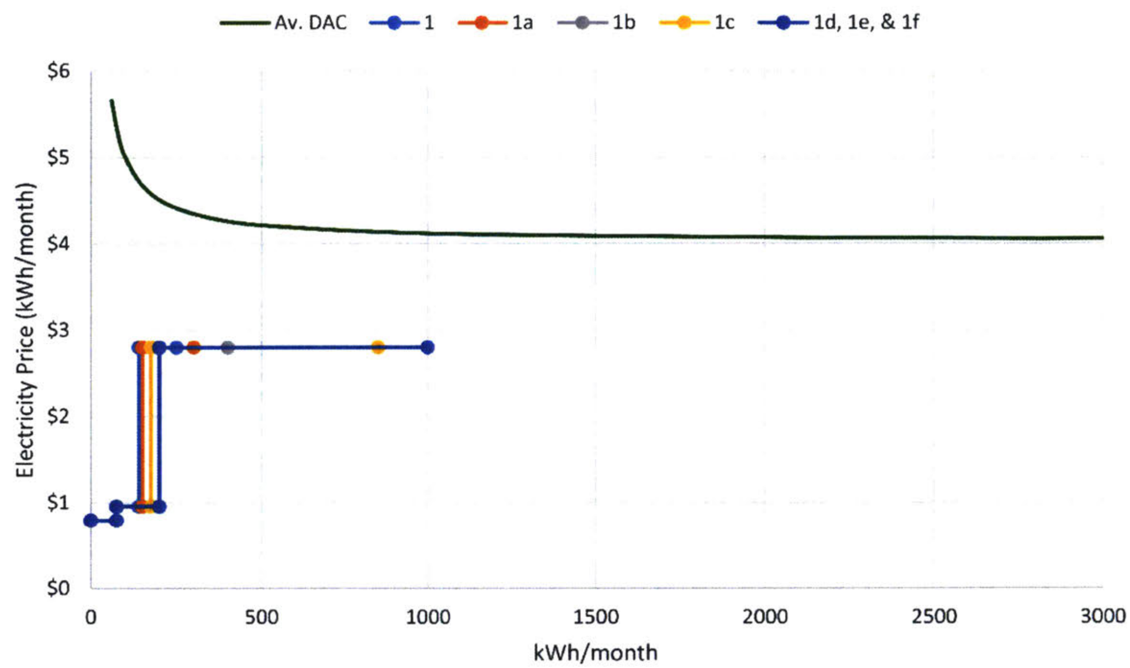
Figure A.18 source: CFE 2017. Figure by author.

Figure A.19 - 2017 Domestic Summertime Electricity Prices by Tariffs



[105] Average DAC prices in Figures A.19 and A.20 are calculated using data from January through April of 2017.

Figure A.20 - 2017 Domestic Non-Summertime Electricity Prices by Tariffs



Figures A.19 & A.20 source: CFE 2017. Figures and calculations by author.

While DAC users are the smallest tier with only ~1.2% of domestic customers, they consume around 4.4% and pay for almost 13% of all domestic electricity (SENER 2017c).

Figure A.21 - 2016 Domestic Tariff Classes

	Users	Energy (TWh)	Sales (Billions MXN)
1	19,530,464	20.09	21.48
1A	2,459,115	2.86	3.00
1B	4,003,516	5.97	6.36
1C	5,600,664	13.05	15.18
1D	1,159,594	3.17	3.65
1E	1,176,389	4.03	3.89
1F	1,292,000	6.64	6.21
DAC	434,193	2.55	8.78

Figure A.21 source: SENER 2017b. Figure by author.

Figure A.22 - 2016 Domestic Tariff Classes

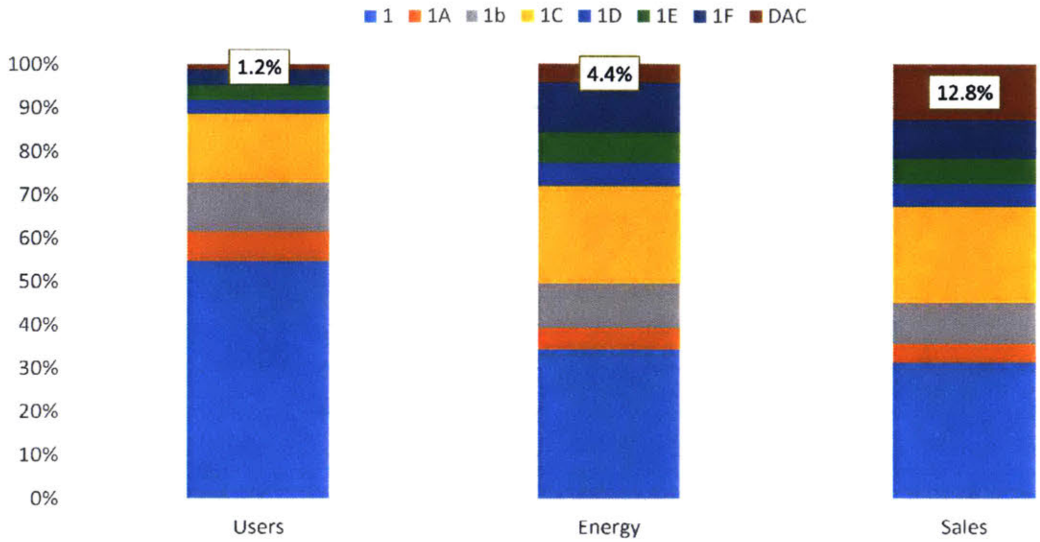


Figure A.22 source: SENER 2017b. Figure by author.

DAC customers pay significantly larger prices for electricity than customers in subsidized tariffs throughout the entire year. In 2016, the average DAC customer consumed 0.47 standard deviations more electricity per month than customers in subsidized tariffs but paid 2.43 standard deviations more for electricity per month than customers with subsidized tariffs (SENER 2017b).

Figure A.23 - 2016 Av. Monthly Consumption by Domestic Tariff Class

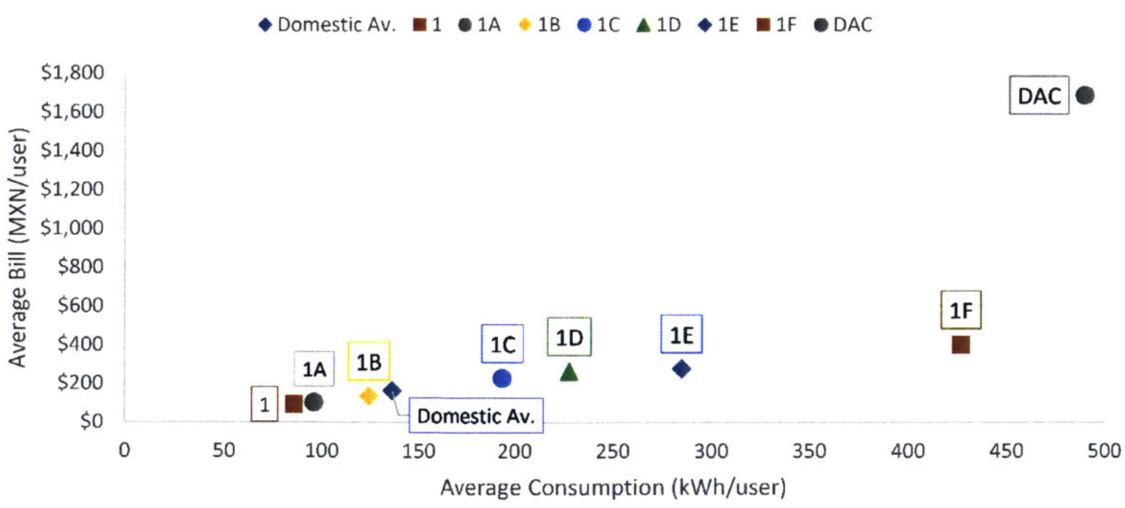


Figure A.23 source: SENER 2017b. Figure by author.

Figure A.24 illustrates CFE's domestic electricity tariff classes across Mexico in 2013. The northwest and northeast regions of the country receive the largest residential subsidies.

Figure A.24 - 2013 Domestic Electricity Tariff Classes in Mexico

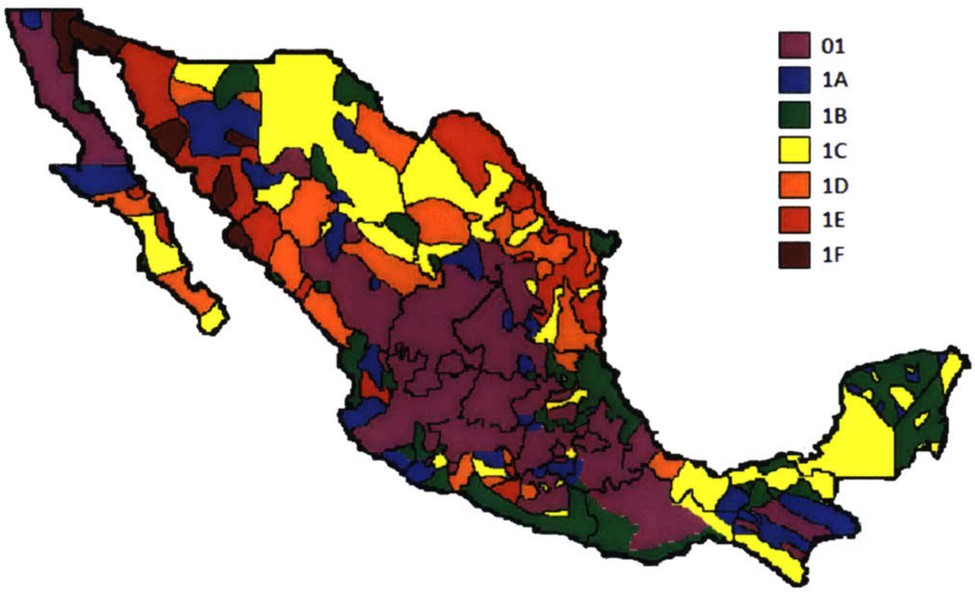


Figure A.24 source: "GoM 2014a."

The National Meteorology Service (SMN) has reported record high temperatures throughout the country in recent years (SMN 2017). With rising temperatures, various regions may currently be under tariffs that grant higher subsidies to domestic customers than illustrated tariffs in Figure A.24.

A.2.2.2 – Commercial Tariffs

CFE has two types of commercial tariffs: Tariff 2 (demand less than 25 kW) and Tariff 3 (demand of more than 25 kW). Around 99% of CFE's commercial customers are under the Tariff 2 structure; however, since Tariff 3 users consume significantly more electricity than Tariff 2 customers do; around 9% of CFE's income from commercial customers corresponds to Tariff 3 customers (SENER 2017b). Similar to DAC tariffs, commercial tariffs are unsubsidized.

Figure A.25 - 2016 Commercial Tariff Classes

	Users	Energy (TWh)	Sales (Billions MXN)
2	3,919,918	13.75	40.01
3	20,313	1.57	3.81

Figure A.25 source: SENER 2017b. Figure by author.

Figure A.26 - 2016 Commercial Tariff Classes

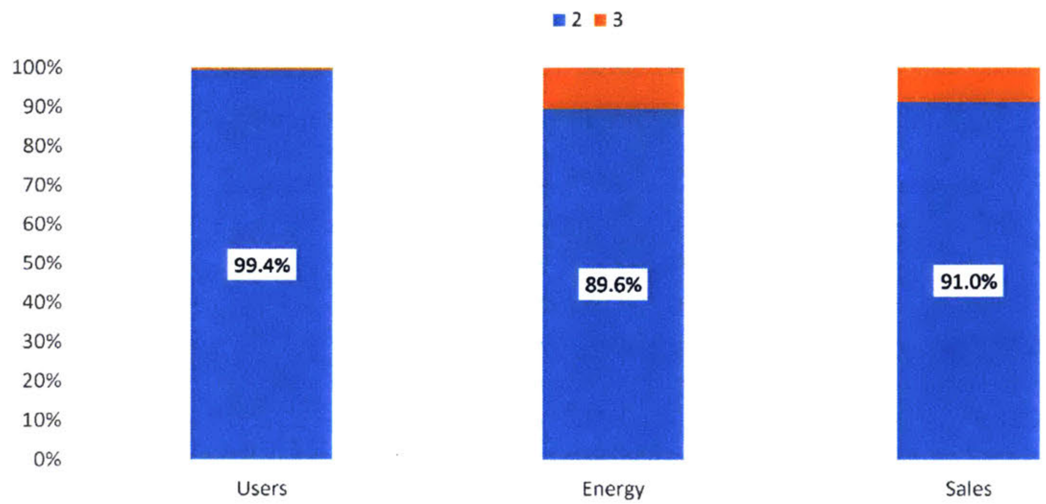


Figure A.26 source: SENER 2017b. Figure by author.

Figure A.27 - Av. Monthly Consumption by Commercial Tariff Class

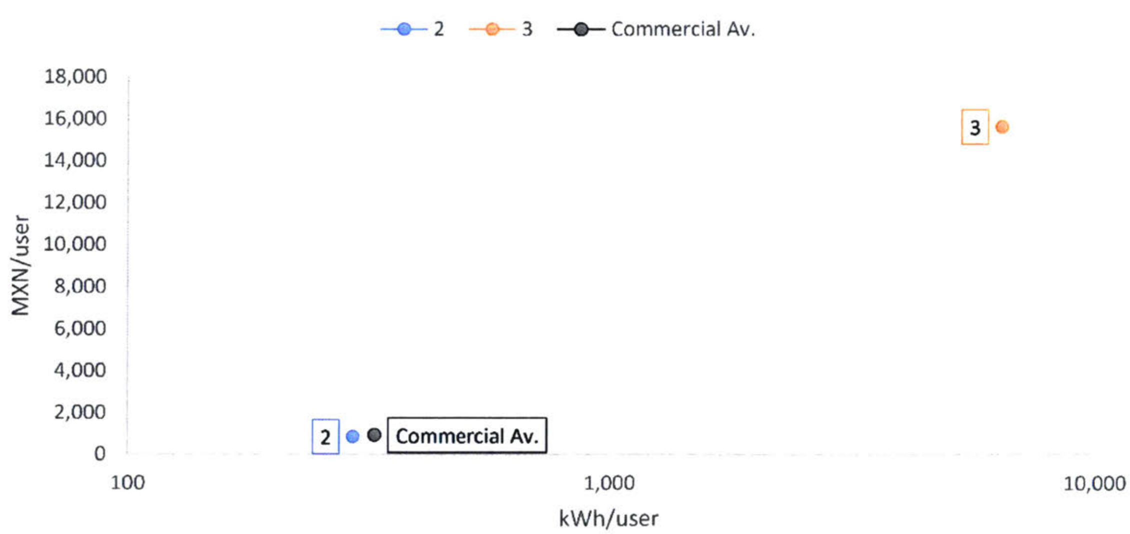


Figure A.27 source: SENER 2017b. Figure by author.

A.2.2.3 – Service Tariffs

CFE has three types of service tariffs: Tariff 5 (public lighting for Mexico City, Monterrey, and Guadalajara), Tariff 5a (public lighting for the rest of the country), and Tariff 6 (water pumping) (SENER 2017b). The service electricity tariff is the second most expensive behind the commercial tariff. Between January 2007 and January 2017, service electricity tariffs have experienced the highest increases. Tariffs for public lighting are more expensive than water pumping, with public lighting tariffs (Tariff 5) in Mexico City, Monterrey, and Guadalajara (the country's largest Metropolitan areas) being more expensive than the rest of the country.

Figure A.28 - Service Tariffs in Comparison to DAC and Commercial Tariffs

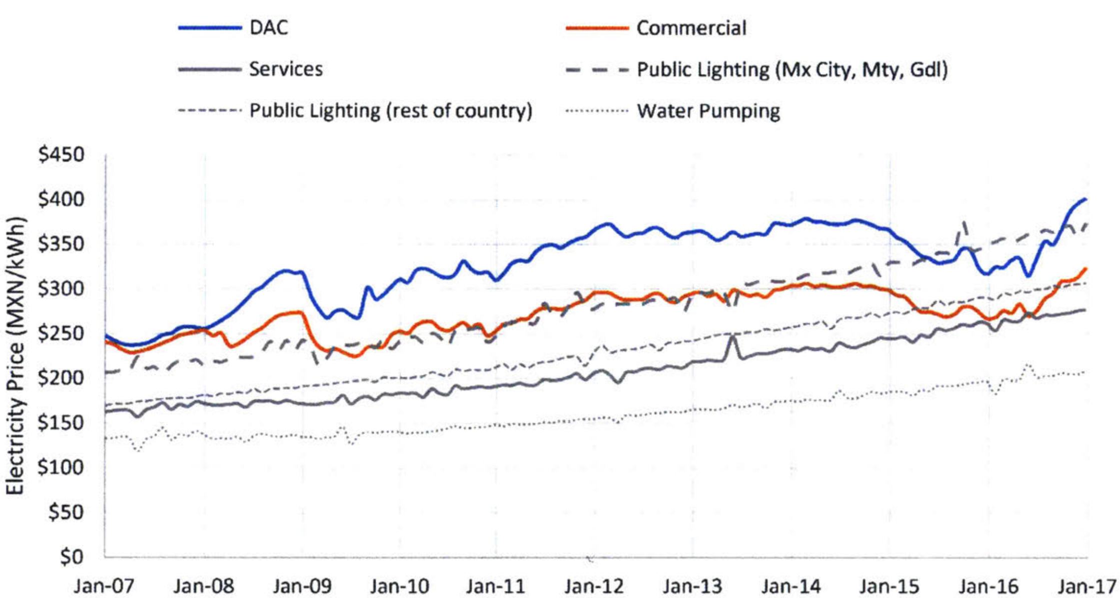


Figure A.28 source: SENER 2017b. Figure by author.

A.2.3 – Distributed Electricity Generation Statistics in Mexico

On April 4, 2017, CRE published statistics on distributed electricity generation in Mexico starting in 2007 through December 31, 2016. The published information includes a 2016 forecast of DG in Mexico until 2025. At the end of 2016, Mexico had ~247.6 MW of installed DG capacity. The total installed capacity was distributed among 29,560 contracts (CRE 2017a).

Figure A.29 - Installed Capacity of DG in Mexico 2007 - 2016

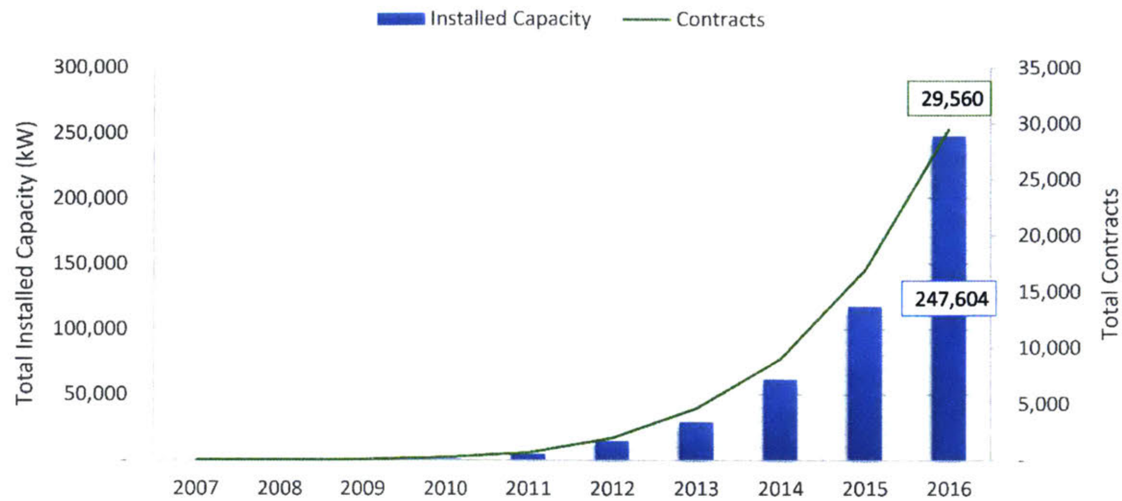
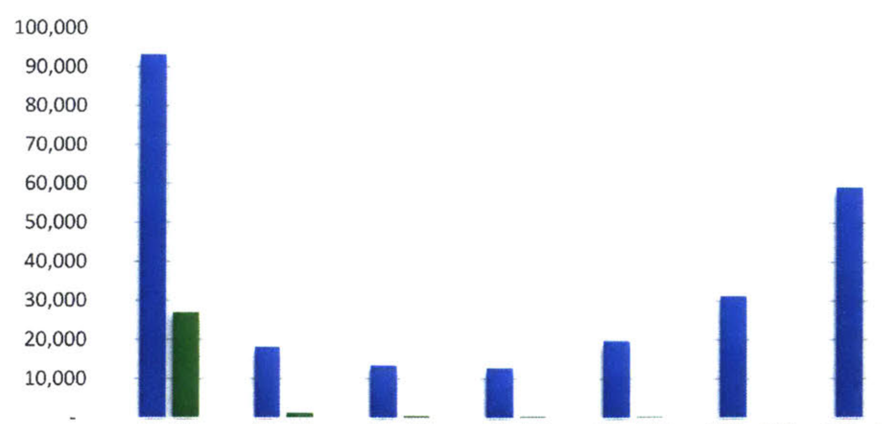


Figure A.29 source: CRE 2017a. Figure by author.

Most DG contracts in Mexico come from installations with capacities of 10 kW or less, aggregating around 91% of all contracts. Nonetheless, these systems make up only ~37.6% of total DG installed capacity. The average installed capacity of contracts with capacities of 10kW or less is 3.46 kW (CRE 2017a).

Figure A.30 - Distribution of DG Systems by Capacity Range (kW)



	0 - 10	10 - 20	20 - 30	30 - 50	50 - 100	100 - 300	300 - 500
■ Total Installed Capacity (kW)	93,137	18,140	13,431	12,742	19,678	31,308	59,168
■ Contracts	26,894	1,244	529	321	285	159	128

Figure A.30 source: CRE 2017a. Figure by author.

The vast majority of installed DG capacity comes from Solar PV systems. Up to December 31, 2016, there were almost 199 MW of small-scale[106] Solar PV systems and 124.7 MW of medium scale[107] Solar PV systems in Mexico. Solar PV systems hold ~98.4% of all installed DG capacity in Mexico. Installed capacity from other technologies totals ~4 MW. Other DG technologies include small and medium scale wind energy, combined Wind – Solar PV energy, biogas, and biomass systems (CRE 2017a).

Figure A.31 - Installed DG Capacity by Technology (MW)

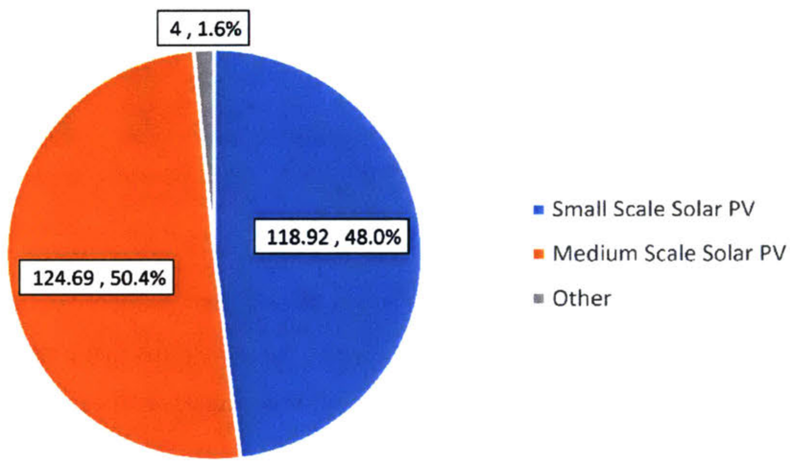


Figure A.31 source: CRE 2017a. Figure by author.

Six states in Mexico have more than 10 MW of installed DG capacity. Three of these states – Estado de México, Nuevo León, and Jalisco – have more than 48% of all installed DG capacity and ~39% of all contracts (CRE 2017a). These states host the most populated urban areas in the country, with Estado de México containing a large population of the Mexico City metropolitan area, the city of Monterrey in Nuevo León, and the city of Guadalajara in Jalisco (GoM 2017b).

