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Mexico´s Energy Reform

An analysis of the market, new policy and integration of renewable energy for economic and sustainable development

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Abstract

In the framework of the approved Energy Reform in 2013, Mexico puts an end to seven decades of centralized control of the energy and electricity markets within the government through the State governed companies CFE (Federal Electricity Commission) and PEMEX (Mexican Oil). During the largest part of last century and the beginning of the current, the Mexican government relied heavily on the revenues generated by PEMEX through the sale of oil to foreign countries and tax revenues from the sale of gasoline and diesel as a monopoly. On the other side, CFE controlled the Mexican electricity market by being the sole owner of the electricity grid and the only company allowed to distribute electricity. Electricity generated by private companies for their operations was allowed but any excess of output had to be sold to CFE solely.

The role of these two companies was fundamental for the economic development of the nation, but in past years due to economic changes both companies lost competitiveness. Their impact on the economy is such, that if they lose competitiveness, so does the country as a whole. The Energy Reform addresses this problem through allowing foreign investment on the energy market, but another key factor for the success of this reform is integrating renewable energy into the Mexican electricity market. Mexico is currently the 7th largest contributor to emissions of CO2 and pollutants to the environment. This research analyses the energy and the electricity markets in Mexico and how a focus on renewable energy can become a strategy for sustained growth of the economy of Mexico, as well as relieving the output of CO2 to the environment to comply with the ever tightening climate policies to fight climate change.

This research explains the economics and key facts of the Mexican energy and electricity markets, the new policies incorporated to the Mexican Law through the Energy Reform, and evaluates the potential of renewable energy with focus on solar energy in order to assess the potential growth of the economy and the relief on the country's environment.

Key words: *CFE, PEMEX, SENER, Energy Reform, solar PV, renewable energy, Estrategia Nacional de Energía (National Energy Strategy), energy policy, GDP, Production Approach.*

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Abbreviations

ANES	Asociación Nacional de Energía Solar (National Solar Energy Association)
ARC	Annual rate of change
BANXICO	Banco de México (Mexican Central Bank)
BCM	Billion cubic meters
CC	Combined Cycle
CELS	Certificados de Energías Limpias (Clean Energy Certificates)
CENANCE	Centro Nacional de Control de Energía (National Energy Control Center)
CFE	Comisión Federal de Electricidad (Federal Electricity Commission)
CNH	Comisión Nacional de Hidrocarburos (National Hydrocarbons Commission)
CO2	Carbon Dioxide
CRE	Comisión Reguladora de Energía (Energy Regulating Commission)
CSP	Concentrated Solar Power
ENE	Estrategia Nacional de Energía (National Energy Strategy)
FDI	Foreign Direct Investment
GHG	Greenhouse gases
GWh	Gigawatt hour
IIE	Insittuto de Investigaciones Electricas (Institute for Energy Investigations)
Kv	Kilovolt
KWh	Kilowatt hour
LA	Latin America

LNG	Liquefied Natural Gas
MBPD	Million barrels per day
MCFD	Million cubic feet per day
MPF	Fondo Mexicano del Petroleo (Mexican Petroleum Fund)
MTOE	Million Tonnes Equivalent
MVA	Megavolt ampere
MWh	Megawatt hour
MXN	Mexican Peso
NAFTA	North American Free Trade Agreement
OECD	Organization for Economic Cooperation and Development
PEMEX	Petroleos Mexicanos (Mexican Oil)
PSP	Passive Solar Power
PV	Photovoltaic
PWC	Price Waterhouse Coopers
RPS	Renewable Portfolio Standard
SEN	Sistema Eléctrico Nacional (National Electric System)
SENER	Secretaría de Energía (Ministry of Energy)
TWh	Terawatt hour
USD	United States Dollar

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1. Introduction to the current state of the mexican energy market and problem statement

1.1 Mexican energy market

1.1.1 Overview

Mexico is a newly industrialized economy, a developing nation in terms of population as well as in terms of institutions whose main goal is to contribute to the economic development of the nation and its inhabitants. A strong and competitive energy and electricity market is a key factor in the success of any nation to become a developed economy. Therefore, the institutions that regulate these markets should follow trends in terms of investment, research and growth strategies that optimize the output of their operations. Nonetheless, different political views and policies can hinder the correct exploitation of the competitive advantages a nation can take of its natural resources. What was considered to be the best policy decades ago for the nation´s interests, can become a structural obstacle toward the future. This was the case of Mexico before the Energy Reform was opened to congress on 2013.