[106] Small Scale DG systems include systems of 10kW or smaller for residential use and systems of 30kW or smaller for general use.

[107] Medium Scale DG systems include all other systems of less than 500kW of installed capacity.

Figure A.32 - Distribution of DG by State

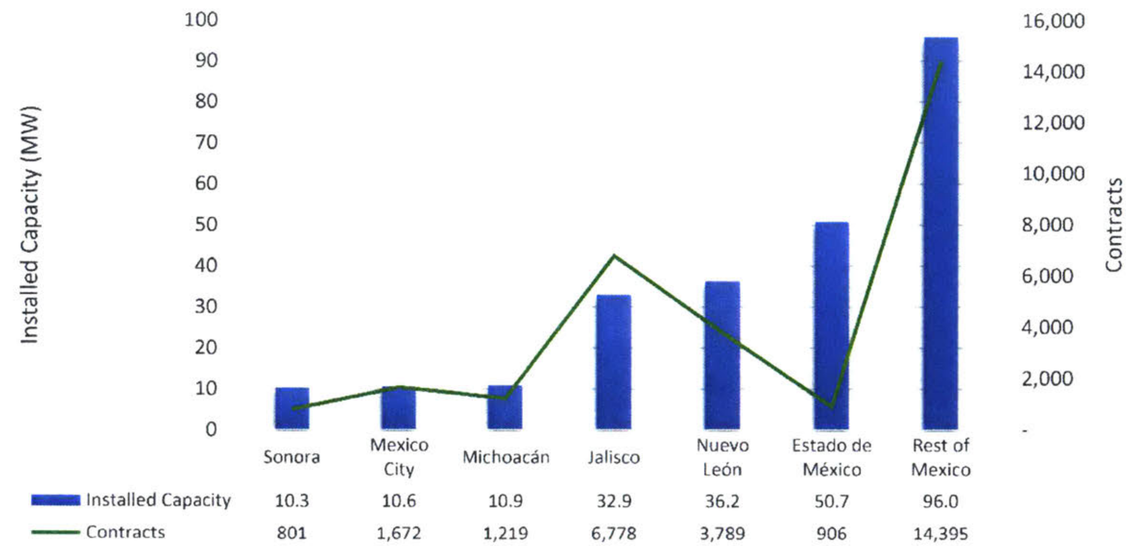


Figure A.32 source: CRE 2017a. Figure by author.

CRE expects an exponential integration of DG systems across Mexico in the upcoming years, forecasting an installed capacity of 1,812 MW and ~160,000 contracts by 2020 and an installed capacity of 9,177 MW and ~682,000 contracts by 2025 (CRE 2017a). This prognosis implies the following growth rates:

- Average annual installed capacity growth rate of 64% from 2016 to 2020, 54% from 2016 to 2023, and 49% from 2016 to 2025.
- Average annual contracts growth rate of 53% from 2016 to 2020, 45% from 2016 to 2023, and 42% from 2016 to 2025.

Figure A.33 - Expected Growth of DG in Mexico

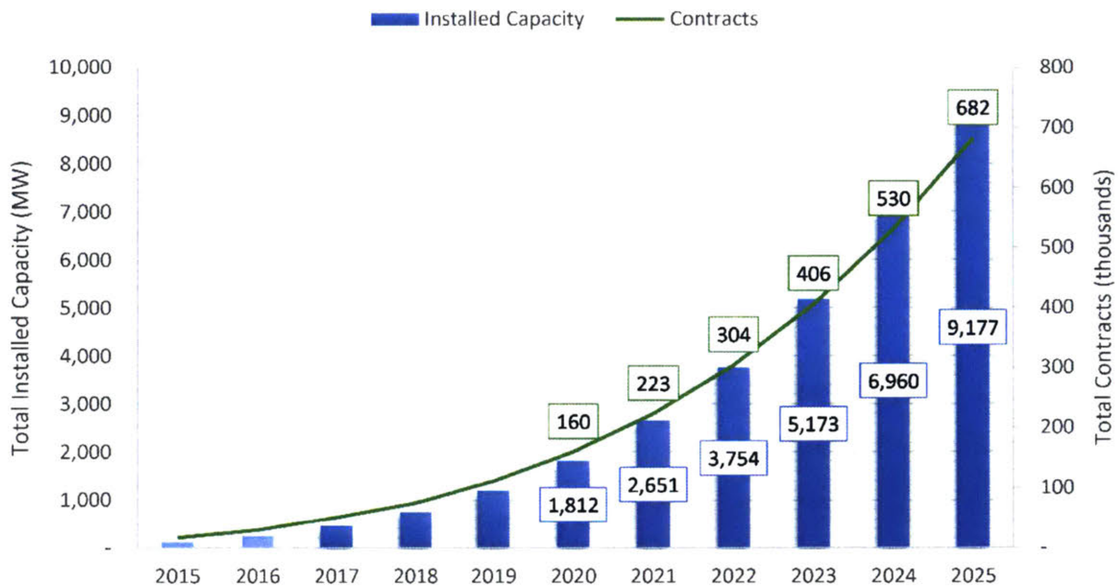


Figure A.33 source: CRE 2017a. Figure by author.

If the current percentage of small-scale Solar PV systems and contracts for DG systems with capacities of 10 kW or less remains consistent, the CRE's expected penetration of DG systems into the Mexican electricity network would entail ~870 MW, ~2,484 MW, and ~4,400 MW of small scale Solar PV by 2020, 2023, and 2025 respectively. Furthermore, there would be ~145 thousand, ~369 thousand, and ~620 thousand contracts for DG systems with capacities of 10 kW or less by 2020, 2023, and 2025 respectively.

Figure A.34 - Forecasted Integration of Small-Scale DG Systems

	Installed DG Capacity (MW)	Small Scale Solar PV (MW)	Contracts for DG Systems with capacity of 10kW or less
2016	247.6	118.9	26,894
2020	1,812.2	870.4	145,598
2023	5,172.6	2,484.3	369,034
2025	9,177.3	4,407.7	620,726

Figure A.34 source: CRE 2017a. Projections by author.

A.3 – Laws, Policies and Regulation

A.3.1 – 2013 Energy Reform and Unbundling of CFE

The 2013 Energy Reform brought forth drastic constitutional changes in order to modernize and provide economic efficiency to the hydrocarbons and electricity industries in Mexico. Concerning matters of the electricity industry, the Energy Reform's principal goal is to lower electricity tariffs through the creation of a competitive Wholesale Electricity Market (WEM) and the reduction of energy losses throughout the transmission and distribution networks.

Prior to the Energy Reform, the electricity utility (CFE) was a state-owned, vertically integrated, non-profit monopoly responsible for electricity generation, transmission, distribution, and retail services. CFE executed tenders for private parties to build its new power plants, transmission, and distribution infrastructure but owned all infrastructure. CFE operated the National Electricity System (SEN) and decided which power plants to dispatch in order to meet electricity demand (DOF 2013b, CFE 2016). The 2013 Energy Reform created a decentralized, independent system operator called The National Center for Energy Control (CENACE) responsible for the economic and technically efficient operation of the SEN. The CENACE operates the new WEM and grants open and indiscriminate access to the country's transmission and distribution networks (DOF 2013b).

In order to create a competitive electricity generation market, the State deemed CFE a Productive State Enterprise[108] (EPE) and unbundled it into nine different companies and two subsidiary companies: six electricity generation companies,[109] CFE Transmission, CFE Distribution, and CFE, which deals with retail and public service. CFE's two subsidiary companies deal with legacy contracts and non-public service electricity supply (García 2016a). Prior to the 2013 Energy Reform, CFE did not have technical, operational, and managerial sovereignty. The company was under the jurisdiction of SENER and the Ministry of Finance and Public Credit (SHCP), preventing CFE from operating autonomously. With the 2013 Energy Reform, CFE gained budgetary and fiscal autonomy (Ortega Lomelín 2016; SENER 2016b).

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[108] Productive State Enterprises are State-owned companies that participate and compete in the open market, operating as privately owned entities. CFE has the mandate to be productive, which means the government will not rescue it if it goes into bankruptcy.

[109] CFE's Generation companies are called Generation I, Generation II, Generation III, Generation IV, Generation V, and Generation VI.

The Energy Reform opened electricity generation and retailing activities to private parties. Though the transmission and distribution networks remain under the ownership and operation of the State through CFE Transmission and CFE Distribution, SENER and CENACE are now the decision-makers parties regarding network expansion and interconnections (DOF 2013b).

A.3.2 – The Law of the Electricity Industry

The Law of the Electricity Industry (LIE) sets out to promote the sustainable development of the electricity industry and guarantee its continuous, efficient, and safe operation for the benefit of its users. It regulates the planning and control of the SEN, the transmission and distribution networks, and other relevant activities related to the electricity industry (GoM 2014b).

The LIE permits aggressive entry of renewable energy technologies into the grid through an auction system. For each auction, SENER and CRE specify an amount of energy, CELs, and capacity added to the electricity market. Generators bid in the auction system a quantity of electricity volume, capacity, and lowest price they are willing to be paid for electricity, creating aggressive competition among generators and lowering the price of future electricity generation (GoM 2014b).

Two auctions have occurred to date. The first auction awarded contracts to install 2.18 GW of new Solar and Wind capacity and purchased ~5.4 TWh of energy from renewable sources. The second auction purchased ~8.9 TWh of energy at record low prices worldwide (USD $33.84/MWh) as well as 1.12 GW of capacity (CENACE 2017c). Power plants with an installed capacity of at least 1 MW can sell energy into the WEM, to either suppliers or qualified users. Nuclear Energy is the only technology that remains under control of the government (GoM 2014b). New regulation requires SENER and CRE to promote the diversification of the electricity generation matrix. SENER develops programs to install and retire power plants in the SEN as well as prepare and coordinate the execution of strategic infrastructure projects to comply with national energy policy (GoM 2014b; SENER 2015a).

A.3.3 – Clean Energy Certificates (CELs)

The 2013 Constitutional reform created Clean Energy Certificates (CELs) to promote larger and quicker integration of renewable technologies into the electricity system. CELs are awarded to power plants that comply with the following criteria (DOF 2013a).

1. Electricity is not generated using fossil fuels,

2. Power plants started operation or added generation capacity after August 2014,
3. Power plants with legacy contracts that generate clean electricity but were built before August 2014 if these plants have undergone a project to expand their production,
4. Power plants sell their electricity into the grid,
5. Power plants comply with the energy efficiency criteria stipulated by the CRE, and,
6. Power plants comply with the criteria of adequate environmental performance established by the Ministry of the Environment and Natural Resources (SEMARNAT for its acronym in Spanish).

The LIE requires every electricity market participant to generate a minimum amount of electricity from carbon free sources. Generators that fail to meet said criteria will need to purchase CELs from parties that have excess CELs or pay fines, therefore increasing the value of clean energy and fomenting the integration of renewable sources into the electricity market (1 CEL = 1 MWh). CELs will be traded on a yearly basis between qualified parties through the WEM (SENER 2017c).

Starting in 2018, participants in the Mexican electricity markets will be required to consume at least 5% of their electricity from clean energy sources or acquire the equivalent amount of CELs, increasing to 5.8% in 2019, 7.4% in 2020, 10.9% in 2021, and 13.9% in 2022 (DOF 2017c). The value of CELs will depend purely on availability of supply of clean energy at each point in time; however, SENER and CRE have established clear goals and regulations concerning CELs.

A.3.4 – Policy and Regulation for Distributed Electricity Generation

Prior to the LIE, the 1992 reforms of the Law of Public Service of Electric Energy regulated distributed electricity resources under the name of "small production." CRE granted small production users basic Net Metering policy; however, the installment of a DG system was subject to approval from CRE and CFE (GoM 1992). With the implementation of the 2013 Energy Reform and subsequently the LIE, Mexico adopted an electricity market structure that thoroughly pursues the addition of renewable technologies to the grid; however, the LIE originally focused on integrating renewable technologies at a utility scale. The regulation included in the Energy Reform concerning DG is in the seventh chapter titled "Distributed Generation". This chapter includes three articles – article 68, 69, and 70 – which, in summary, state the following (GoM 2014b):

- DG will have open access and not be discriminated against by Distribution Networks,
- Distribution Networks will be reinforced and expanded to support DG,

- CRE will elaborate and enforce the regulation required for matters of efficiency, quality, reliability, continuity, and safety of DG,
- SENER will promote the granting of credits and other financing schemes for clean distributed generation,
- CRE will promote the training of companies and their personnel as well as professionals and independent technicians for the installation of clean distributed generation.

On February 16, 2016, the administrative dispositions of open access and lending of services into the Electricity Transmission and Distribution Networks were published in the Official Gazette. On December 15, 2016, the Manual for Interconnectivity of Generation Centers with capacities lower than 0.5 MW was published (DOF 2016c). On March 3, 2017, the CRE published the official general guidelines and methodology for calculation of benefits awarded to owners of distributed electricity generation systems and clean distributed electricity generation systems in Mexico, specifically focusing on systems of less than 0.5 MW in installed capacity. In summary, the SENER offers owners of low-tension DG systems of less than 0.5 MW three different retribution options (DOF 2017b):

1. Net Metering: Considers the difference between the amount of energy generated by the DG system and consumed by the user for a set period. Policy is indifferent to the time of day that electricity is generated or consumed by the user. When the owner of a DG system produces more electricity than it consumes, the Generator will receive credits for surplus energy. Credits are automatically paid to the energy invoiced in each subsequent billing period, up to a maximum of 12 months. After that period, the Generator will receive the settlement of the overdue credit (not paid after 12 months) to the average value of the Local Marginal Price during the time interval in which the credit was generated, calculated in the node corresponding to the Point of Interconnection, in terms of the Payment Conditions section, contained in these Provisions.
2. Net Billing: Considers the flows of electric energy received and delivered to and from the General Distribution Networks, assigning them a value that can vary from purchase to sale.
3. Full Sale of Generated Electricity: Considers the flow of electric energy delivered to the General Distribution Networks at an assigned a sale value.

Owners of DG systems are obliged to sign an interconnection contract with the supplier of interconnectivity services (CFE Distribution or CFE Transmission), must choose one retribution method, and operate under said scheme for at least one year. All DG systems have open and indiscriminate access to the transmission and distribution networks as long as they comply with the technical operation guidelines established in interconnectivity contracts (DOF 2016a). Prior to the 2013 Energy Reform, CFE blocked the development of DG by not granting interconnection to potential adopters on technical grounds. Though CFE still signs the interconnection contracts, CENACE and CRE are the parties responsible for granting access to the transmission and distribution networks (GoM 2014b).

Appendix B – Distributed Electricity Generation

B.1 – Recent Development of the Solar Energy Industry

Government incentives, dropping prices, and improved technology has made the integration of clean distributed energy sources more prevalent across electricity markets. While stakeholders may have differing opinions on clean DG technologies, the public, electricity utilities, and policy makers expect the integration of clean DG to continue to grow (MITEI 2016). However, electricity transmission and distribution networks were not designed to accommodate a high penetration of distributed energy sources (EPRI 2014). The increasing addition of intermittent renewable distributed generation technologies has caused significant economic and technical impacts on the operation of an industry originally designed to function with centralized power plants far from consumption load centers. Clean DG resources can provide substantial value to electricity markets and society as well as imperil grid reliability and increase costs of operation.

B.1.1 – Costs and Performance

Costs of technologies such as Solar PV have dropped significantly in recent years and are expected to continue dropping, increasing viability of adoption of these technologies across the globe (IEA 2014). At the end of 2014, the average cost of installation of Solar PV modules in the US at a residential scale (10 kW or less) was USD $3.25/W. Around 20% of the cost refers to the modules ($0.65/W) while the remaining 80% are Balance-of-System (BOS) costs ($2.60/W). Utility Scale PV systems are still significantly cheaper, with BOS costs around $1.15/W, totaling in installed cost of $1.80/W (MITEI 2015). Module prices are similar across other regions of the world; however, BOS costs vary heavily from country to country. With less expensive labor costs, the installed costs of modules may decrease significantly. Residential Solar PV installation prices in Mexico normally range between USD $2.20/W and $2.50/W (EVA México 2017; Geckologic 2017).

The community solar market is becoming a mainstream driver of U.S. solar market growth. Starting in 2017, community solar is expected to consistently drive 20% – 25% of annual non-residential PV market and become a half-gigawatt per year market by 2019 (GTM 2017). Community Solar tend to be mid-size systems that range from a few hundred kilowatts up to 5 MW in capacity. Given the larger average size of community scale installations as compared to residential Solar PV systems, BOS prices tend to mirror that of utility scale installations rather than residential scale Solar PV systems, providing more attractive forms of investment (RMI 2017).

Optimal conditions for Solar PV system performance occur in dry regions with consistent sunlight and high solar irradiation (C-G 2011). In the northern hemisphere, maximum output of solar modules happens when panels facing south at a tilt that varies depending on the latitude of the installation site. In the US, solar module tilt normally ranges between 30° and 50° (C-G 2011). Solar module tilt for optimum performance in Mexico is closer to a 20° - 30° (Sandia Laboratories 2017). Solar Modules reach peak operation at around 42°C. With hotter temperatures, module performance begins to decrease (Dubey, Sarvaiya, and Seshadri 2013).

B.2 – Solar Resource in Mexico

Solar energy is widely regarded to play a significant role in Mexico's electricity generation in coming years by advocacy groups and the public (Muncino 2015). Mexico's geographical location is ideal for the exploitation of solar resources. The daily average solar irradiation stands at 5.5 kWh/m^2 and can exceed 8 kWh/m^2 in the northwest.

Figure B.1 - Solar Irradiation in Mexico

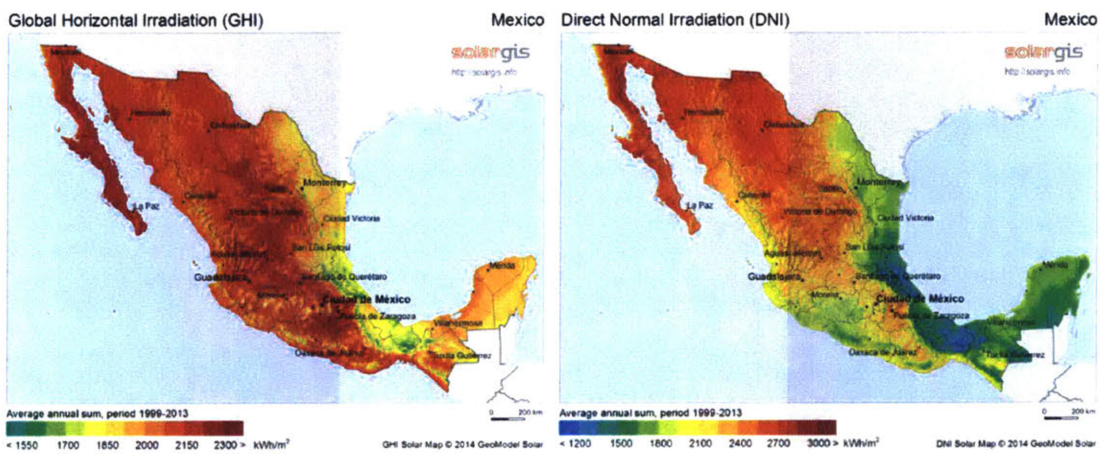

Figure B.1 source: SolarGIS 2017.

Interviewed stakeholders unanimously identified the tremendous potential that exists in Mexico for Solar PV systems. Climate conditions are optimal for the performance of solar energy technologies in a large portion of the country. Daniel Chacón (2017), a member of the advocacy group Climate Initiative of Mexico (ICM), studied the current potential for rooftop Solar PV systems in Mexico, finding that there is enough room "for 80 or more GW of capacity. There are enough clients for at least 60 GW of capacity or more." Tomás Gottfried, owner of a clean DG system, expressed similar sentiments, further explaining the technical benefits that Solar PV may have on the grid.

> "Solar is a huge opportunity for Mexico because the resource is so abundant, the falling costs of the technology, and it's easily installed in urban settings. I think Mexico City could be entirely roofed with solar panels, which in some way would reduce the load off of the transmission grid which is close to saturation already, so it would be a win-win as far as the grid is concerned" (Interview, Tomas Gottfried 2017).

Stakeholders within government institutions, private Solar PV companies, and advocacy groups shared Tomas Gottfried's views, envisioning an increased role for solar energy in Mexico at both the distributed and centralized level. Edmundo Gil Borja, Managing Director of Distribution and Commercialization of Electric Energy and Social Entailment in SENER, and Oliver Flores, Managing Director of Generation and Transmission of Electric Energy in SENER, shared their opinion on the role of solar energy for electricity production in Mexico.

> "From my point of view, the development of DG in Mexico will be through solar panels. [Solar energy] will have a very important participation in the future of generation of the country. Solar will be the principal technology in Mexico concerning DG" (Interview, Edmundo Gil Borja 2017).

> "I believe our potential resources will be a catalyst for this. The potential we have is an important catalyst and we cannot ignore that. Having good resources and a transparent, competitive, and deregulated market are important factors for the deployment of these systems" (Interview, Oliver Flores 2016).

Diego Villarreal had an insightful perspective on why Solar PV systems fit the Mexican electricity industry so well.

> "[Solar PV systems are] a very natural fit, especially in a place like Mexico where operating complex systems require human capital that is not necessarily available. You do not require fuel; you are not exposed to market volatilities once you have set it up. From that perspective, it is a very attractive option" (Interview, Diego Villarreal 2016).

B.3 – Mechanisms to Incentivize Adoption of Clean Distributed Generation

Policy makers promote the integration of renewable technologies – both at utility and distributed scale – for various reasons. Renewable technologies like wind and solar energy operate with local resources, reducing the need to purchase fuels shipped from distant locations and increasing energy independence. Furthermore, life cycle GHG emissions from electricity generated with renewable technologies is immensely lower than electricity generated with conventional fossil fuel technology, helping decarbonize the grid and mitigate climate change (Weisser 2007).

Governments across the world have increasingly adopted clean energy generation targets. Setting ambitious, long-term renewable energy targets demonstrates political commitment, catalyzing change in countries by providing official mandates for action (REN21 2017). To achieve their targets, policy makers often adopt mechanisms to incentivize the deployment of renewable technologies.

Well-designed renewable energy policies and their effective regulation is the key to promote generation of low-carbon electricity around the world (Narula 2013). Different schemes and mechanisms exist to incentivize the deployment of Clean DG sources across electricity markets. One of the most common mechanisms to incentivize DG is a Feed-In Tariff scheme (FIT). FIT programs establish a price of electricity sale that provides reasonable profits for owners of DG systems (Ritzenhofen and Spinler 2016). Profits given to owners of FIT contracts increase the cost of operation of electricity systems, which are then normally socialized by electricity utilities among its customers (Yamamoto 2012).

Early adopters of renewable energy policies preferred FITs as a mechanism to incentivize the deployment of renewable technologies (particularly in Europe). In 2015, FIT was still the most commonly used mechanism across energy markets. However, Net Metering (NetM) policies have gained traction in recent years. From 2012 to 2015, the number of FIT policies across various national and state electricity markets increased by 8%, while the number of NetM policies increased by 44.4% (REN21 2017).

Figure B.2 - Renewable Energy Policies by Type (2012 - 2015)

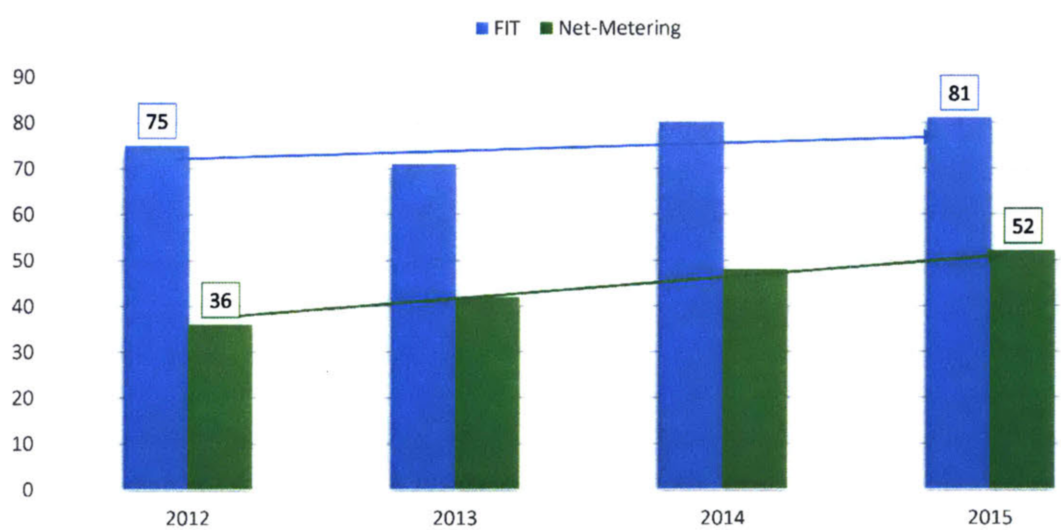

Figure B.2 source: REN21 2017. Figure by author

Though increasing in popularity, Brown and Bunyan (2014) argue that NetM policy "...was never developed as part of a fully and deliberatively reasoned pricing policy. Net metering was simply never a conscious policy decision." They argue that NetM was a default product of two practical and technological considerations: (1) residential DG had such an insignificant presence in the market that its economic impact was negligible, and (2) until recently, meters were only capable of running forwards, backwards, or stopping (Brown and Bunyan 2014).

NetM policies provide compensations based on the difference of electricity consumed and produced by a DG system over a billing period. If a customer has generated more electricity than it consumed in a billing period, they sell the difference to the electric utility at an established price of electricity. Otherwise, the household buys the excess of consumption from the electric utility at the according retail price (Boero, Backhaus, and Edwards 2016).

NetM allows high levels of residential DG adoption with less burden on non-adopting households than under FIT schemes since the latter needs to raise resources to pay for Clean DG generated electricity by increasing standard electricity rate, having a strong impact on the welfare of non-adopting households (Boero, Backhaus, and Edwards 2016; Dufo-López and Bernal-Agustín 2015). Retail electricity prices in European countries which have adopted FIT mechanisms have increased substantially more than US electricity markets that have adopted NetM mechanisms (EIA 2017).

Prior to the 2013 Energy Reform, Mexico offered DG adopters basic NetM policies. With the Energy Reform, CRE offers Clean DG adopters 1:1 net metering, net billing, and direct sale options. The Energy Reform's principal goal in matters of the electricity sector is to lower electricity tariffs and the cost of electricity generation (DOF 2017a). Given the government's reluctance to raise domestic tariff prices (Expansión 2016), recollection of resources required by FITs to pay for Clean DG generated electricity (Boero, Backhaus, and Edwards 2016) would either increase CFE's costs or require increased electricity subsidies. However, the government is looking to eliminate electricity subsidies given to the domestic sector (C.V 2016). NetM policies certainly fit the Energy Reform's goal better than FIT programs by having less impact on the increase of electricity tariffs.

Along with NetM policies, CRE awards Clean Energy Certificates (more commonly known as Renewable Energy Certificates or RECs) for their production of clean energy (DOF 2017b). RECs are government regulations designed to promote installment of clean energy technologies by creating a market price for emissions of pollutants that previously did not exist, addressing the impact of externalities caused by pollutants (Investopedia 2009). Similar to RECs, policy makers design Cap and Trade systems (C&T) to limit total emission levels of a specific chemical through the creation of Allowances. C&T and RECs are commonly used mechanisms to limit CO_2 emissions from electricity markets across the globe, including Europe, California, New England, India, and Western Canada (UCS 2017).

C&T and REC programs with strict implementation and continuous corrections promote renewable energy generation in an economically efficient manner with benefits to all stakeholders (Narula 2013). Improper valuation of allowances or RECs can have negative economic and performance impact on electricity markets. When Europe's C&T system – EU Emissions Trading System (EU ETS) – awarded allowances to renewable energy projects of non-regulated parties (developing countries outside the EU not subject to CO_2 emission limits), allowance prices collapsed severely due to an excess of allowance supply (*The Economist* 2012). With low allowance prices, EU ETS failed to provide incentives for companies and nations to reduce their CO_2 emissions.

RECs have been accused of having minimal impact on adoption of renewable energy technologies, and therefore, carbon emission reductions. Lacey (2011) argues that the reason RECs typically don't drive change is that the REC component of a clean energy deal isn't material to project financing. The prices people are willing to pay for RECs under voluntary markets are usually too low to induce significant change.

B.4 – Evolution of Electricity Grids with Distributed Energy Resources

MITEI's (2016) *Utility of the Future Study* defines Distributed Energy Resources (DER) as "any resource capable of providing electricity services that is located in the distribution system." DERs include distributed generation, demand response, energy storage, and energy control devices that are located and function at the distribution level (MITEI 2016). DERs are expected to play a larger role in electricity networks across the globe (EPRI 2014).

The rapidly increasing volume of DERs installed in random locations on the distribution network has forced electricity utilities to assess the reliability impact across the grid (Department of Energy 2017). Current customer driven deployment of DERs misses opportunities for utilities to capture significant system value. For DERs to truly become resources that add value to the system, they must be brought onto the grid as part of an overall planning strategy that leverages the locational benefits of DERs to support future grid planning and investments (ICF 2016).

A DER strategy can target location-specific or broader system issues to maximize benefits, address distribution system needs, and align compensation accordingly (MITEI 2016). Energy losses can be further reduced, voltage stabilization can be improved, and system reliability further enhanced by determining the optimal placement of DG sources rather than through random client-based adoption (Haghighat 2015).

Appendix C – Solar Modeling Methodology

C.1 – Solar Energy Modeling

C.1.1 – General Overview of Software and Tools

This thesis uses Sandia National Laboratories' solar energy modeling tools developed for MATLAB and Python. The vast majority of Solar PV System outputs and performance modeled and presented in this thesis use the Python script called 'PVLIB Python'. From Sandia National Laboratories' website:

> "Sandia National Laboratories is facilitating a collaborative group of photovoltaic (PV) professionals (PV Performance Modeling Collaborative or PVPMC). This group is interested in improving the accuracy and technical rigor of PV performance models and analyses. Such models are used to evaluate current performance (performance index) and determine the future value of PV generation projects (expressed as the predicted energy yield) and, by extension, influence how PV projects and technologies are perceived by the financial community in terms of investment risk. Greater confidence in the accuracy of performance models will lead to lower financing costs and an increase in the number of projects that are built. The PVPMC provides a collaborative venue for working towards these goals" (PVPMC 2017).

C.1.2 – Solar Irradiation Information

Solar irradiation data used for the various solar models was obtained from the National Solar Radiation Database (NSRDB) (NSRDB 2016). NSRDB provides detailed hourly solar irradiation and climate data for various regions of the planet. The solar energy models presented in this thesis uses averaged hourly solar irradiation data from 2005 through 2015, resulting in a one-year data set with 8784 different (all hours of a leap year). Non-leap years omit data for February 29 altogether. The averaged climate variables include:

- Global Horizontal Irradiation (GHI)
- Direct Normal Irradiation (DNI)
- Direct Horizontal Irradiation (DHI)
- Pressure
- Temperature
- Dew Point
- Wind direction
- Wind speed

For the solar models included in this thesis, solar irradiation data for the city of La Paz, Baja California Sur was used. La Paz is the state's largest city and load center. La Paz's geographical coordinates used are (1) latitude = 24.13°, and (2) longitude = -110.15° with an elevation of 48m and in a time zone GMT –7hrs.

C.1.3 – Solar Modeling

The "PVLIB Python" provides a detail forecast of Solar PV System output based on the inputted geographic and weather information. The script calculates in detail the solar azimuth and zenith angles at any hour and calculates the Angle of Incidence (AOI) between the sun's rays and the PV array depending on the tilt and direction that the Solar PV array is facing. The angle of incidence between the sun's rays and the Solar PV array is determined with the following formula:

$$AOI = cos^{-1}\left[cos(\theta_Z)cos(\theta_T) + sin(\theta_Z)sin(\theta_T)cos(\theta_A - \theta_{A,array})\right]$$

Where θ_A and θ_Z are the solar azimuth and zenith angles, respectively. θ_T and $\theta_{A,array}$ are the tilt and azimuth angles of the array, respectively. Azimuth angle convention is defined as degrees east of north (e.g. North = 0, East = 90, West = 270). Array azimuth is defined as the horizontal normal vector from the array surface (PVPMC 2017). An array facing south has an array azimuth of 180 deg. Array tilt is defined as the angle from the horizontal plane.

The plane of array (POA) beam component of irradiance is calculated by adjusting the DNI by the angle of incidence (AOI) in the following manner (PVPMC 2017):

$$POA = DNI * cos(AOI)$$

All models consider an albedo of 0.2, which represents the reflectivity of asphalt and concrete. The systems uses the Hay and Davies diffuse model, which divides the sky diffuse irradiance into isotropic and circumsolar components. Horizon brightening is not included. An anisotropy index, A_i, is defined as:

$$A_i = \frac{DNI}{E_a}$$

Where E_a is the extraterrestrial radiation. The Hay and Davies model formulation for sky diffuse radiation is (PVPMC 2017):

$$E_d = DHI * \left[A_i cos(AOI) + (1 - A_i)\frac{1 + cos(\theta_T)}{2}\right]$$

The electricity outputs provided by the PVLIB Python script consider the use of a 220 W Canadian Solar CS5P – 220M Solar Panel in AC Power. In order to scale up to the desired PV array, the number of panels required in the system multiplied the model's electricity output. In example, if the system had a total installed capacity of 2.2 MW, then the electricity outputs obtained by the PVLIB

Python script were multiplied by a factor of 10. I use AC output for all solar models. AC Output of one solar panel set up in La Paz, BCS at a 25° tilt facing south is as follows:

Figure C.1 - AC Output of CS5P.220M Solar Panel in La Paz, BCS at 25° Tilt facing South

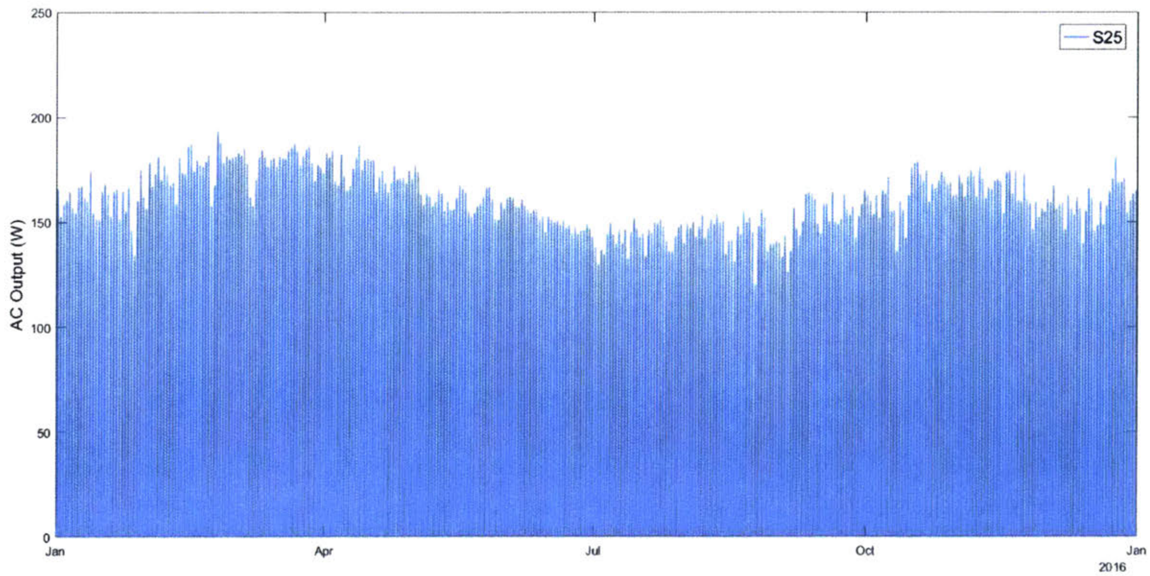

Figure C.1 by author.

Detailed specifications of the Solar Panels used can be found in Figure C.26 in Section C.5 of this Appendix.

C.1.4 – Electricity Generation Savings with Solar PV

Integration of distributed Solar PV into a distribution electricity network reduces the net electricity demand bestowed on the system (Perez-Arriaga 2013). I calculate electricity savings based on the hourly reduction of needed electricity generated by BCS's centralized power plants to meet electricity demand. As less generation is required from centralized power plants, both the volume and the marginal price of production may decrease as shown in Figure C.2.

Figure C.2 - Electricity Generation Savings with Solar PV

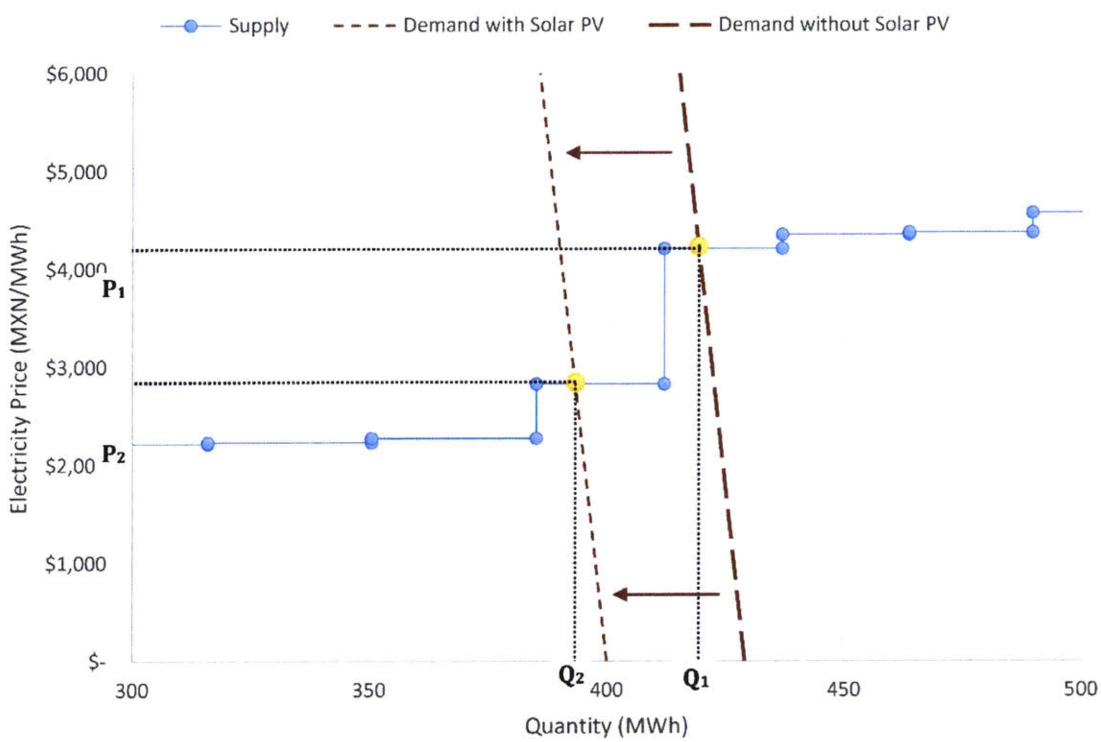

Figure C.2 by author.

The electricity demand data used throughout this thesis comes from the PRODESEN's 2016 – 2030 electricity demand forecast (SENER 2015a). The forecast includes hourly electricity demand data for each region of the country from January 1, 2016 to December 31, 2030. Electricity savings calculations with the integration of Solar PV systems presented throughout this thesis use the electricity demand forecast for the Baja California Sur transmission network.

I created the BCS WEM supply curve using each power station's maximum offering capacity and average price bid into the WEM from January 1, 2017 to February 18, 2017. I use the assembled supply curve to estimate electricity generation savings in 2017. For 2016 and 2018, I used the same bid data, but prices decrease and increase 3.5% respectively due to expected inflation.[110] WEM supply curves for 2019 through 2030 include the power plants expected to come online and go offline. I consider a $0/MWh bid for renewable energy power plants (geothermal and solar) that come online.

[110] Mexico's annual target inflation is 3%. The country's average annual inflation this decade is approximately 3.5% (Banco de México 2017).

I use the current lowest bid prices for prospective Turbogas and Internal Combustion power plants expected to come online in the BCS network. Each year considers a 3.5% price increase in bid prices. Figures C.28 through C.41 in Section C.5 of this Appendix depict supply curves for the years 2016 through 2030 (except for 2017).

SENER has planned for two combined cycle power plants to come online in 2026 and 2028. There are currently no combined cycle power plants in the BCS transmission network; therefore, marginal costs of operation of combined cycle power plants in the state Baja California were used as a reference. While the state of Baja California has an isolated electricity transmission and distribution network as well, it neighbors the state of California. Transporting natural gas to power plants in Baja California is much cheaper than in Baja California Sur, meaning the projected savings from 2026 to 2030 do not account for high transportation costs of natural gas into Baja California Sur. I represent accumulated annual electricity savings for a non-leap year with the following formula:

$$\sum_{t=1}^{8760} (P_1)(Q_1) - (P_2)(Q_2)$$

C.2 – Baja California Sur Case Study

C.2.1 – Solar Irradiation in Baja California Sur

The state of Baja California Sur (BCS) has very high levels of solar irradiation. Constituting the southern half of the Baja California Peninsula, in the past 10 years, the state of Baja California Sur has averaged a daily Global Horizontal Irradiation (GHI) of 6.1 kWh/m^2 and a monthly aggregate GHI of more than 185 kWh/m^2. Since 2006, the state has averaged an annual GHI accumulation of ~2250 kWh/m^2 (" NSRDB" 2017).

Figure C.3 – Solar Irradiation in Baja California Sur, Mexico

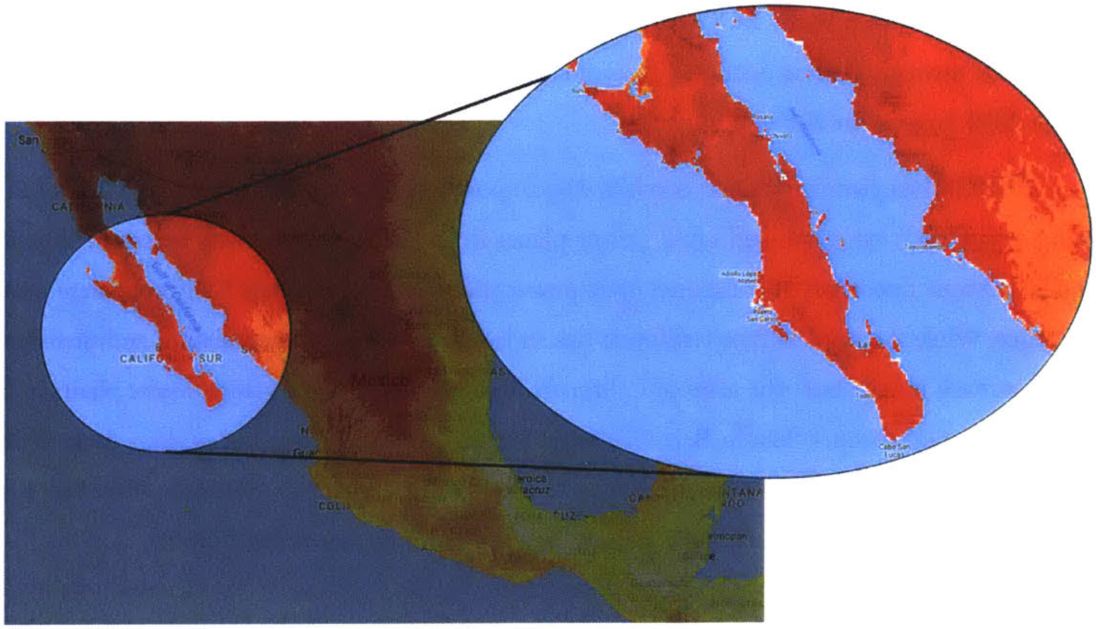

Figure C.3 source: NSRDB 2017. Figure by author.

Figure C.4 - Baja California Sur GHI

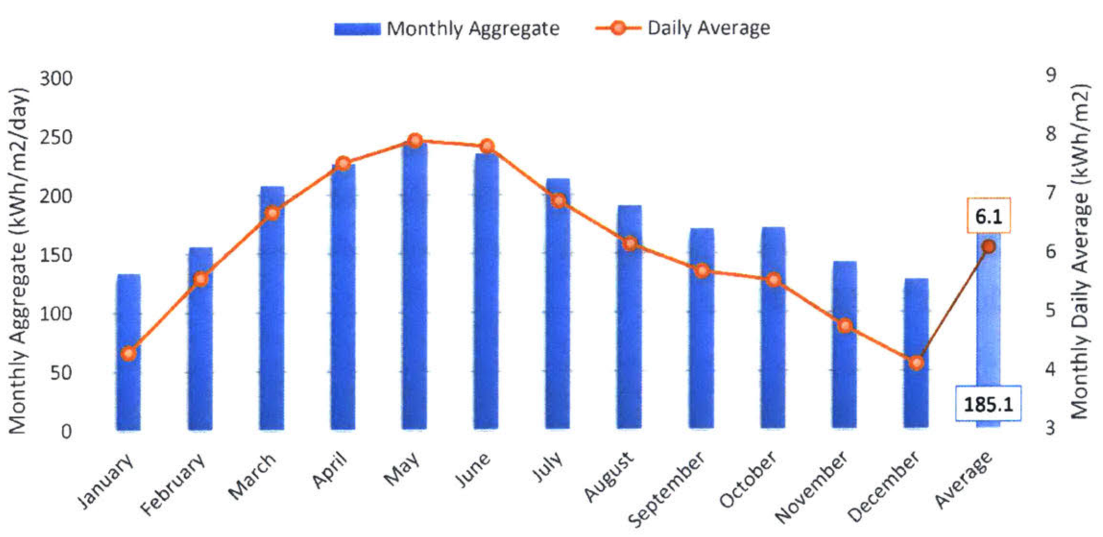

Figure C.4 source: NSRDB 2017. Figure by author.

<u>C.2.2 – Baja California Sur Transmission and Distribution Network</u>

The vast majority of Mexico interconnects through one large transmission network that spans from northwest Sonora State to the eastern most points of the country. The states of Baja California and Baja California Sur each have their own independent transmission networks. The Baja California Sur Transmission Network covers three major load centers (Villas Constitución, La Paz, and Los Cabos), has an installed capacity of 749.2 MW, and spans the southern region of the State (SENER 2015a, SENER 2016a).[111]

Figure C.5 - Transmission Network in Mexico

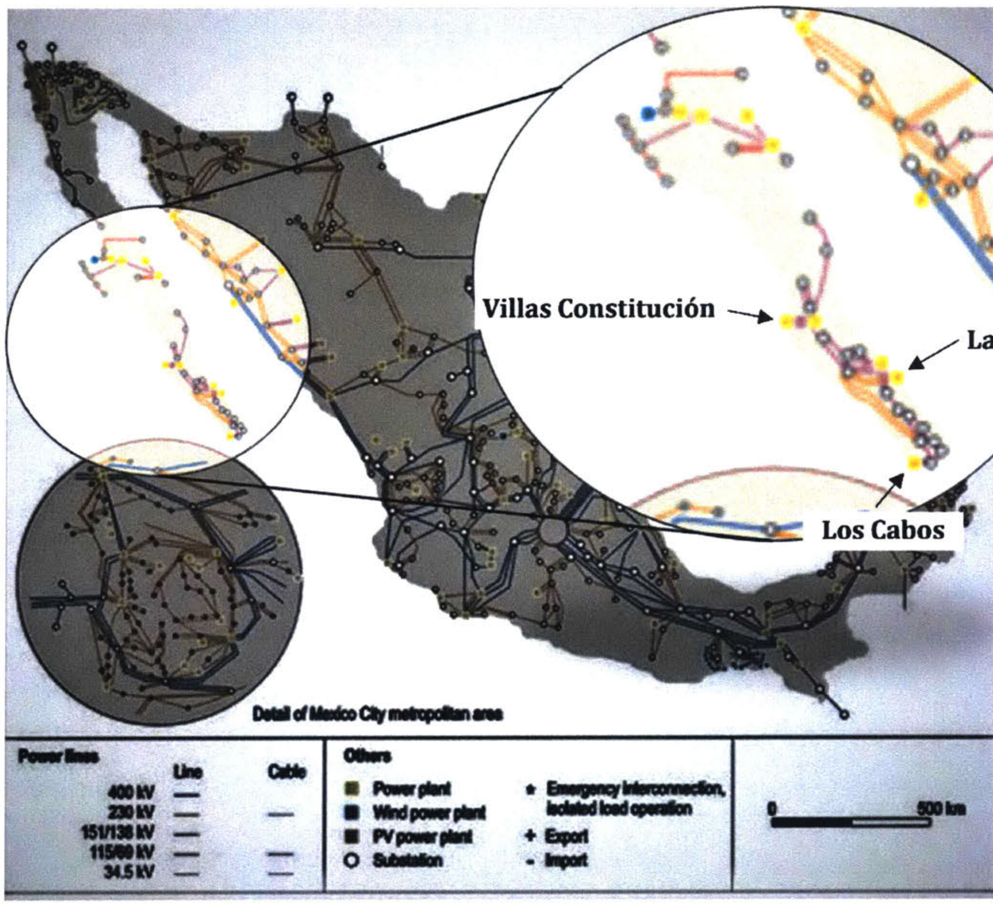

Figure C.5 source: SENER 2017c. Figure by author.