The Mexican territory is well endowed with natural resources including oil and gas, which ruled economic development in the last century and certainly will be important for at least the first half of this century. But more importantly for the future, its blessed location near the tropics and long coasts give Mexico a considerable potential in terms on renewable energies, in particular solar power.

In Mexico, PEMEX is the state-owned company that administers the exploitation and distribution of oil and natural gas, and is the major agent in respect to the energy market in the country. Founded 78 years ago by Mexican president Lazaro Cárdenas, PEMEX is the largest company in Mexico in terms of revenues with its production output of 2.55 million barrels per day (PEMEX, 2016). The energy market focus is on the export of crude oil to foreign countries and the import of distilled oil products such as gasoline and diesel mainly from the USA (Cruz Serrano, 2014).

In respect to the electricity market, the state-owned company CFE controls the generation, transmission and distribution of electricity in Mexico to households and the industry. It was founded in 1937, in order to unify the supply of electricity which was being procured by 3 private companies before that time (CFE, 2014). The creation of CFE was contemplated in order to modernize the electricity sector which could only supply the service to less than half of the 18.3 million population of the time. The volume of the electricity market in Mexico has now reached 310 TWh and 98.5% of the population has access to electricity as of 2016 (CFE, 2016).

These 2 companies, as robust as they may seem (PEMEX is the 10th largest crude oil producer and CFE is the 15th largest electricity producer), face major challenges in the coming years due to an increase on the demand of energy of the country (Reyes-Heroles G.G., 2015). The overview of the energy demands and forecast of production for the country come as follows (Reyes-Heroles G.G., 2015):

- Mexico is the 15th economy in the world in terms of GDP.
- Expected increase in oil production from 2.5 mbpd in 2014, to 3.0 mbpd in 2018 and 3.5 mbpd in 2025.
- Deep water reserves of 27,000 million barrels of crude oil in Mexican territory.
- Current demand of refined products is 50% larger than national production.
- 30% increase on the demand of petroleum products since 2003.
- 5.6% per year increase on the demand of natural gas since 2000.
- Expected increase in natural gas production from 5.7 thousand millions of cubic feet to 8 thousand in 2018 and 10.4 thousand in 2025.
- 25% increase in the length of the national duct system with expected investment of $7,454 million USD.
- The commercial electricity market expected growth is about 6% per year with foreseen investments of $57,000 million USD.

To achieve these challenges, major reformation and investments are necessary on both sectors in order to cope with the structural complexity of such fast paced changes. As an answer to this situation, the Mexican executive power proposed to the government on December 2013 an energy sector comprehensive reform, which is the subject of research of this text. To land the new policy proposed in this reform, it is necessary first to analyze in detail each sector and its governing agent to make an appropriate assessment of the feasibility and fitness for reform.

1.1.2 Summary of Primary Energy market: PEMEX

The energy market in Mexico is divided into production of oil and fossil fuels for domestic consumption and export, and imports of energetics such as gasoline, diesel, LNG, etc. Exploration, exploitation and transport are components of the Mexican energy market, as well as import operations. All operations are handled solely by the state company PEMEX.

Pemex is the largest and most vital company in Mexico to date. Founded in 1933 as PETROMEX, the company declared revenue of $117.5 billion USD in 2015 and employed 140,000 people in Mexico. In 2015, PEMEX produced 1.2 mbd of oil and 6 mcfd of natural gas. Also, in this year the company was subdivided into 7 subsidiary firms including: Pemex Exploration and Production, PEMEX Drilling and Services, PEMEX Logistics, PEMEX Cogeneration and Services, PEMEX Fertilizers and PEMEX Ethylene (PEMEX, 2016).