The Baja California Sur transmission network currently has 16 different power plants connected to the network. Thirteen new power plants will come online between 2018 and 2029 while ten power plants will come offline by 2027. Total installed capacity is expected to increase to ~1,100 MW by 2019, ~1,200 MW by 2021, and ~1,300 MW by 2029 (SENER 2017a, SENER 2015a).

[111] The state of Baja California Sur has two separate transmission networks. "*Mulegé*" is a smaller network with an installed capacity of ~138 MW that covers the northern region of the state.

Figure C.6 – Baja California Sur Transmission Network Power Plants

Central/Project	Status	Technology	Fuel	Capacity (MW)
Baja California Sur I Central	In Operation	Internal Combustion	Fuel-Oil	162.7
Ciudad Constitución	In Operation	Turbo-gas	Diesel	33.2
La Paz_TG1	In Operation	Turbo-gas	Diesel	18.0
La Paz_TG2	In Operation	Turbo-gas	Diesel	25.0
Los Cabos (CFE-T-25000-1_2_3_4)	In Operation	Turbo-gas	Diesel	75.0
Los Cabos (CFE-T-30000-1_2_3_4)	In Operation	Turbo-gas	Diesel	104.0
Los Cabos_1_TG	In Operation (offline 2019)	Turbo-gas	Diesel	30.0
Los Cabos_2_TG	In Operation	Turbo-gas	Diesel	27.4
Los Cabos_3_TG	In Operation (offline 2019)	Turbo-gas	Diesel	27.2
Punta Prieta II_U1	In Operation	Conventional Thermal	Diesel	37.5
Punta Prieta II_U2	In Operation	Conventional Thermal	Diesel	37.5
Punta Prieta II_U3	In Operation	Conventional Thermal	Diesel	37.5
San Carlos (Agustin Olachea A.)_U1	In Operation	Internal Combustion	Fuel-Oil	31.5
San Carlos (Agustin Olachea A.)_U2	In Operation	Internal Combustion	Fuel-Oil	31.5
San Carlos (Agustin Olachea A.)_U3	In Operation	Internal Combustion	Fuel-Oil	41.1
Servicios Comerciales de Energia	In Operation	Solar PV		30.0
CCI CFE 04	For Bidding (2018)	Internal Combustion	Fuel-Oil	43.0

CCC CFE 09	For Bidding (2019)	Internal Combustion	Fuel-Oil	114.0
CCC CFE 11	For Bidding (2019)	Internal Combustion	Fuel-Oil	139.0
CCC CFE 13	For Bidding (2019)	Internal Combustion	Fuel-Oil	117.0
CG PP 02	Construction to begin (2021)	Geothermal		13.0
CG PP 03	Construction to begin (2021)	Geothermal		22.0
CS PP 32	In Construction (2021)	Solar PV		30.0
CG PP 04	Construction to begin (2021)	Geothermal		27.0
CCGE GEN 01	New Project (2021)	Efficient Cogeneration		7.0
CTG LIE 02	New Project (2023)	Turbogas	Diesel	94.0
CCC LIE 06	New Project (2026)	Combined Cycle	Natural Gas	137.0
CS AUT 18	In Construction (2028)	Solar PV		30.0
CCC LIE 13	New Project (2029)	Combined Cycle	Natural Gas	123.0

Figure C.6 source: SENER 2015a. Figure by author.

The majority of the power plants run on fuel oil and diesel that is shipped-in, creating expensive electricity generation. Electricity in BCS is dispatched based on the lowest prices bid into the network's wholesale electricity market (CENACE 2017a). Based on the operation rules of the WEM in BCS, the average electricity supply curve of the BCS system between January 1, 2017 and February 18, 2017 is as follows (SENER 2017a, SENER 2015a, CENACE 2017b):

Figure C.7 - BCS Average 2017 Wholesale Electricity Market Supply Curve

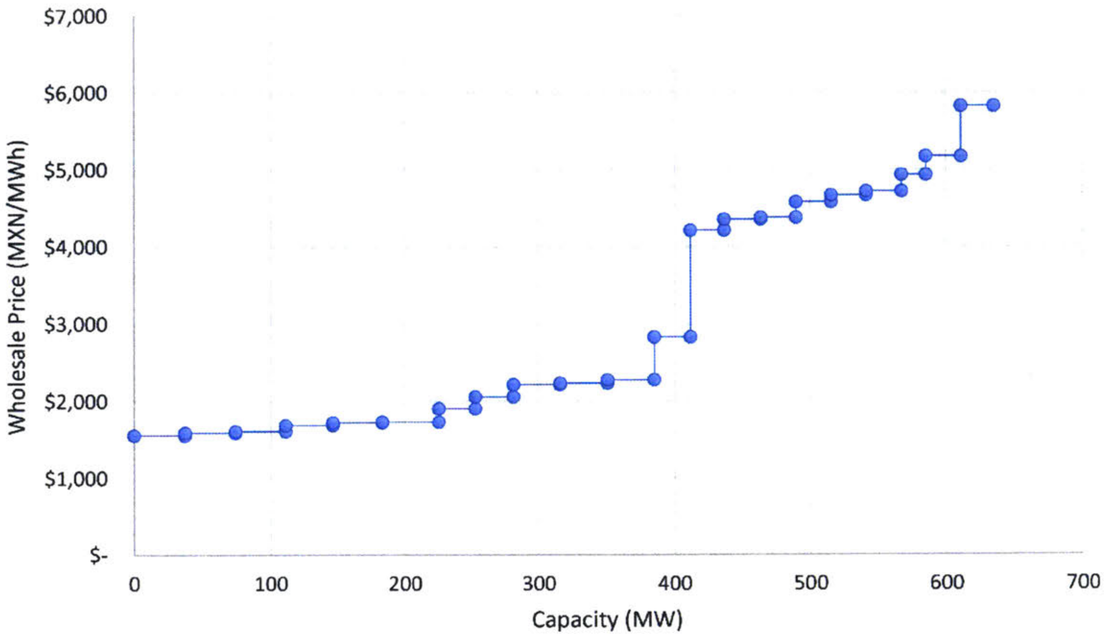

Figure C.7 source: SENER 2017a, SENER 2015a, CENACE 2017b. Figure by author.

Each power station's maximum capacity and average price bid into the WEM assembles the BCS electricity supply curve in Figure C.7. No further data was available during the construction of the supply curve.

C.2.3 – Clean DG to Lower Peak Electricity Demand

As mentioned in section 3.2.3, peak electricity demand in Mexico tends to happen once the sun has set. Heavy integration of distributed Solar PV would aggravate the difficulty and costs incurred by conventional plants to meet peak demand. Figure C.8 compares Baja California Sur's 2016's average monthly electricity demand with average global horizontal irradiation of the city of La Paz.

Figure C.8 - 2016 BCS Average Monthly Electricity Demand and GHI

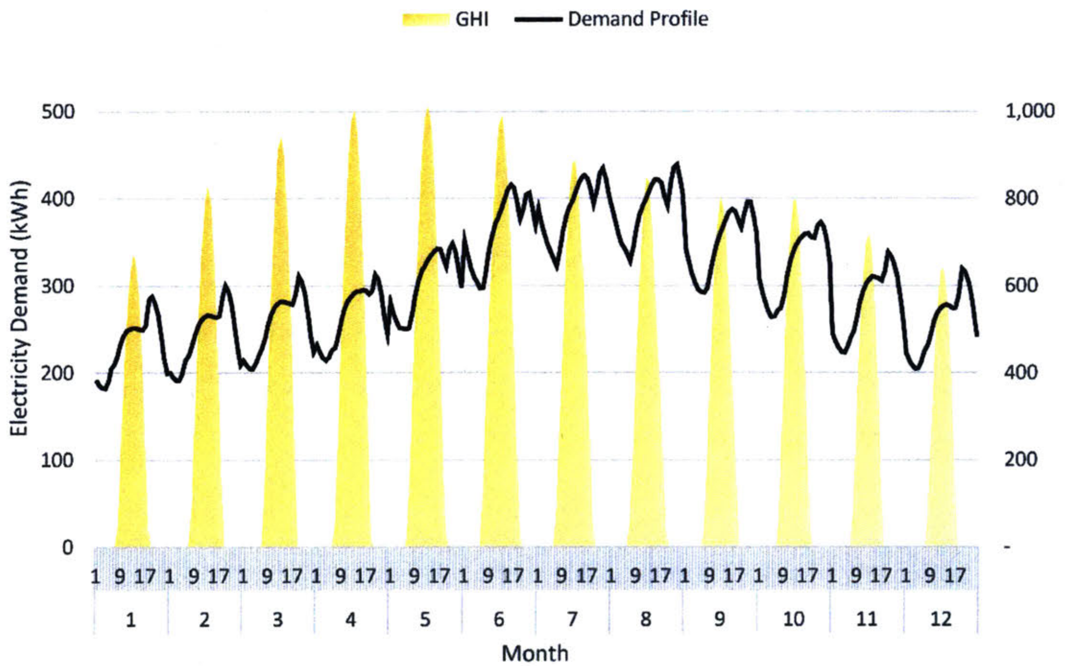

Figure C.8 source: NSRDB 2017; CENACE 2017b. Figure by author.

During the months with lower electricity consumption,[112] peak demand happens around 9-10pm. At this time, the sun has set. However, the months with higher electricity demand[113] coincide with extended solar irradiation periods. Peak electricity demand during these months occur at times when the sun has not fully set. Strategic deployment of distributed Solar PV can help lower peak demand as compared with customer-driven deployment of distributed Solar PV.

Using Sandia National Laboratories' Solar Energy modeling tools (PVPMC 2017), I determined that aggregated annual Solar PV output for Baja California Sur's largest city (La Paz) happens when Solar PV modules face south with a 25° tilt. However, having solar panels face west at different angles will better assist lowering peak electricity demand during the months with highest electricity consumption. Assuming a 5% integration of distributed Solar PV energy in Baja California Sur's transmission and distribution network, I compared the effect that different Solar PV module positions can have on peak electricity demand during the month of June 2016:

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[112] January, February, March, April, 1 half of May, 2 half of October, November, and December.

[113] Second half of May, June, July, August, September, and first half of October.

Figure C.9 - Peak Electricity Demand Reduction with Different Solar PV Arrangements

Solar PV Position and Tilt	Peak Electricity Demand (kWh)	Electricity Saved (kWh)
No Solar PV	415.46	0
Facing south at 25° tilt	395.76	19.8
Facing west at 30° tilt	388.12	27.44
Facing west at 45° tilt	387.12	28.44

Figure C.9 source: NSRDB 2017; CENACE 2017b; PVPMC 2017. Figure and calculations by author.

Figure C.10[114] shows the normalized GHI and electricity demand profile of Baja California Sur's transmission and distribution network with a 5% penetration of distributed Solar PV with different module positions during June 2016.[115]

Figure C.10 - BCS Norm. Demand Profile w/Solar PV - June 2016

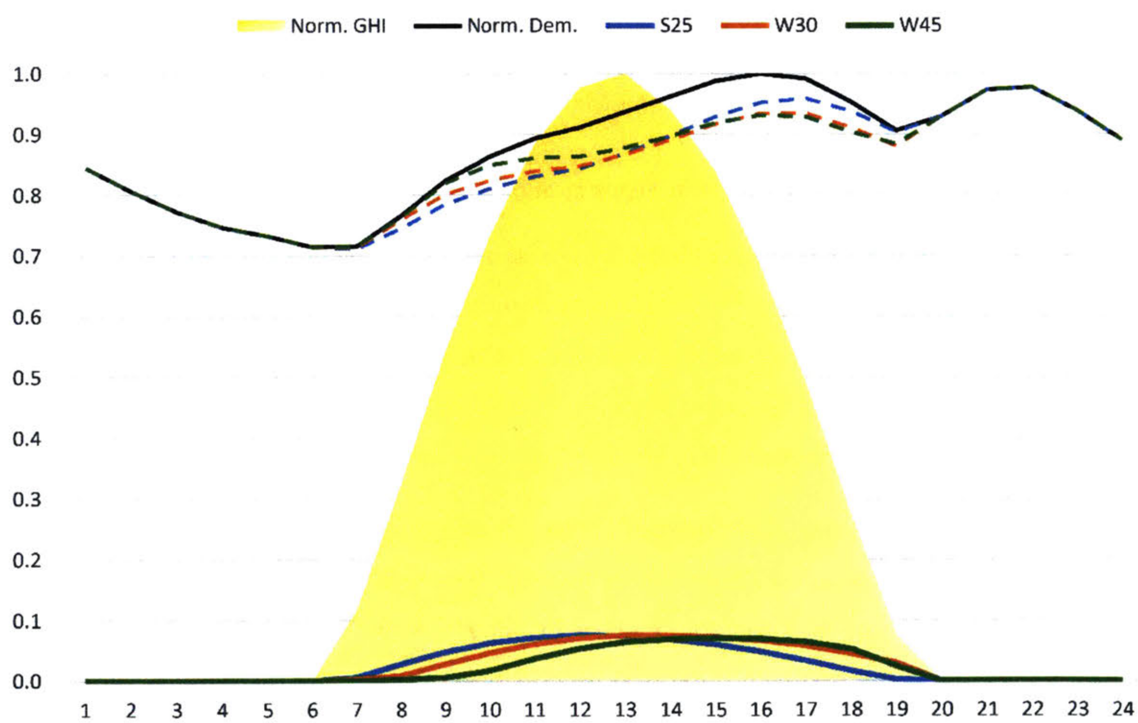


Figure C.10 source: NSRDB 2017; CENACE 2017b; PVPMC 2017. Figure and results by author.

[114] Figures C.42 through C.53. repeat this exercise for all months of the year

[115] In Figure C.10, line names S25, W30, and W45 refer to Solar PV panels facing South at a 25° tilt, West at a 30° tilt, and West at a 45° tilt respectively.

Figure C.11 - Electricity Consumption Reduction during June 2016's Peak Demand Week

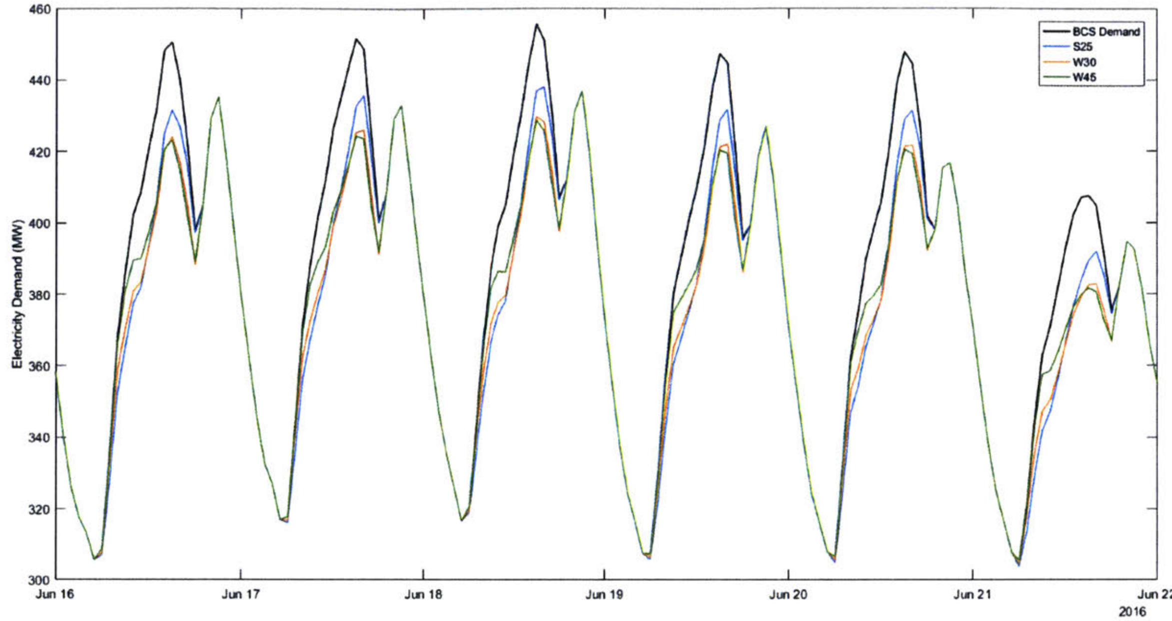


Figure C.11 source: NSRDB 2017; CENACE 2017b; PVPMC 2017. Figure and results by author.

Figure C.12 - Electricity Consumption Reduction during June 2016's Peak Demand Day

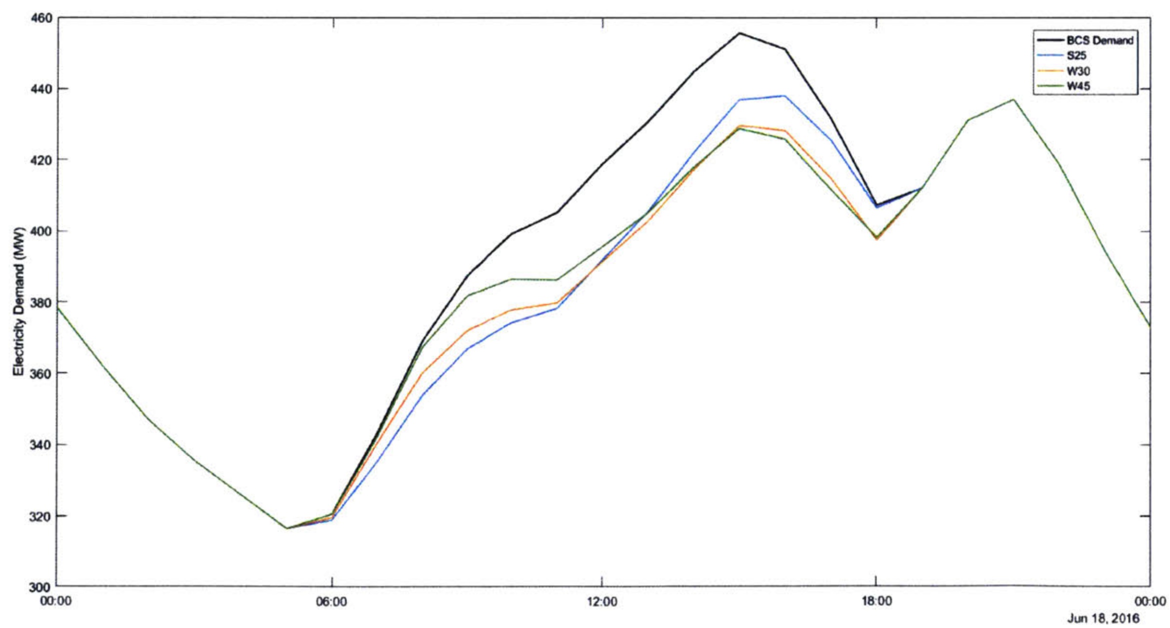


Figure C.12 source: NSRDB 2017; CENACE 2017b; PVPMC 2017. Figure and results by author.

CRE and SENER have used the California electricity market as a model for the development of DG policies in Mexico. High integration of residential Solar PV systems in the Californian market require gas plants to ramp up aggressively to meet peak electricity demand while the sun is setting (John 2014). When interviewed, Thomas Cuccia (Interview, 2017) – a Policy Specialist at CAISO – mentioned that the state of California is planning to adjust its current electricity demand profile by implementing Time of Use Rates, and modifying its demand curve in a way that will reduce the peak demand and the high costs it entails.

Policy makers have the opportunity to strategically plan its deployment of DERs to adjust its current electricity demand profile in a way that best fits the system's needs. Even though Solar PV output is maximized when panels face South at a 25°, it might be in the CFE's best interest to lower peak demand in the months with highest electricity consumption. If left to market forces, customer-driven deployment of clean DG technologies will fail to capture these benefits and possibly strain the electricity sector.

C.2.4 – Reduction of GHG emissions

Total CO_2 emission reduction would depend on the balance between the emissions saved from reduced electricity demand currently met through conventional power plants and the potential increased emissions required by internal combustion plants to meet peak electricity demand. Ignoring added CO_2 emissions to the system and assuming 74 kgs of CO_2 for every million BTUs of electricity generated with fuel oil or diesel (IPCC 2016), a 5% integration of Solar PV into the BCS system would reduce 437.5 thousand tons of CO_2 emitted to the atmosphere.

Figure C.13 - Reduction of GHG Emissions with 5% integration of Clean DG in Baja California Sur

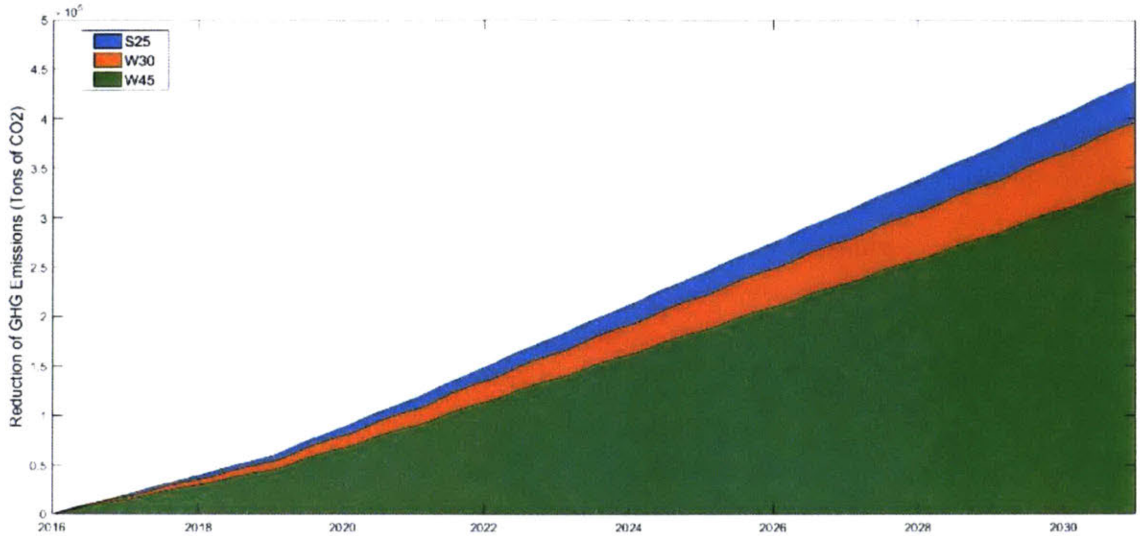


Figure C.13 by author.

C.2.5 – Utility vs. Distributed Installation Comparison

Solar energy power plants installed at a utility scale have lower installation costs ($1.80/W) as compared to significantly smaller residential solar energy systems ($3.20/W) (MITEI 2015); however, utility scale systems often require the construction of transmission lines. Building transmission lines is an expensive endeavor that usually requires years to plan and construct.

Figure C.14 - Transmission Line Costs

Line Description	*New Line Cost 2014 ($/Mile)*
230 kV Single Circuit	$959,700
230 kV Doubt Circuit	$1,536,400
345 kV Single Circuit	$1,343,800
345 kV Double Circuit	$2,150,300

Figure C.14 source: "Pletka 2014."

In order to compare electricity generation cost savings of Solar PV systems at utility and distributed scales, the methodology described in Section C.1 in this appendix was utilized, considering different installation costs:

- Utility Scale: USD $1.80/W (MITEI 2015)
- Community Scale: USD $2.50/W (RMI 2016).

The integration of Solar PV energy equivalent to 5% of total installed capacity in the BCS transmission grid at both utility ($1.80/W) and distribution ($2.50/W) scale would require the following investment costs:

Figure C.15 - Investment Costs for Solar PV Facilities

Year	Approximate BCS Electricity Network Installed Capacity (MW)	Solar Energy Installed Capacity (MW)	Investment Cost Utility Scale (million USD)	Investment Cost Distributed Scale (million USD)
2016	749.21	39.43	$ 93.89	$ 67.60
2017	749.21	39.43		
2018	749.21	39.43		
2019	1,104.98	58.16	$ 51.61	$ 37.16
2020	1,104.98	58.16		
2021	1,204.00	63.37	$ 15.84	$ 11.40
2022	1,204.00	63.37		
2023	1,204.00	63.37		
2024	1,204.00	63.37		
2025	1,204.00	63.37		
2026	1,204.00	63.37		
2027	1,204.00	63.37		
2028	1,204.00	63.37		
2029	1,308.83	68.89	$ 24.77	$ 17.84
2030	1,308.83	68.89		

Figure C.15 by author.

This paper assumes identical electricity demand reduction from both utility and distributed Solar PV facilities; therefore, annual electricity generation savings for systems with solar panels facing south with a 25° tilt and west with a 30° tilt are as follows:

Figure C.16 - Electricity Generation Savings

Year	South 25 (millions USD)	West 30 (millions USD)
2016	$ 19.3	$ 19.4
2017	$ 23.0	$ 23.0
2018	$ 24.0	$ 23.0
2019	$ 37.4	$ 34.3
2020	$ 46.8	$ 45.0
2021	$ 49.0	$ 46.6
2022	$ 51.0	$ 47.1
2023	$ 52.1	$ 46.9
2024	$ 63.5	$ 60.9
2025	$ 73.5	$ 68.7
2026	$ 81.5	$ 71.7
2027	$ 67.7	$ 61.5
2028	$ 79.9	$ 76.3
2029	$ 73.4	$ 71.1
2030	$ 80.2	$ 76.6

Figure C.16 by author.

Highest electricity generation savings occur at a utility scale with panels facing south with a 25° tilt. This arrangement provides total savings of USD ~$688.3 million and a 2016 NPV of USD ~$387.5. When panels face west with a 30° tilt at utility scale, total savings of USD ~$638.2 million and a 2016 NPV of USD ~$357.6. At a distributed scale, when panels face south with a 25° tilt, total savings are USD ~$636.2 million and a 2016 NPV of USD ~$343.7. When panels face west with a 30° tilt at a distributed scale, total savings are USD ~$586.1 million with a 2016 NPV of USD ~$313.9.

Figure C.17 - Cash Flow and Savings

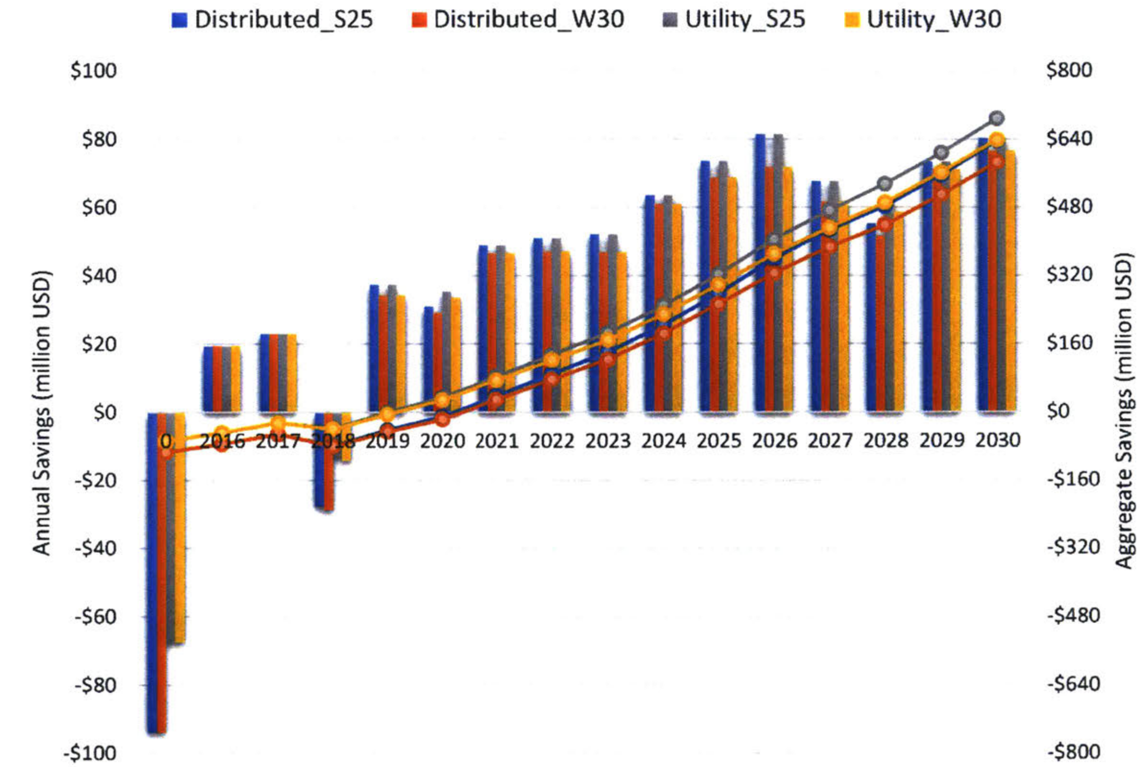


Figure C.17 by author.

The difference in savings between each Solar PV array set-up for 2016 to 2030 is USD ~$43.7 million. Using prices found in Figure C.14, this sum could construct ~45.6 miles of 230 kV Single Circuit transmission lines or ~28.5 miles of 230 kV Double Circuit transmission lines, around 41% or 26% respectively of the 230 kV transmission lines expected to be built in BCS between 2018 and 2024.

C.3 – Flaws in Solar Model

The solar models I develop and use in this thesis are simple and do not account for a number of variables that would surely affect the various financial models presented throughout this document. The model does not consider:

- Fluctuation in marginal costs of operation for each power plant due to variations in operational or fossil fuel costs.[116] The marginal costs of operation of each plant only

[116] CFE reports that 80% of its electricity generation prices are due to fuel costs (CFE 2014).

increase with annual inflation. Furthermore, marginal costs of operation in the supply curve are based on 50 days only.

- The modification of ramp-up costs in power plants due to integration of Solar PV at both distributed and utility scale. The model does not reflect possible increases in ramp-up costs on the electricity supply curves.
- Power plant shutdowns. Model assumes all power plants are operational 24 hours per day throughout the entire year. This includes utility scale solar energy power plants being operational during the nighttime.
- Transportation costs of natural gas for incoming Turbogas and Internal Combustion power plants.
- Development of technologies. Solar PV module costs will continue to decrease in coming years (IEA 2014); however, model assumes fixed installation costs throughout all periods. Furthermore, model does not account for potential development of technologies such as storage units that may significantly alter how electricity markets function.

C.4 – Methodology to Determine Cities for Pilot Project

Some of the regions with the highest average temperatures during summertime also have the best solar resource in Mexico. Using data from the National Population Council (CONAPO), I identified all municipalities with more than 100,000 inhabitants (GoB 2017b). In 2016, 146 municipalities had more than 100,000 inhabitants.[117]

[117] In Figure C.18, I represent neighboring municipalities with more than 100,000 inhabitants one time, resulting in 90 different locations.

Figure C.18 – Urban Areas with Municipalities with more than 100,000 inhabitants

Figure C.18 source: SolarGIS 2017; GoM 2017b. Figure by author.

A complete list of municipalities illustrated in Figure C.18 is found in Figure C.54.

I obtained the annual Global Horizontal Irradiation and July temperatures for all municipalities (SolarGIS 2017) and calculated Z-Scores for each parameter in order to determine what cities have the best conditions for distributed Solar PV. The resulting temperature and GHI Z-Score distribution of municipalities is as follows:

Figure C.19 - GHI vs. July Temp Z-Scores of Urban Areas with more than 100,000 Inhabitants

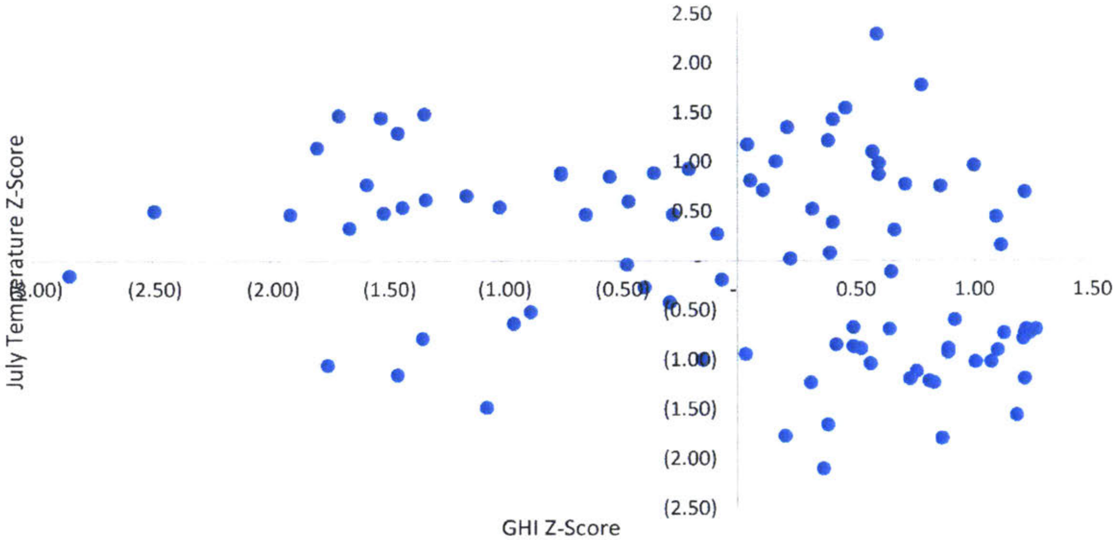


Figure C.19 source: SolarGIS 2017; GoM 2017b. Figure and results by author.

In order to determine the cities with the best conditions for distributed Solar PV, I focus on the 23 urban areas with positive Z-Scores for both GHI and July Temperatures.

Figure C.20 - Municipalities with more than 100,000 Inhabitants best Suited for Distributed Solar PV

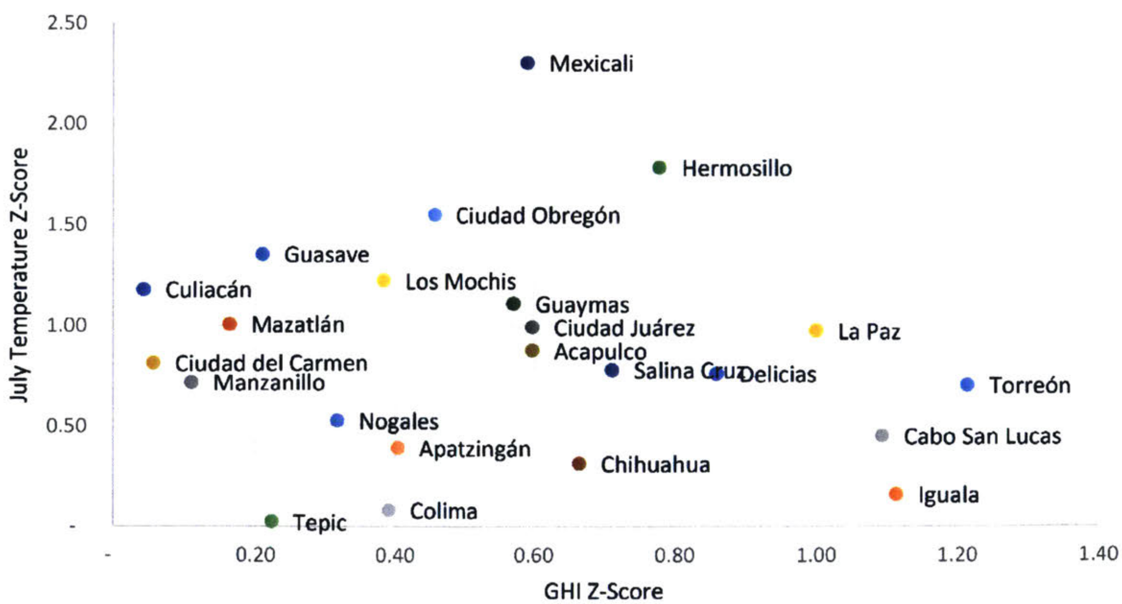


Figure C.20 source: SolarGIS 2017; GoM 2017b. Figure and results by author.

Figure C.21 - Municipalities with more than 100,000 Inhabitants best suited for Distributed Solar PV (GHI)

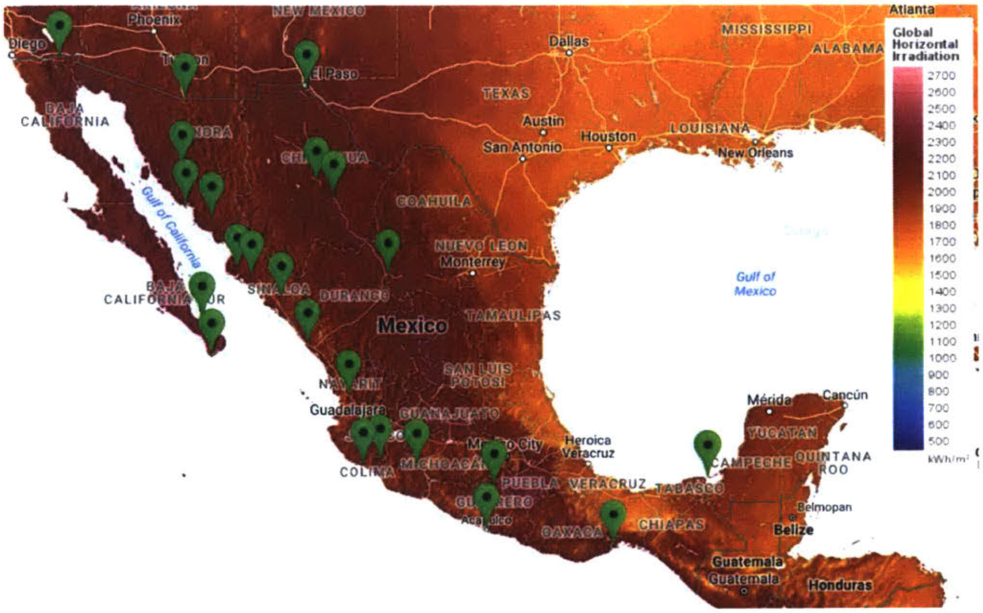


Figure C.21 source: SolarGIS 2017; GoM 2017b. Figure by author.

Figure C.22 - Municipalities with more than 100,000 Inhabitants best suited for Distributed Solar PV (Temperature)

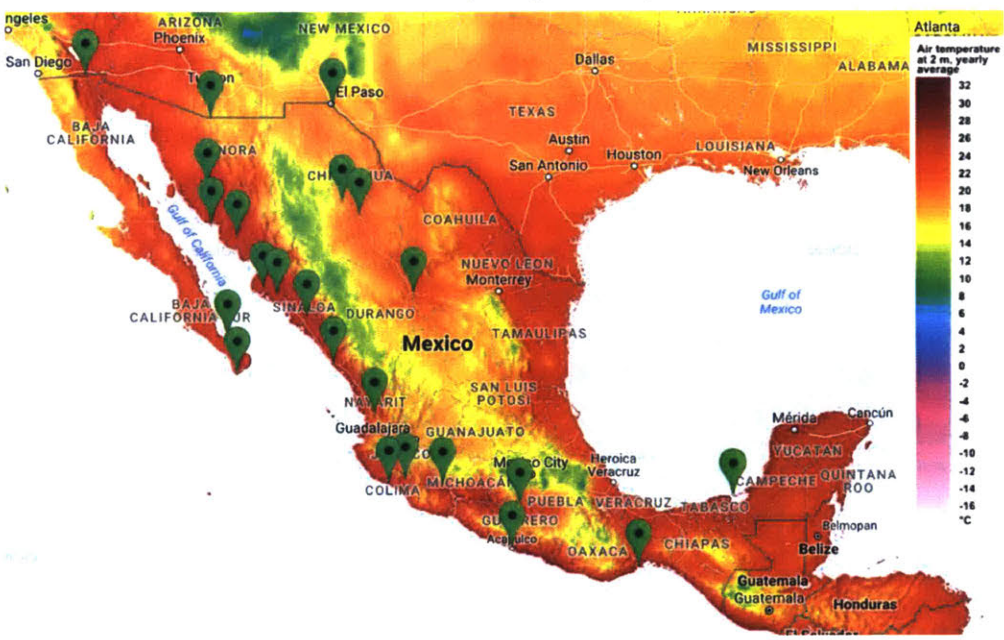


Figure C.22 source: SolarGIS 2017; GoM 2017b. Figure by author.

Figures C.21 and C.22 show how urban areas with high GHI and high temperatures are predominantly found along the pacific coast of the country. All municipalities depicted in Figures C.20 through C.22 have an accumulated annual GHI of at least 2,100 kWh/m^2 (SolarGIS 2017).

By running the same Z-Score progression with the remaining 23 urban areas, I determine that five of the cities most apt for pilot projects of distributed Solar PV systems are Mexicali, Hermosillo, Ciudad Obregón, Los Mochis, and Guasave.

Figure C.23 - Recommended Cities for Distributed Solar PV Pilot Projects

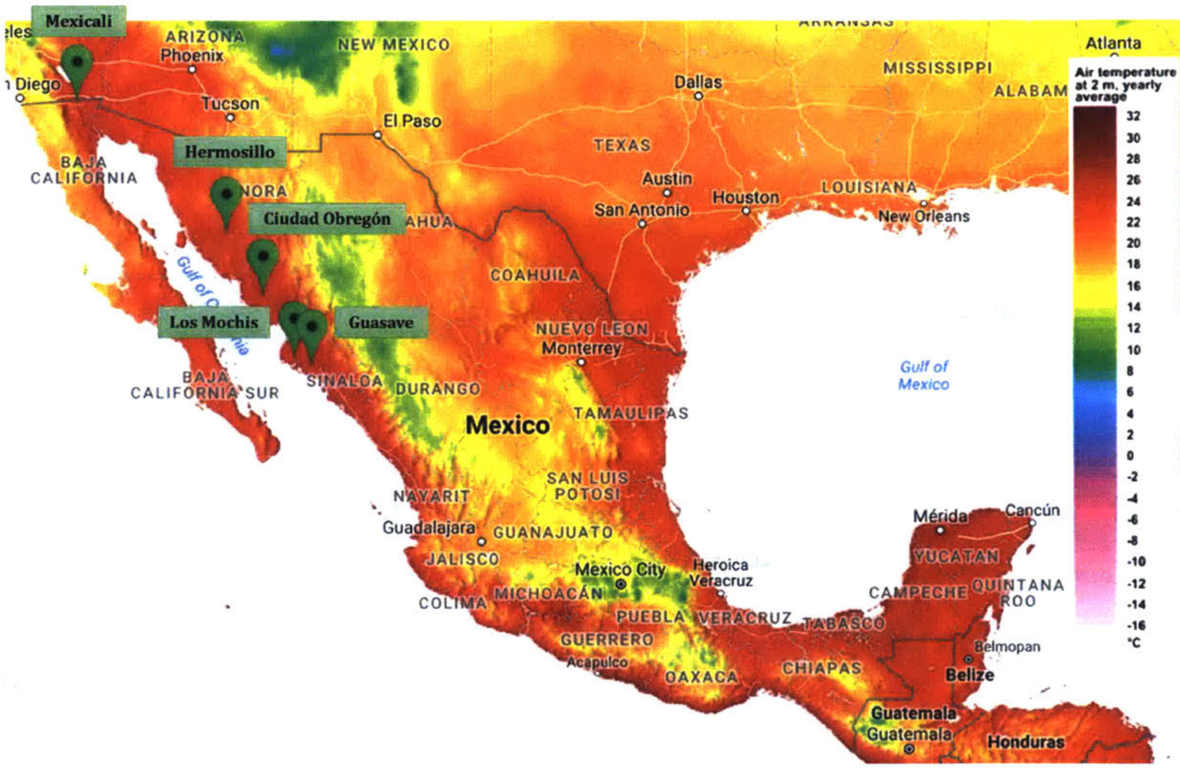


Figure C.23 source: SolarGIS 2017; GoM 2017b. Figure by author.

In 2013, the cities of Mexicali, Hermosillo, Ciudad Obregón, Los Mochis, and Guasave were classified in Domestic Tariff Class 1F. These cities received the highest domestic electricity subsidies.

Figure C.24 - Recommended Cities for Distributed Solar PV Pilot Projects

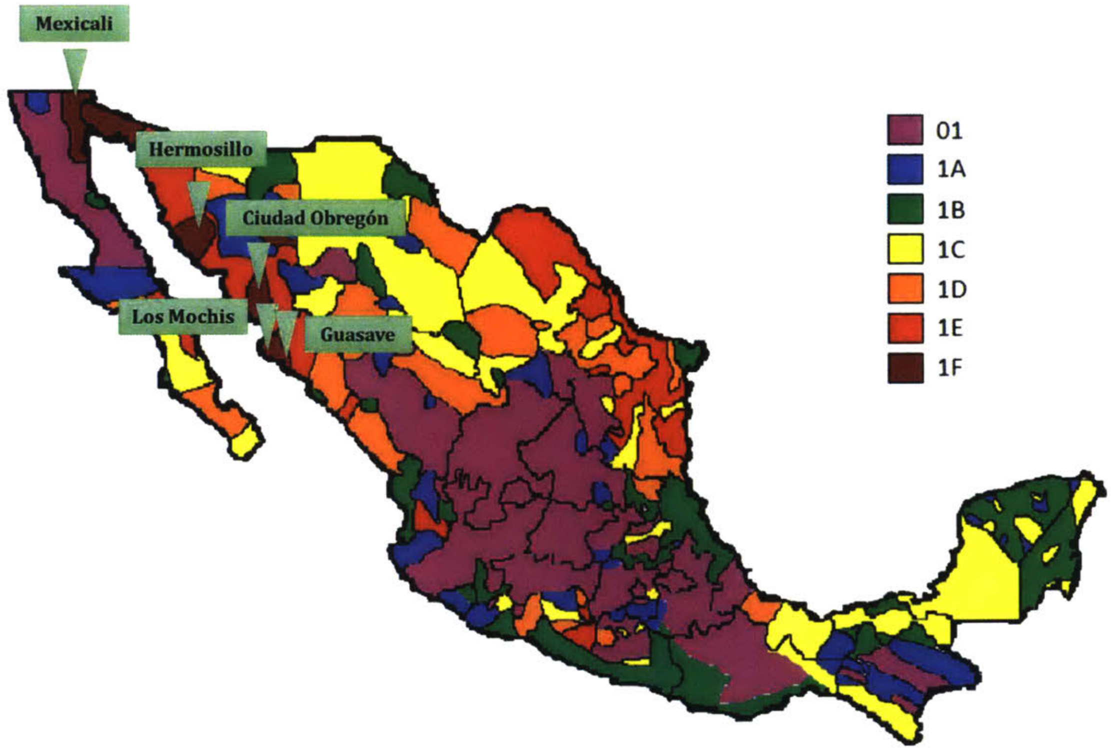


Figure C.24 source: SolarGIS 2017; GoM 2014a; GoM 2017b. Figure by author.

Figure C.25 - Specifications of Recommended Cities for Distributed Solar PV Pilot Projects

Municipality	Population	Temp. July	GHI
Mexicali	1,039,260	35.7	2,189
Hermosillo	882,716	33.0	2,217
Ciudad Obregón	334,325	31.8	2,169
Guasave	309,507	30.8	2,132
Los Mochis	287,624	30.1	2,158

Figure C.25 source: SolarGIS 2017; GoM 2017b. Figure by author.