For context, PEMEX ranks in the following global positions (PEMEX, 2016):

Context	**Rank**
Proven oil reserves	17th
Proven Natural Gas reserves	31st
Oil production	10th
Gas Production	12th
Primary Oil distillation capacity	13th

Table 1:PEMEX international ranking

PEMEX is a vertically integrated company and follows a value supply chain like in the following figure:

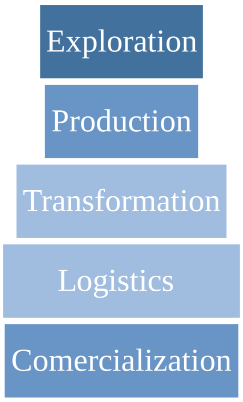

Figure 1: PEMEX corporate structure (PEMEX, 2016)

In respect to its performance, the following results correspond to the end of fiscal year 2015 (PEMEX, 2016).

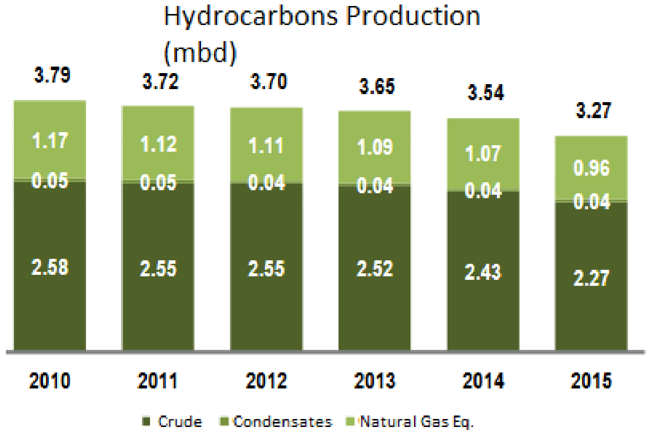

Figure 2: Hydrocarbons production (PEMEX, 2016)

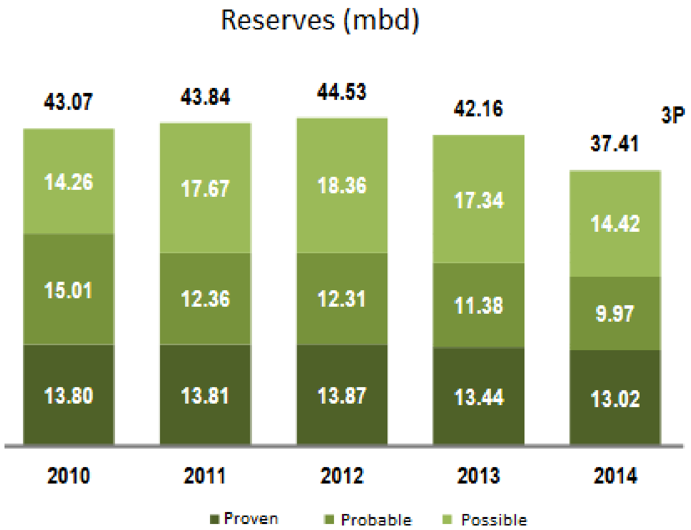

Figure 3: Reserves (PEMEX, 2016)

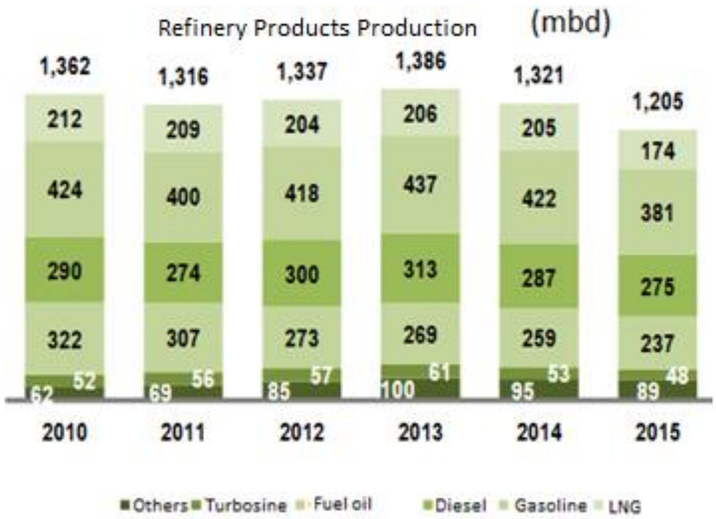

Figure 4: Refinery products production (PEMEX, 2016)

1.1.3 Summary of the Electricity market: CFE

In Mexico the electricity market is mainly controlled by the Comisión Federal de Electricidad, CFE, which was founded on August 14th 1937 by the federal government and is to date the largest electric utilities company in Latin America with more than 40 million customers (CFE, 2015). Its main responsibilities encompass electricity generation, transmission, distribution and trading. Its birth can be compared to that of PEMEX, since before its inception electricity was supplied by 3 private foreign companies. The quality of service was poor and the government found in CFE the solution to create a first class service to motorize its development as an industrializing nation.