C.5 – Additional Solar Modeling Figures and Information

Figure C.26 - Canadian SolarCS5P-220M (220 W) Solar Panel Specifications

Category	*Specifications*
STC Power Rating	220 W

PTC Power Rating	200.1 W
STC Power per unit of area	12.0W/ft² (129.4W/m²)
Peak Efficiency	12.94%
Power Tolerances	0%/+2%
Number of Cells	96
Nominal Voltage	N/A
Imp	4.68A
Vmp	47V
Isc	5.01A
Voc	58.8V
NOCT	45°C
Temp. Coefficient of Power	-0.45%/K
Temp. Coefficient of Voltage	-0.206V/K
Series Fuse Rating	10A
Maximum System Voltage	600V
Type	Monocrystalline Silicon
Output Terminal Type	Multicontact Connector Type 4
Output Cable Wire Gauge	12 AWG
Output Cable Wire Type	PV Wire
Frame Color	Clear
Length	63.1in (1,602mm)
Width	41.8in (1,061mm)
Depth	1.6in (40mm)
Weight	44.1lb (20kg)
Installation Method	Rack-Mounted

Figure C.26 source: PVPMC 2017 Figure by author.

Figure C.27 - Baja California Sur Wholesale Electricity Market Average Bid Information (1/1/2017 - 2/18/2017)

Power Plant Station	*Maximum Capacity (MW)*	*Average Cost (MXN/MWh)*
77AIEFOMOVV0JBB	37	$ 1,512.85
77AIEFOMOVA8O7V	37	$ 1,537.11
6DU0LFOMOVV0JBB	37	$ 1,559.90
77AIEFOMOVA7N95	37	$ 1,578.93
77AIEFOMOV4R3LV	42.37	$ 1,587.38
6DU0LFOMOVA7N95	37	$ 1,595.11
6DU0LFOMOVA8O7V	37	$ 1,612.83
JWS1I853U6BCWAG	37	$ 1,652.22
6DU0LFOMOVZHVNK	35	$ 1,688.08
6DU0L853U6BCWAG	37	$ 1,724.15
6DU0LFOMOV4R3LV	42.37	$ 1,731.57

JWS1I853U64ZYK7	28	$ 1,836.02
6DU0L853U64ZYK7	28	$ 1,906.64
77AIEFOMOVZIIVNK	35	$ 1,948.89
JWS1I853U6ZJ8CX	28	$ 1,984.16
6DU0L853U6ZJ8CX	28	$ 2,060.50
ON3008FYE37NZXE	34.58	$ 2,114.35
ON3008FYE396KOV	34.57	$ 2,133.52
ON3008FYE3VDPO5	34.58	$ 2,205.34
6DU0L8FYE37NZXE	34.58	$ 2,217.97
6DU0L8FYE396KOV	34.57	$ 2,233.97
6DU0L8FYE3VDPO5	34.58	$ 2,276.66
6DU0LXVJPCFVJYK	27	$ 2,831.22
9CR1WXVJPCFVJYK	27	$ 2,833.30
77AIEFOMOV59U5O	25.87	$ 3,704.00
9CR1WGAVSK7J06F	26.85	$ 4,186.64
6DU0L8FYE3H88F8	24.78	$ 4,209.42
6DU0LGAVSK7J06F	26.85	$ 4,352.46
6DU0LGAVSKV7U7K	26	$ 4,375.57
9CR1WGAVSKV7U7K	26	$ 4,488.30
6DU0LFOMOV59U5O	25.87	$ 4,576.21
6DU0LGAVSKGU5IW	26	$ 4,665.66
6DU0LGAVSK9954W	26	$ 4,713.95
9CR1WGAVSKGU5IW	26	$ 4,785.79
9CR1WGAVSK9954W	26	$ 4,835.34
ON3008FYE3H88F8	24.78	$ 4,866.05
6DU0L8FYE3NLVM5	17.86	$ 4,930.75
9CR1WGAVSKK57VD	25.83	$ 5,026.92
6DU0LGAVSKK57VD	25.83	$ 5,172.99
ON3008FYE3NLVM5	17.86	$ 5,688.33
6DU0LGAVSKC87A9	23.86	$ 5,823.38
9CR1WGAVSKC87A9	23.86	$ 5,889.16

Figure C.27 source: "CENACE 2017b" Figure by author.

Figure C.28 - BCS average 2016 Wholesale Electricity Market Supply Curve

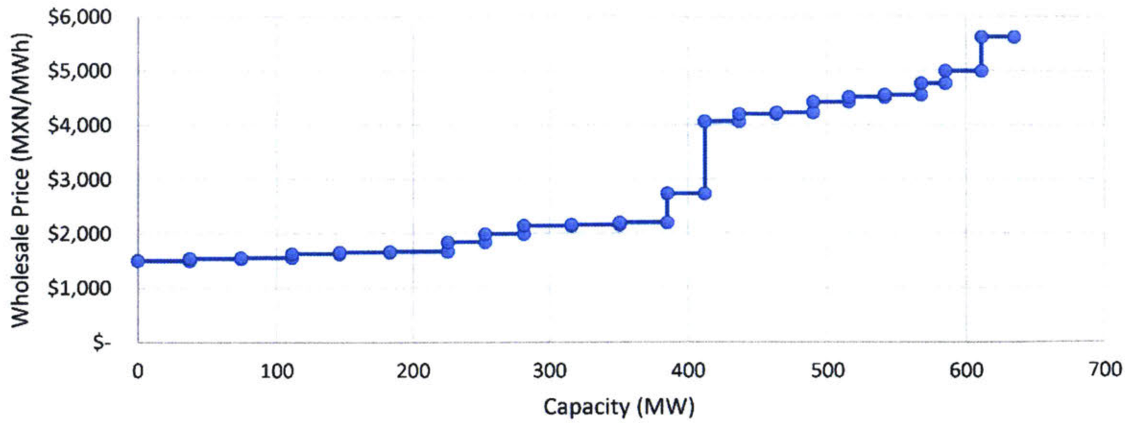


Figure C.29 - BCS average 2018 Wholesale Electricity Market Supply Curve

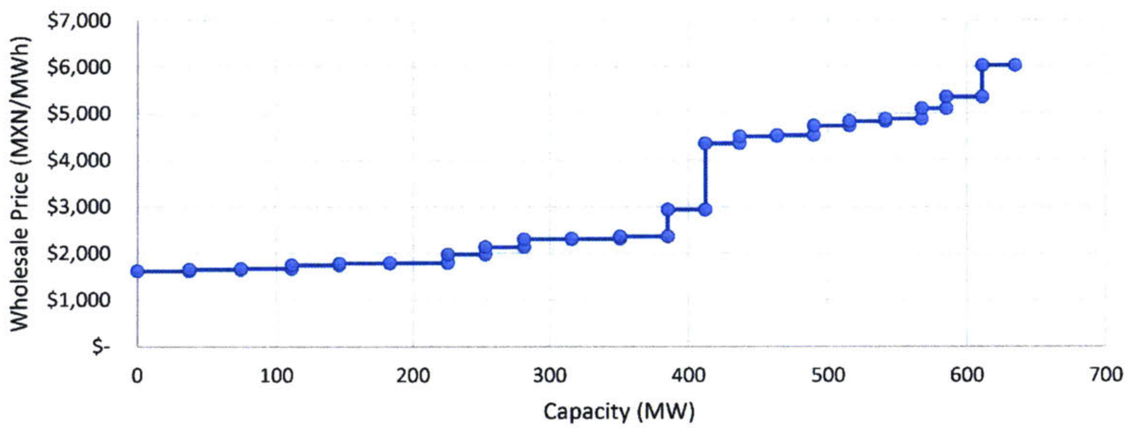


Figure C.30 - BCS average 2019 Wholesale Electricity Market Supply Curve

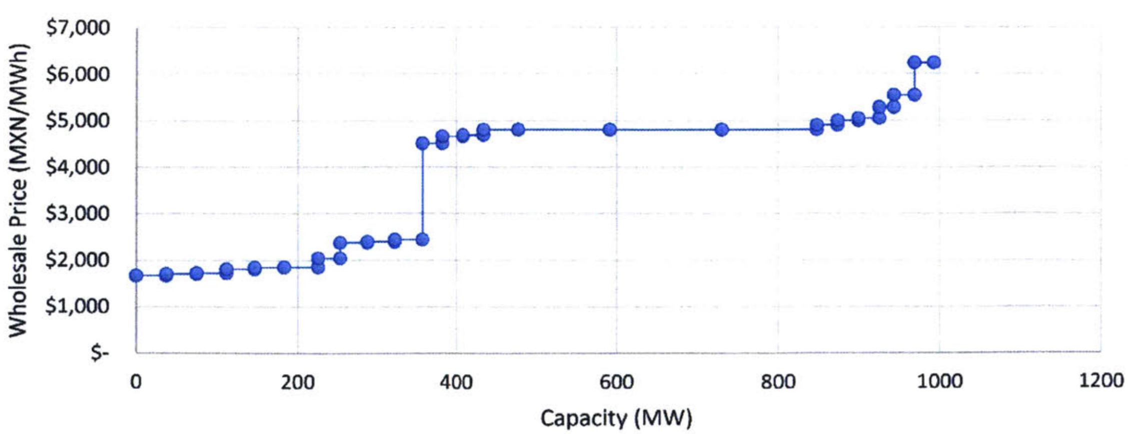


Figure C.31 - BCS average 2020 Wholesale Electricity Market Supply Curve

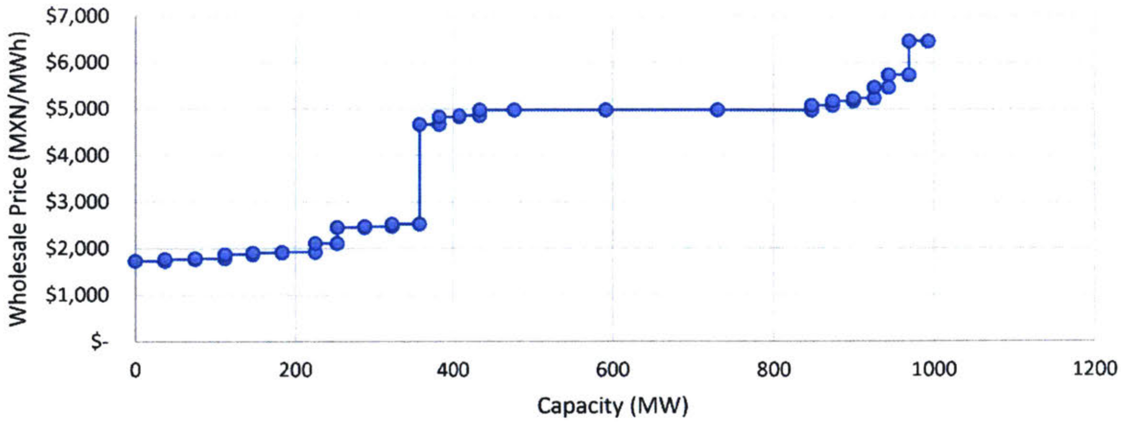


Figure C.32 - BCS average 2021 Wholesale Electricity Market Supply Curve

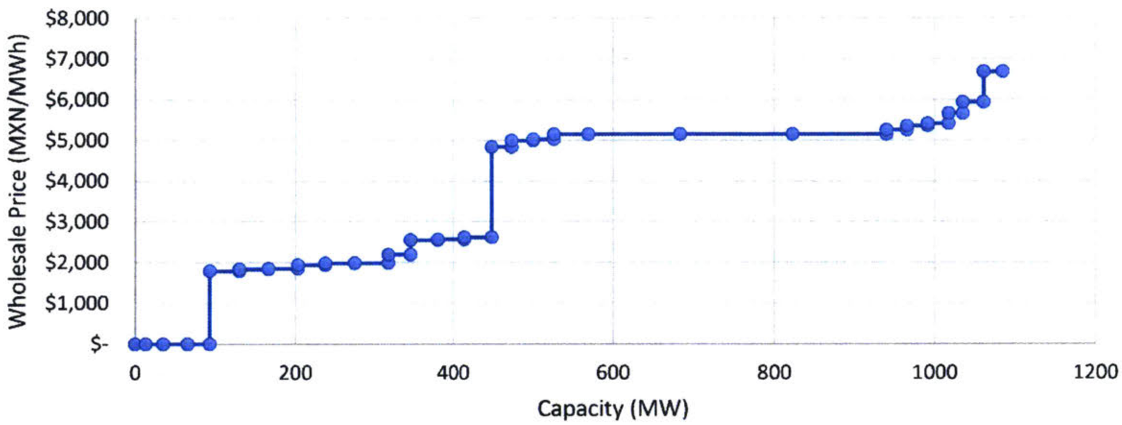


Figure C.33 - BCS average 2022 Wholesale Electricity Market Supply Curve

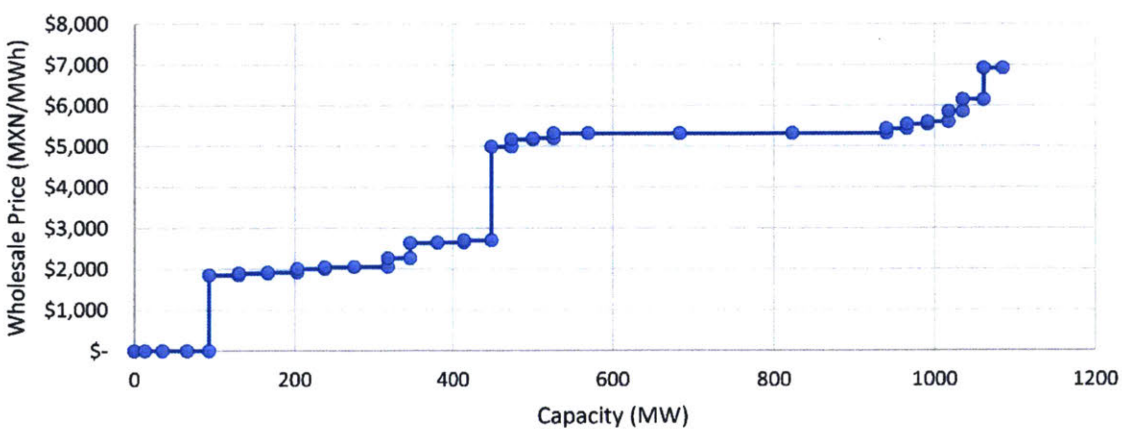


Figure C.34 - BCS average 2023 Wholesale Electricity Market Supply Curve

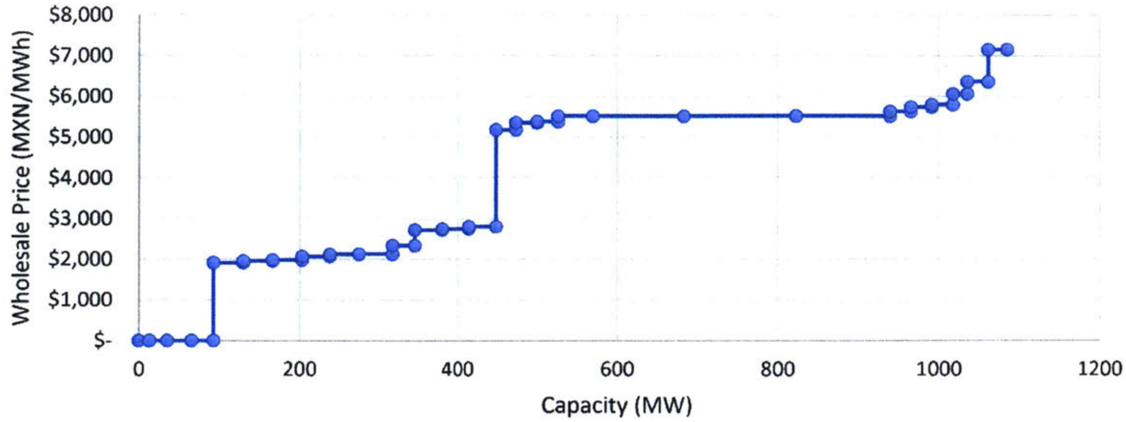


Figure C.35 - BCS average 2024 Wholesale Electricity Market Supply Curve

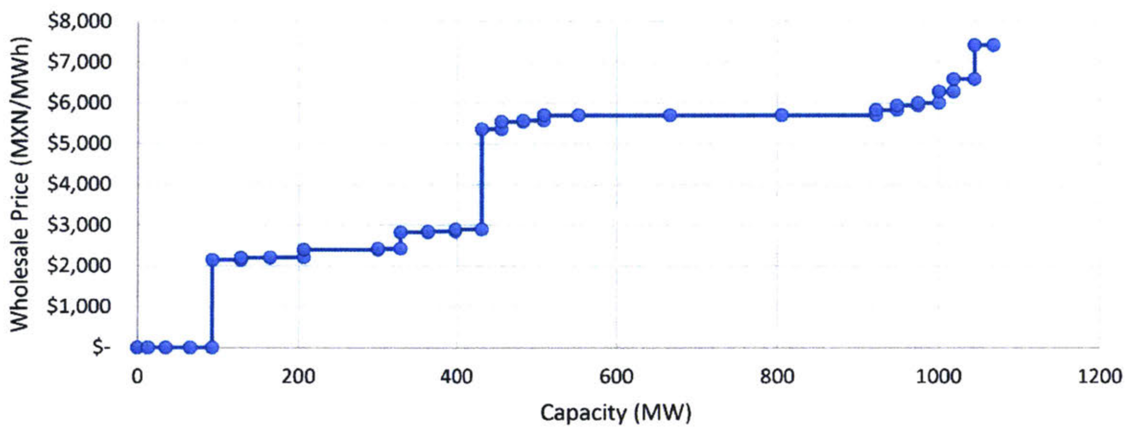


Figure C.36 - BCS average 2025 Wholesale Electricity Market Supply Curve

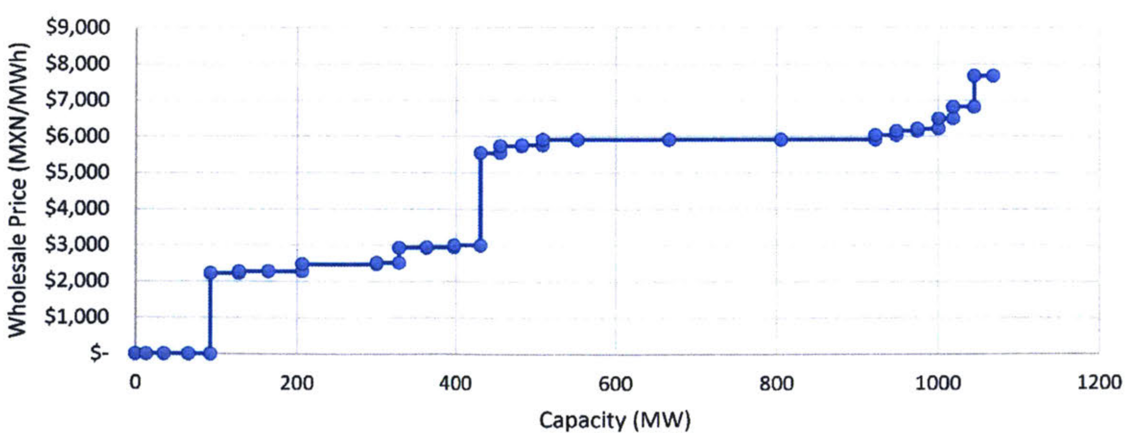


Figure C.37 - BCS average 2026 Wholesale Electricity Market Supply Curve

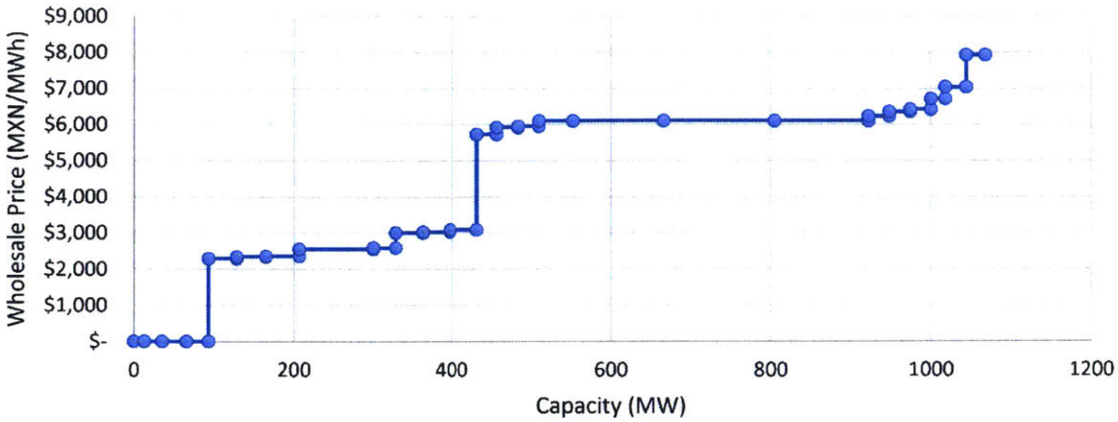


Figure C.38 - BCS average 2027 Wholesale Electricity Market Supply Curve

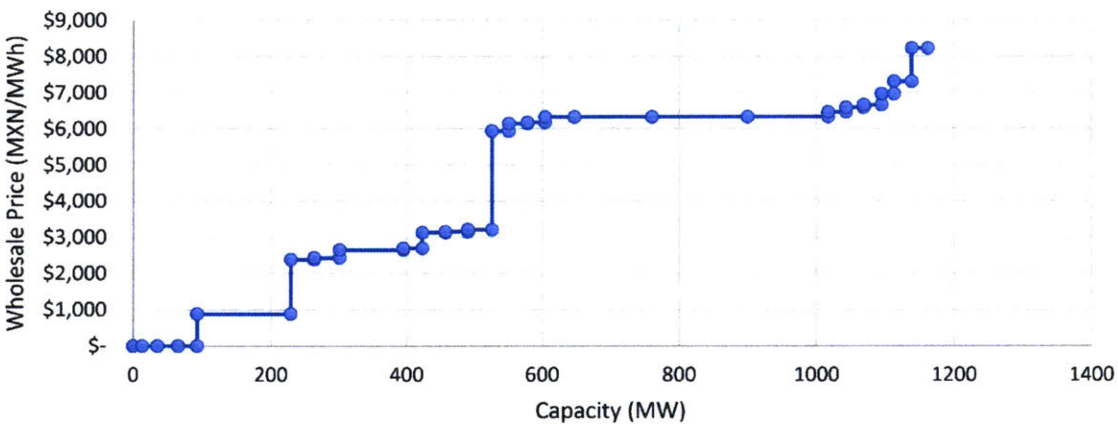


Figure C.39 - BCS average 2028 Wholesale Electricity Market Supply Curve

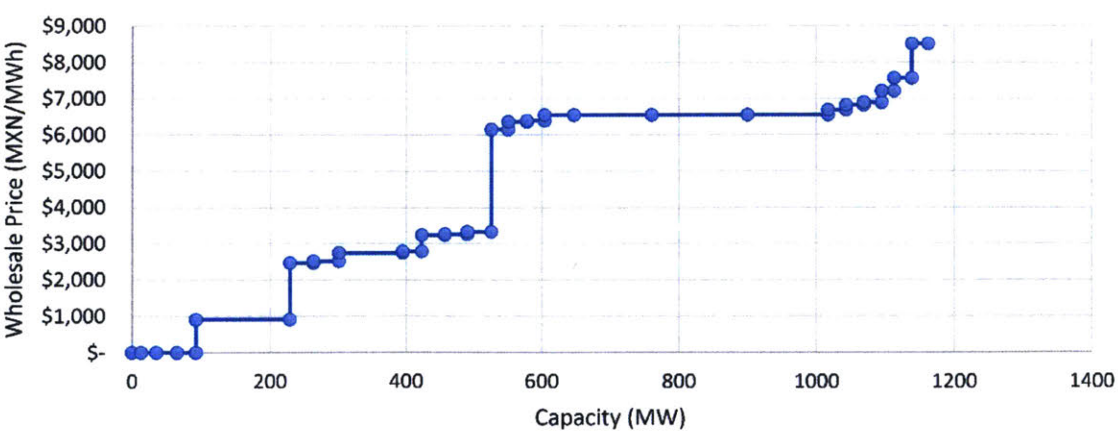


Figure C.40 - BCS average 2029 Wholesale Electricity Market Supply Curve

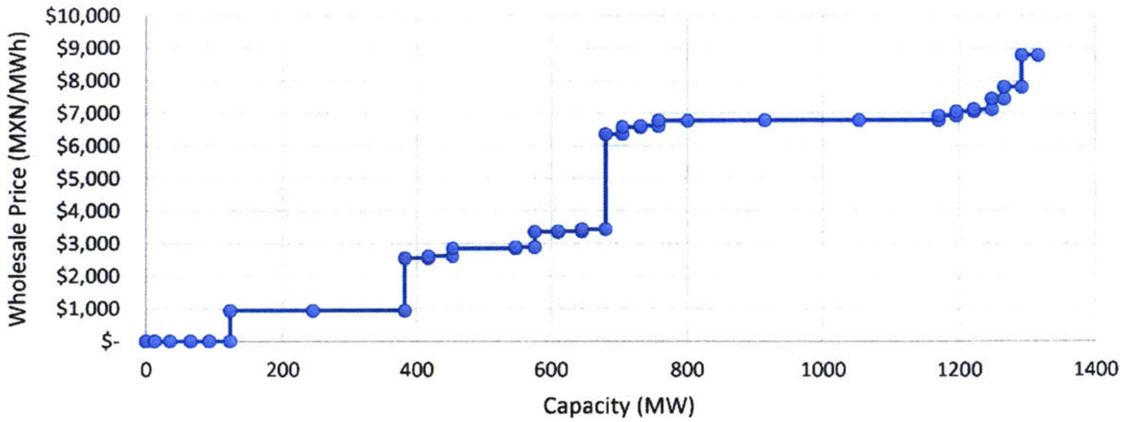
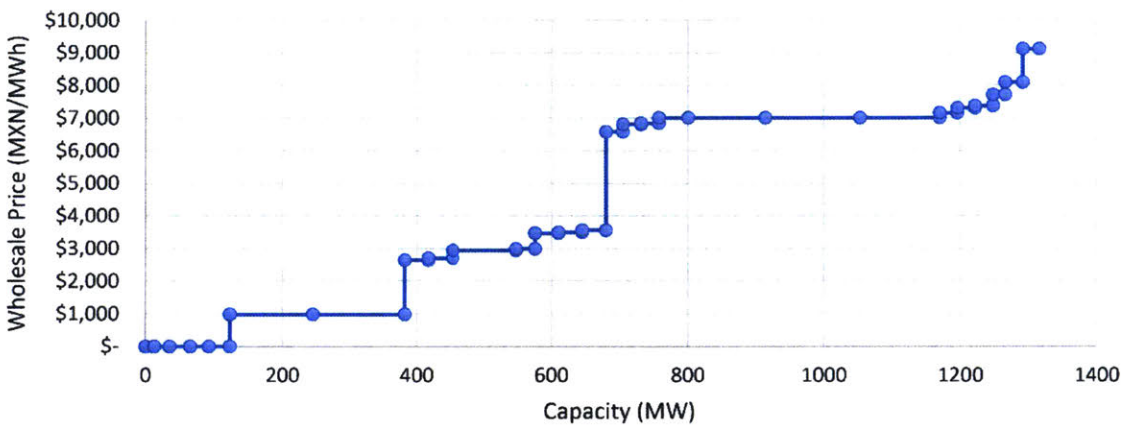


Figure C.41 - BCS average 2030 Wholesale Electricity Market Supply Curve



Figures C.28 – C.41source: SENER 2017a, SENER 2015a, CENACE 2017b.

Figure C.42 - BCS Norm. Demand Profile w/Solar PV - January 2016

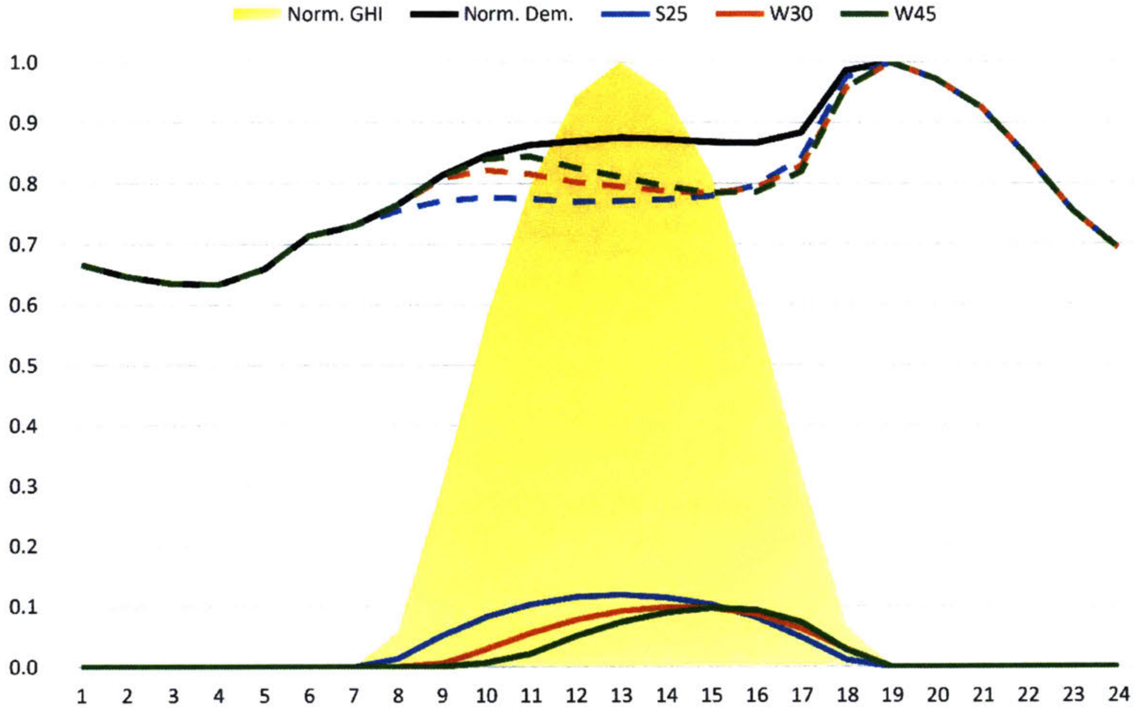


Figure C.43 - BCS Norm. Demand Profile w/Solar PV - February 2016

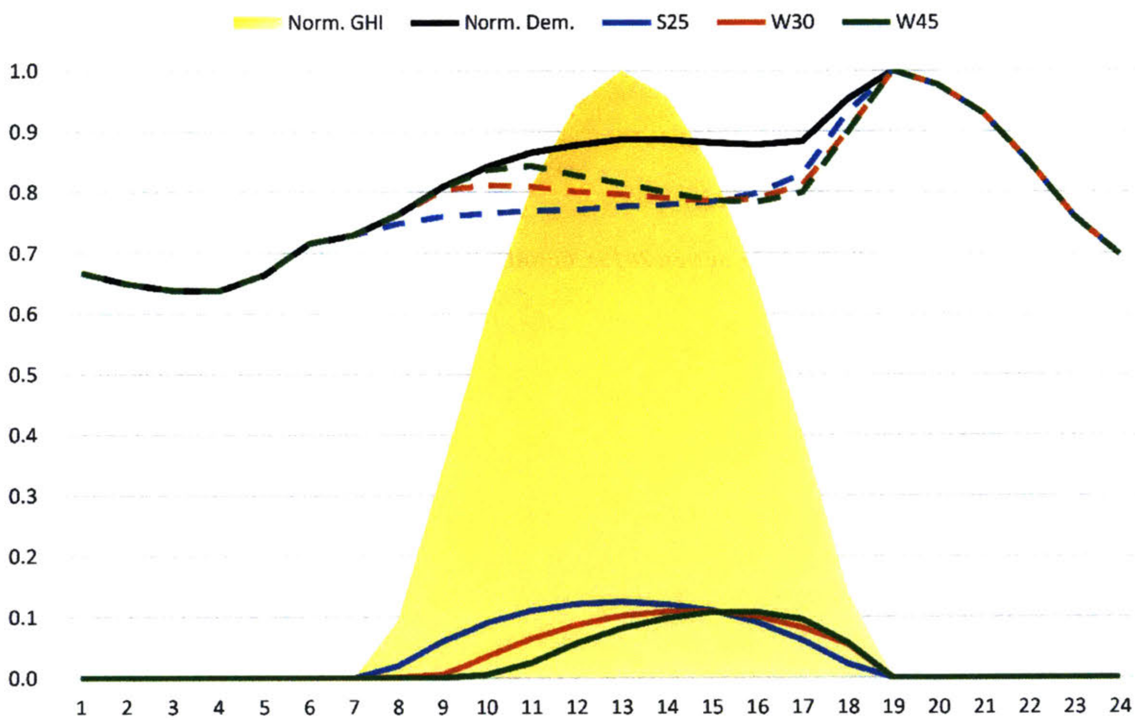


Figure C.44 - BCS Norm. Demand Profile w/Solar PV - March 2016

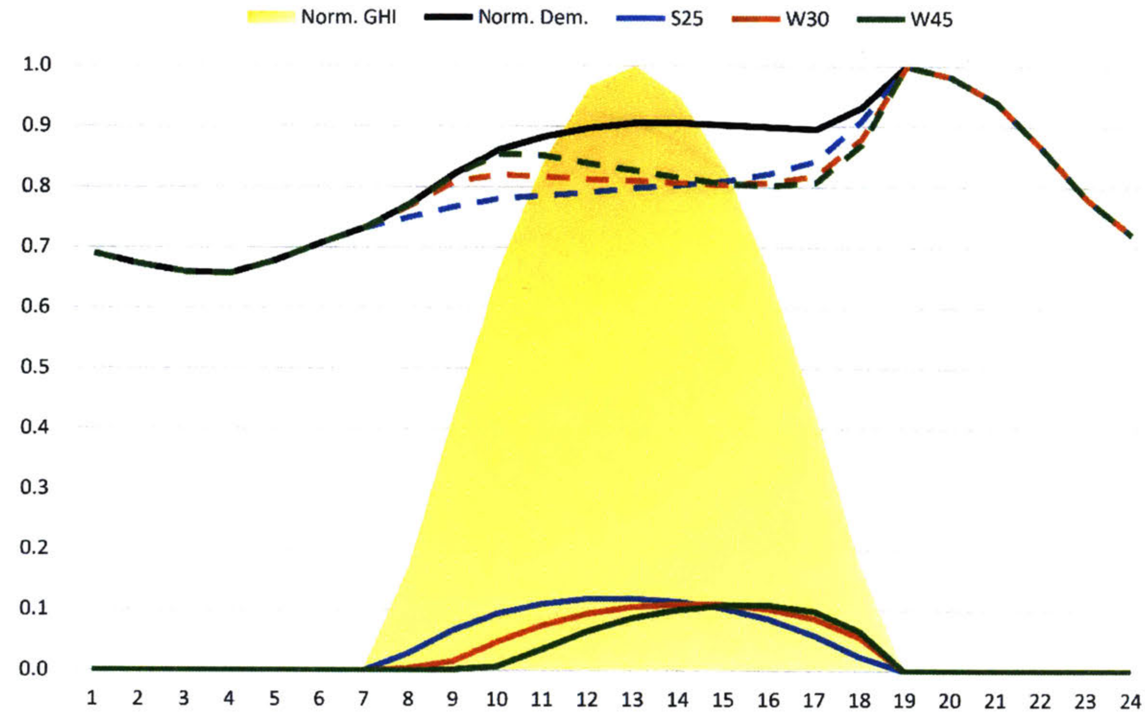


Figure C.45 - BCS Norm. Demand Profile w/Solar PV - April 2016

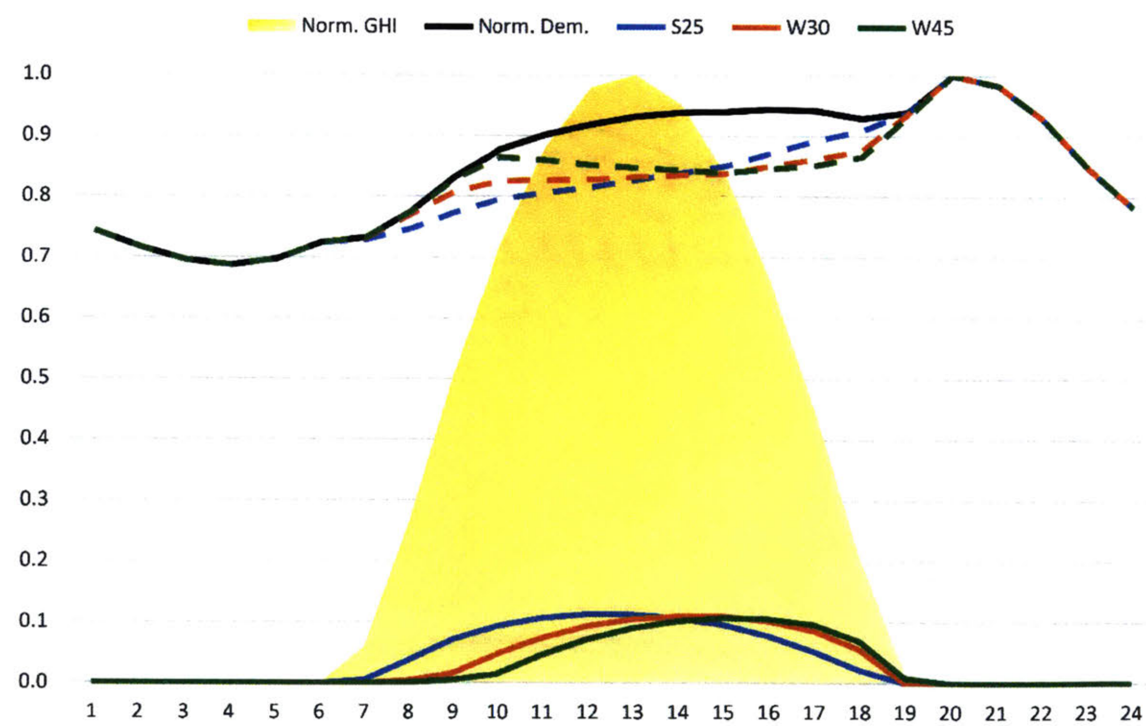


Figure C.46 - BCS Norm. Demand Profile w/Solar PV - May 2016

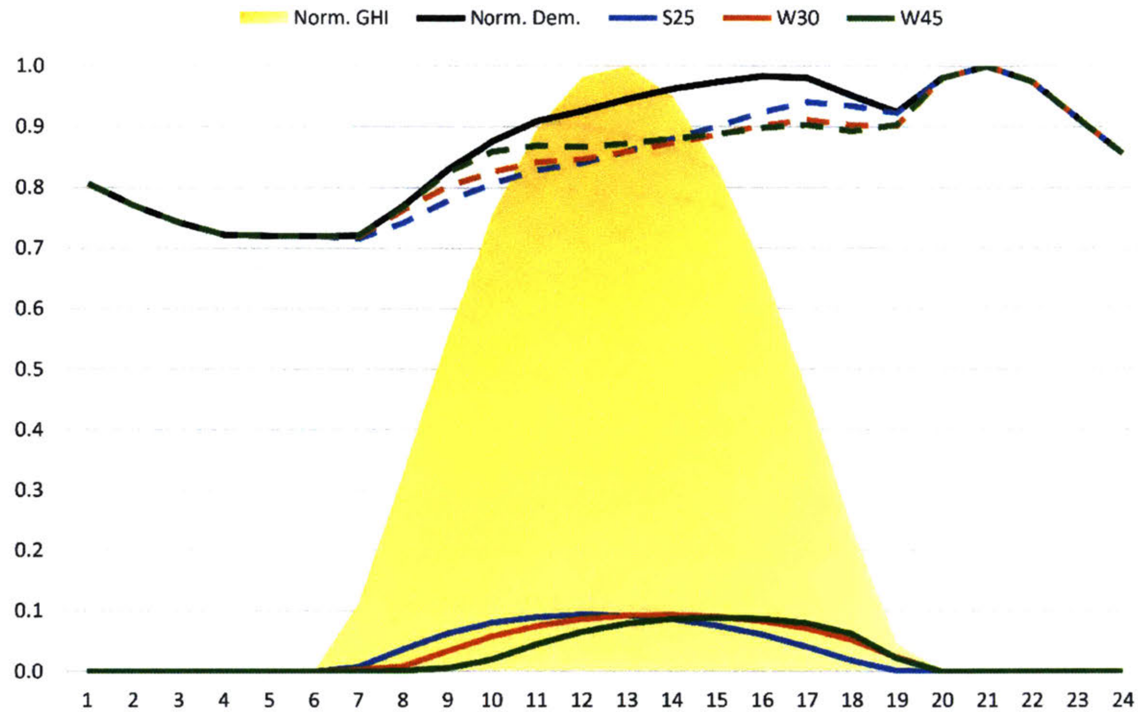


Figure C.47 - BCS Norm. Demand Profile w/Solar PV - June 2016

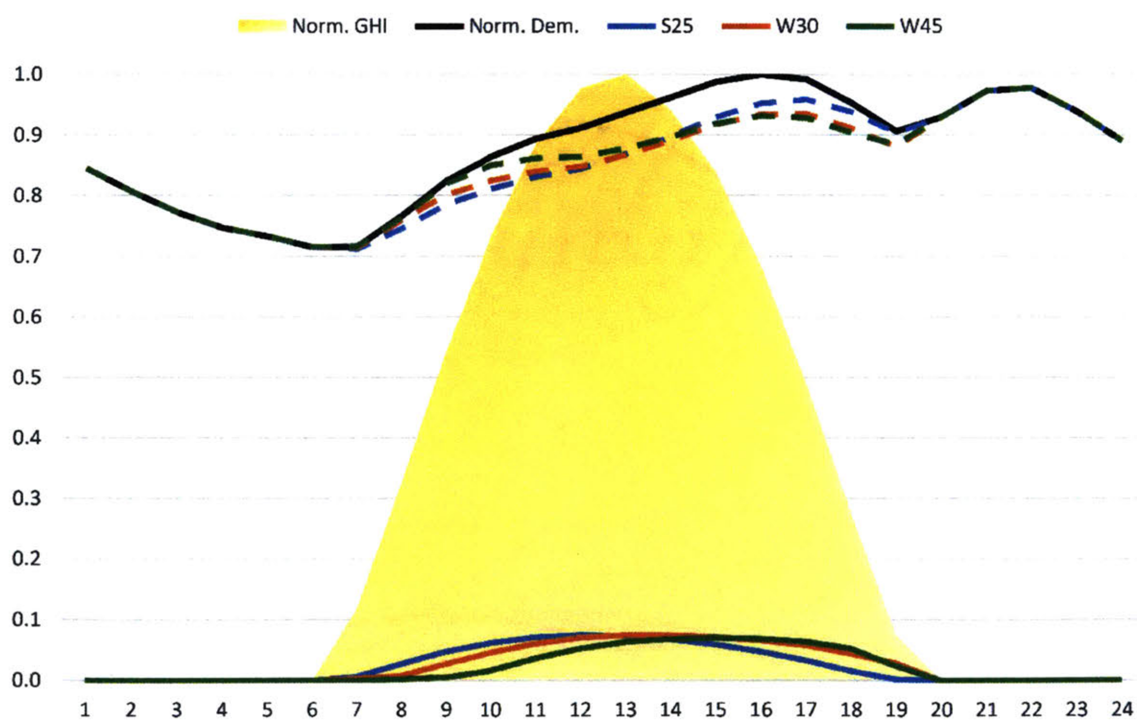


Figure C.48 - BCS Norm. Demand Profile w/Solar PV - July 2016

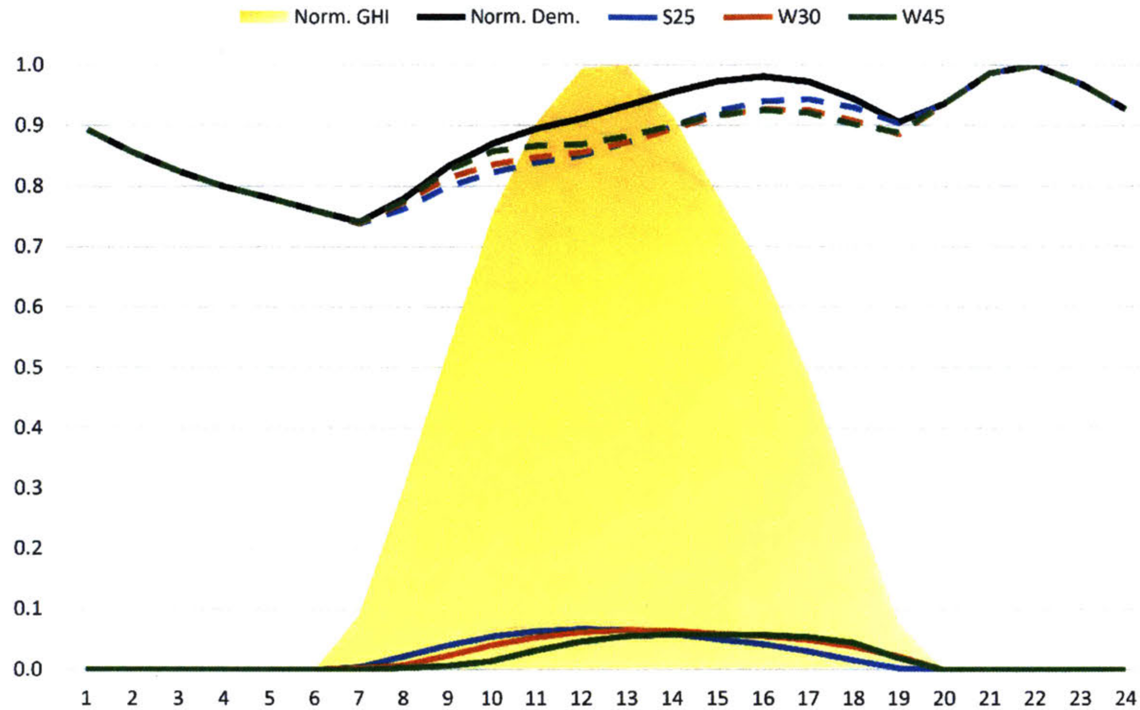


Figure C.49 - BCS Norm. Demand Profile w/Solar PV - August 2016

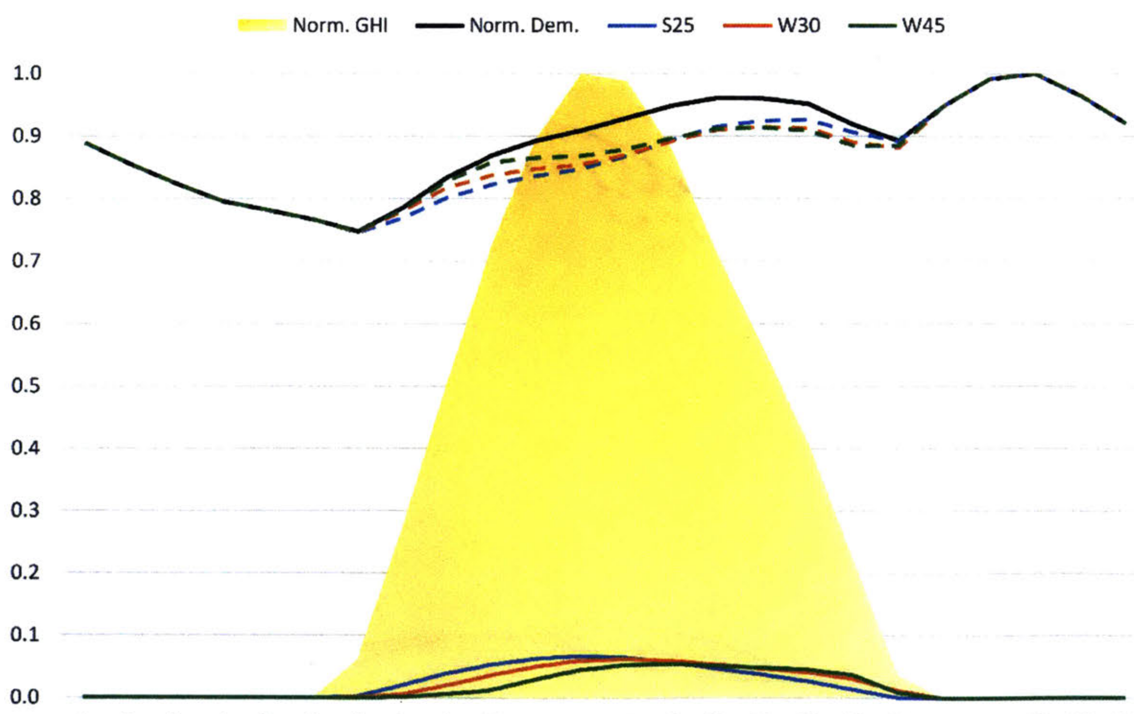


Figure C.50 - BCS Norm. Demand Profile w/Solar PV - September 2016

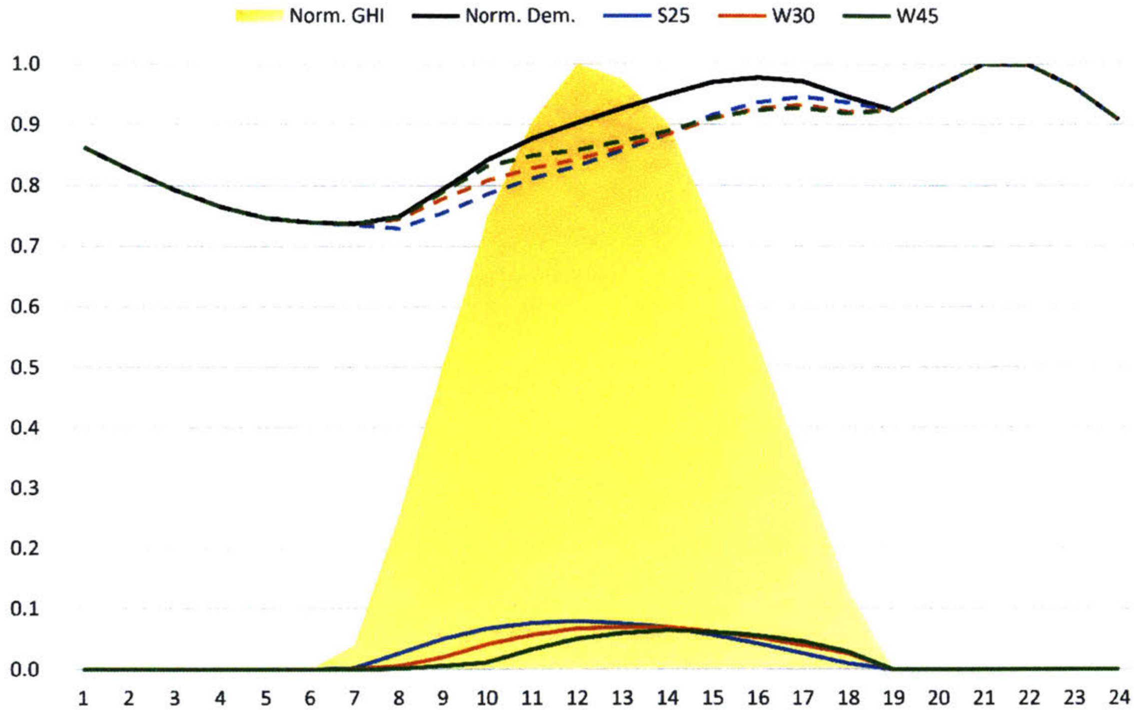


Figure C.51 - BCS Norm. Demand Profile w/Solar PV - October 2016

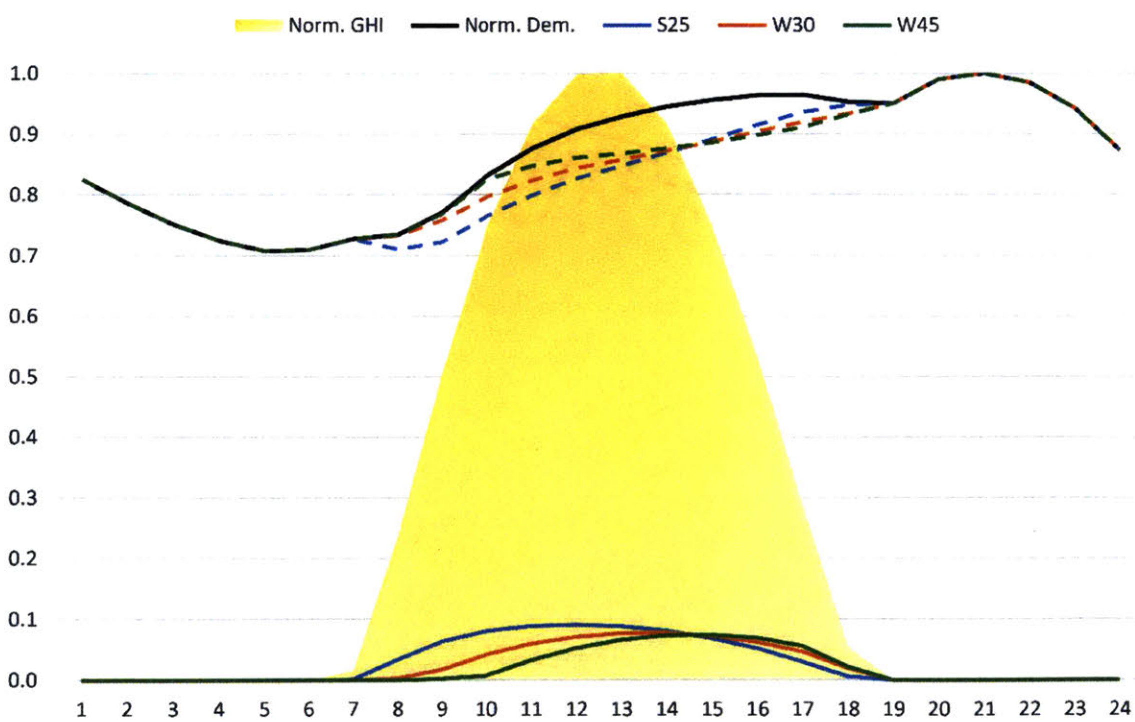


Figure C.52 - BCS Norm. Demand Profile w/Solar PV - November 2016

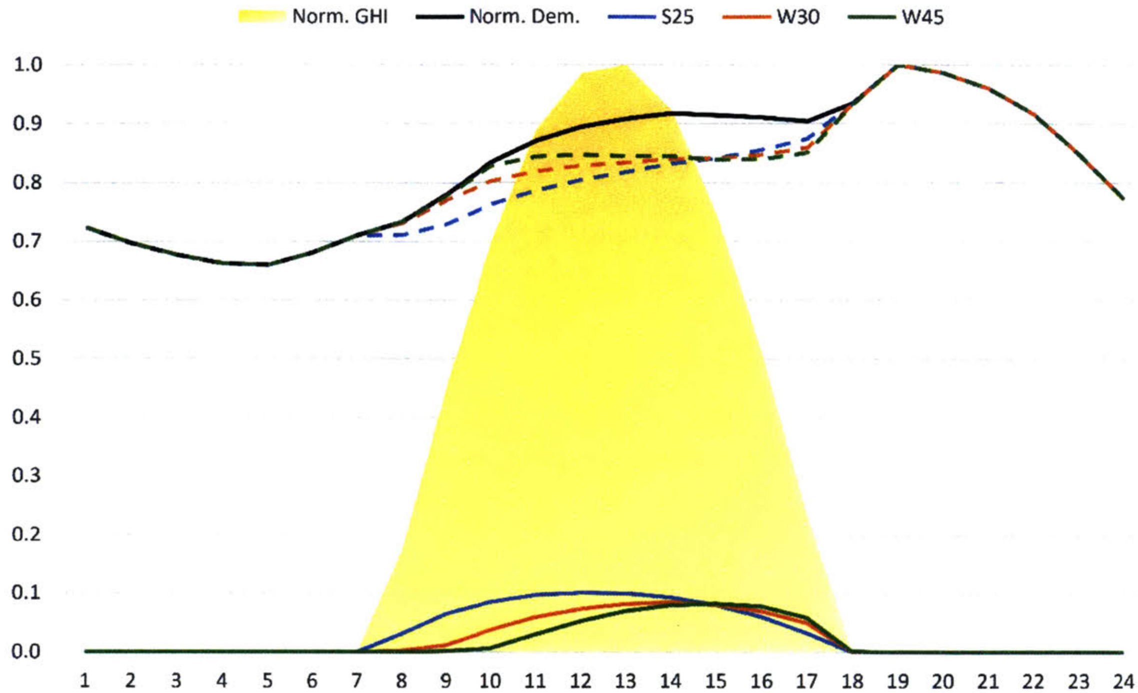
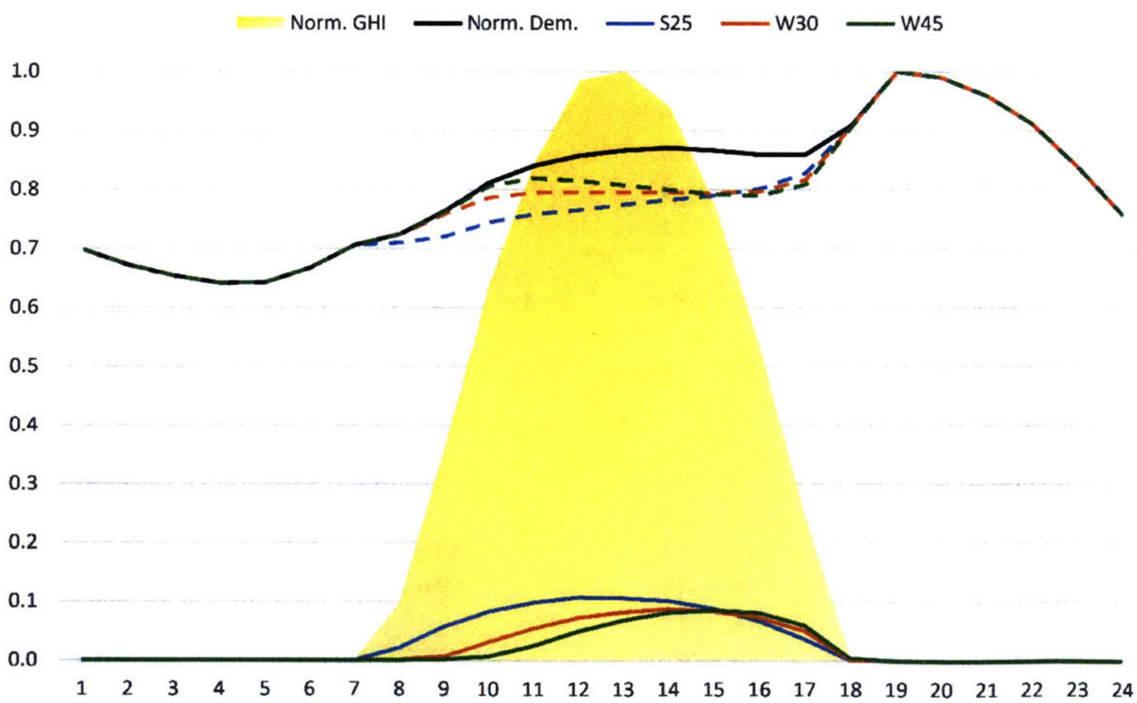


Figure C.53 - BCS Norm. Demand Profile w/Solar PV - December 2016



Figures C. 42 - C.53 source: NSRDB 2017; CENACE 2017b; PVPMC 2017. Figure and results by author.

Figure C.54 - Municipalities with more than 100,000 Inhabitants

Municipality	Population
Iztapalapa	1,798,073.9
Ecatepec de Morelos	1,778,081.6
Puebla	1,518,583.3
Guadalajara	1,513,498.1
Juárez	1,422,149.0
Tijuana	1,411,843.4
León	1,284,388.4
Zapopan	1,223,813.2
Monterrey	1,193,586.0
Nezahualcóyotl	1,178,865.1
Gustavo A. Madero	1,166,483.3
Chihuahua	907,431.8
Naucalpan de Juárez	848,743.4
Mérida	845,704.5
Hermosillo	799,164.8
Aguascalientes	783,029.3
Saltillo	782,551.0
San Luis Potosí	775,219.7
Benito Juárez	764,845.1
Culiacán	764,696.4
Mexicali	742,300.8
Álvaro Obregón	731,225.5
Chimalhuacán	715,054.7
Acapulco de Juárez	714,738.0
Guadalupe	701,832.0
Tlalnepantla de Baz	692,398.9
Reynosa	670,602.4
Torreón	668,534.8
Querétaro	645,493.4
San Pedro Tlaquepaque	616,200.6
Coyoacán	610,111.7
Morelia	606,189.3
Tuxtla Gutiérrez	600,148.8
Durango	579,979.3
Tlalpan	574,792.5
Apodaca	545,005.1
Atizapán de Zaragoza	541,054.9
Cuauhtémoc	532,108.2
Toluca	527,726.4
Cuautitlán Izcalli	527,716.4
Matamoros	491,690.5
Xalapa	456,828.0
San Nicolás de los Garza	452,452.3
Tonalá	450,878.9
Veracruz	432,954.6
Mazatlán	420,834.3
Venustiano Carranza	417,894.9
Xochimilco	407,028.4
General Escobedo	406,110.0
Nuevo Laredo	405,533.8
Azcapotzalco	404,443.8
Irapuato	401,332.5
Valle de Chalco Solidaridad	399,925.0
Benito Juárez	396,477.7
Tepic	381,568.5
Miguel Hidalgo	379,559.5
Iztacalco	374,525.0
Ixtapaluca	370,593.1
Celaya	354,034.2
Cuernavaca	353,230.2
Centro	345,419.2
Victoria	336,547.8
Cajeme	334,325.2
Nicolás Romero	327,315.4
Tecámac	321,057.5
Tampico	311,029.6
Tláhuac	306,077.5
Ensenada	298,966.6
Coacalco de Berriozábal	298,185.2
Soledad de Graciano Sánchez	289,404.4
Santa Catarina	288,306.7
Ahome	287,623.9
Uruapan	282,455.3
Gómez Palacio	279,097.4
Tehuacán	266,697.6
Oaxaca de Juárez	260,311.5
Pachuca de Soto	257,402.7
La Paz	249,726.9
Campeche	244,548.1
La Magdalena Contreras	241,106.0
Nogales	239,115.4

Coatzacoalcos	239,082.9
Tultitlán	233,548.0
Monclova	232,065.2
Puerto Vallarta	226,971.9
Tapachula	219,252.5
Tultitlán	217,793.6
Ciudad Madero	210,915.2
Juárez	206,311.6
Chilpancingo de los Bravo	203,226.7
Solidaridad	201,228.9
Chalco	198,867.2
Poza Rica de Hidalgo	194,734.1
Carmen	189,576.6
Chicoloapan	188,495.9
Othón P. Blanco	177,995.5
San Luis Río Colorado	177,373.7
San Cristóbal de las Casas	175,664.0
Jiutepec	173,553.4
Salamanca	171,559.5
Cuajimalpa de Morelos	164,251.0
Cuautla	163,894.3
Piedras Negras	159,507.1
San Juan del Río	153,758.7
Colima	152,748.7
Zamora	151,155.9
Altamira	150,900.8
Manzanillo	148,916.0
Guadalupe	144,961.2
Acolman	144,534.5
Acuña	144,517.4
Córdoba	142,379.4
Villa de Álvarez	137,601.3
Zacatecas	135,753.4
Ciudad Valles	133,882.2

Delicias	132,371.6
San Pedro Garza García	132,258.7
Cuauhtémoc	131,294.1
Cuautitlán	131,187.0
Ocosingo	129,892.0
Fresnillo	129,104.4
Huixquilucan	128,516.9
García	128,404.0
Boca del Río	128,226.2
Navojoa	126,959.8
Guaymas	126,054.5
Orizaba	125,096.1
Iguala de la Independencia	122,953.5
Tlajomulco de Zúñiga	122,308.0
Texcoco	115,114.6
Hidalgo del Parral	114,289.1
Minatitlán	112,520.8
Comitán de Domínguez	111,247.4
Mexicali	110,690.2
Guasave	109,448.3
Culiacán	109,054.4
San Juan Bautista Tuxtepec	108,918.7
Lagos de Moreno	106,881.1
Río Bravo	106,233.3
Temixco	105,891.8
Tulancingo de Bravo	105,560.0
Zapotlán el Grande	103,876.3
Apatzingán	102,061.3
Chilón	101,698.7
Kanasín	101,230.0
Tepatitlán de Morelos	100,693.0

Figures C.54 source: GoM 2017b. Figure by author.

Appendix D – Additional Information

Figure D.1 – Interviewed Individuals

Group	Interviewee	Company and Position	Date of Interview
Private Companies, Solar Associations, and Advocacy Groups	**Jesús Luis Suarez**	Founder and CEO of Energía Verde Alternativa, S.A. de C.V.	12/20/2016
	Roberto Capuano Tripp	Co-founder and COO of Enlight, S.A. de C.V. and President of the Distributed Generation Committee in ASOLMEX (Mexican Association of Solar PV Energy)	12/24/2016
	Daniel Chacón Anaya	Official at Iniciativa Climática de México (ICM)	2/20/2017
	Tomas Gottfried Blackmore	Engineering Manager for *Potencia Industrial* and owner of Distributed Generation system	3/13/2017
Ministry of Energy	**Diego Villarreal**	Deputy Managing Director of Electric Industry Coordination	12/29/2016
	César Alejandro Hernández Alva	Managing Director of Electricity Analysis	1/3/2017
	Carlos Ortiz Gómez	Managing Director of Technological Research and Formation of Human Resources	1/3/2017
	Leticia Rojas	Deputy Director of Technological Research and Formation of Human Resources	1/3/2017
	Edmundo Gil Borja	Managing Director of Distribution and Commercialization of Electric Energy and Social Entailment	2/8/2017
	Oliver Ulises Flores Parra Bravo	Managing Director of Generation and Transmission of Electric Energy	2/16/2017
Regulatory Commission of Energy	**Guillermo Zuñiga Martínez**	National Commissioner	1/13/2017
	Alejandro Chanona Robles	Coordinator of Advisors to the Commissioner President	2/14/2017

Independent System Operators	**Nemorio González Medina**	Director of System Operation and Planning at CENACE	2/16/2017
	Tom Cuccia	Lead Stakeholder Engagement and Policy Specialist at CAISO	2/28/2017
Federal Commission of Electricity	**Miguel Angel Loredo Gutiérrez**	Deputy Manager of Electricity Distribution Planning Management	2/28/2017
	Héctor Hugo Espinosa Morales	Electricity Distribution Planning Management	2/28/2017
	Ramón Avila Vázquez	Electricity Distribution Planning Management	2/28/2017

Figure D.2 - Interview Outline

1. What is your current position?
2. How did you come to be in your current position?
3. Can you briefly explain your role and responsibilities?
4. What has been the planning process for clean DG regulation in Mexico?
5. Who do you view as stakeholders in the electricity market in Mexico?
6. What do you consider to be the most valuable virtues of clean DG?
    a. Do you view Energy Independence as a real virtue of clean DG systems? Is it something that the [stakeholder name] is pursuing?
7. What is your opinion on the different mechanisms used to promoted clean DG deployment and their use in the Mexican Electricity Market? (i.e., Feed-In Tariffs, net metering, subsidies, etc.)
    a. What do you think of Feed-In Tariffs increasing costs to the electric utility and its customers?
    b. What do you think of Net-Metering schematics and their inability to differentiate between peak and non-peak hours of electricity consumption and production?
    c. What do you think of the recently implemented Clean Energy Certificate market and how can it be used to promote the deployment of clean DG?
    d. What do you think about the use of direct subsidies to promote clean DG in Mexico? Where do you think the subsidies should come from?
8. Out of the previously mentioned mechanisms and other mechanisms, which one would you prefer to see implemented in Mexico?
9. What role do you see clean DG playing in Mexico's Clean Energy targets and commitments?
10. What do you think of the large volume of subsidies given to residential electricity customers?
    a. Should these subsidies be restructured?
11. What do you see as the biggest barriers to implement clean DG in Mexico?
12. What do you think is the position of other Stakeholders with regards to how the deployment of clean DG should be incentivized in Mexico?

13. Given the very small penetration of DG that currently exists and is expected to persist in the near future, do you think the Mexican government should be pursuing more aggressive forms of DG incentive mechanisms?
    a. Are you concerned with the financial burden that clean DG incentives can bring to the Mexican electricity market?
    b. Are you concerned with the technical burden that clean DG incentives can bring to the Mexican electricity market?
14. If it were up to you, how would you regulate clean DG in order to promote it?
    a. If Mexico were to mimic the regulation of another electricity market, which one would it be?
15. How do you view the roll-out of clean DG to happen in Mexico?
16. Any closing remarks?

Figure D.3 - List of Acronyms

Acronym	Name
ANET	*"Asociación Nacional de Energy Solar"* National Association of Solar Energy
ASOLMEX	*"Asociación Mexicana de Energía Solar Fotovoltáica."* Mexican Solar Photovoltaic Energy Association.
BC	Baja California
BCS	Baja California Sur
BNEF	Bloomberg New Energy Finance
CAISO	California Independent System Operator
CEL	*"Certificado de Energía Limpia"*. Clean Energy Certificate
CENACE	*"Centro Nacional de Control de Electricidad"*. National Electricity Control Center (Independent System Operator)
CFE	*"Comisión Federal de Electricidad"*. Federal Commission of Electricity (Electricity Utility)
COFEMER	*"Comisión Federal de Mejora Regulatoria"*. Federal Commission of Regulatory Improvement.
CONUEE	*"Comisión Nacional para el Uso Eficiente de la Energía"*. National Commission for the Efficient Use of Energy.
CRE	*"Comisión Reguladora de Energía"*. Regulatory Commission of Energy
DAC	*"Domestica de Alto Consumo"*. Refers to CFE's unsubsidized residential electricity tariff. Translation = Domestic High Consumption
DER	Distributed Energy Resources
DOF	"Diario Oficial de la Federación". Official Journal of the Federation
DG	Distributed Electricity Generation

EIA	U.S. Energy Information Administration
EPE	*"Empresa Productiva del Estado"*. Productive State Enterprises
GHI	Global Horizontal Irradiation
ICM	*"Iniciativa Climática de México"*. Climate Initiative of Mexico
IEA	International Energy Agency
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
LIE	*"Ley de la Industria Eléctrica"*. Law of the Electric Industry of Mexico
LTE	*"Ley de Transición Energética"*. Law of Energy Transition
OECD	Organization for Economic Co-operation and Development
PAN	*"Partido de Acción Nacional"*. National Action Party
PRODESEN	*"Programa de Desarrollo del Sistema Eléctrico Nacional"* Development Program of the National Electricity System
QCA	Qualitative Comparative Analysis
SEMARNAT	*"Secretaría del Medio Ambiente y Recursos Naturales"*. Ministry of the Environment and Natural Resources.
SEN	*"Sistema Eléctrico Nacional"*. National Electricity System
SHCP	Ministry of Finance and Public Credit
SIN	*"Sistema Interconectado Nacional."* National Interconnected System (refers to transmission network)
SEMARNAT	Ministry of the Environment
SENER	Ministry of Energy of Mexico
WEM	Wholesale Electricity Market

Figure D.4 - Exchange Rates used throughout Thesis

Year	*Av. Ex Rate*				
2000	$ 9.4568	*2006*	$ 10.9034	*2013*	$ 12.7696
2001	$ 9.3360	*2007*	$ 10.9274	*2014*	$ 13.3032
2002	$ 9.6714	*2008*	$ 11.1438	*2015*	$ 15.8755
2003	$ 10.7913	*2009*	$ 13.4983	*2016*	$ 18.6886
2004	$ 11.2871	*2010*	$ 12.6287	*2017*	$ 20.0537
2005	$ 10.8895	*2011*	$ 12.4301		
		2012	$ 13.1689		

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