Generation and trading

In 2015, 309,553 GWh of electricity were generated, roughly 80% from conventional sources and the rest from clean sources, including 10% from hydroelectricity. The CFE's electric centrals of the country generated 55.2% of the total power, 28.8% came from independent producers and the rest from individuals for own consumption primarily. Independent producers are companies that generate electricity with their own infrastructure and investment but must sell its output to CFE, in order for the latter to distribute and sell it to end users. Individuals such as private companies can produce their own energy for their operations and consumption, but must sell all its excess of power to CFE at a fixed rate. Basically, although there are other parties generating electricity, only CFE can make a profit of transmission, distribution and wholesaling in the pre-reform scenario.

Electricity generation in Mexico is classified into *conventional* and *clean sources* of generation (PRODESEN, 2016). In the next table we can see a summary of electricity output by technology and its annual rate of change:

Technology	Output 2014 (GWh)	Output 2015 (GWh)	ARC (%)	No. of Facilities
Conventional	**236,103**	**246,601**	4.4	
Combined-cycle	149,490	155,185	3.8	63
Thermoelectric	37,219	39,232	5.4	67
Carbon	33,613	35,599	0	3
Gas turbine	9,126	11,648	27.6	126
Internal Combustion	2,308	2,651	14.8	265
Fluidized bed reactor	4,347	4,286	-1.4	3
Clean	**65,360**	**62,952**	**-3.7**	
Renewable	51,404	46,207	-10.1	

Hydroelectric	38,893	30,892	-20.6	12 large scale
Wind	6,426	8,745	36.1	32 wind parks
Geothermal	6,000	6,331	5.5	8 centrals
Solar	85	78	-7.7	9 PV centrals
Others				
Nuclear	9,677	11,577	19.6	1 plant
Bioenergy	1,387	1,369	-1.3	70 centrals
Efficient cogeneration	2,892	3,795	31.2	11 centrals
Regenerative brakes	0	4	100	10 equipped trains
Total	301,463	309,553		

Table 2: Outlook on Mexico's electricity generation (PRODESEN, 2016)

Transmission

Transmission and the national electricity grid are activities and assets reserved to the State for being considered key for the interests of the country. The National Transmission Grid, is composed of 53 regions, with an installed transmission capacity of 71,397 watts. In the following table we can see a summary of the transmission grid of the National Electric System:

Transmission lines	Length 2014 (km)	Length 2015 (km)	ARC (%)
CFE	102,315	102,657	0.3
Transmission (161 to 400 kV)	51,734	52,001	0.5
Potential level 400 kV	23,641	24,307	2.8
Potential level 230 kV	27,543	27,172	-1.3
Potential level 161 kV	550	522	-5.1
Transmission (69 to 138 kV)	50,581	50,656	0.1
Potential level 138 kV	1,532	1,608	5
Potential level 115 kV	46,115	46,147	0.1
Potential level 85 kV	156	156	0
Potential level 69 kV	2,778	2,745	-1.2
Others	1,632	1,736	6.4
Tension level 400 kV	390	390	0
Potential level 230 kV	1,242	1,346	8.4
Total	103,557	104,393	0.4

Table 3: Outlook on Mexico's electricity transmission (PRODESEN, 2016)

In respect to trans-border interconnections, Mexico has a total of 13 interconnections with other countries, 5 of them for emergency cases in order to increase energy security in the country in the case of a disaster that compromises the generation and transmission infrastructure. The rest are used for electricity trading between countries. Of the 13 connections, 11 are with the USA and two are shared among Guatemala and Belize in Central America. In the next figure we can see the location of this interconnection points:

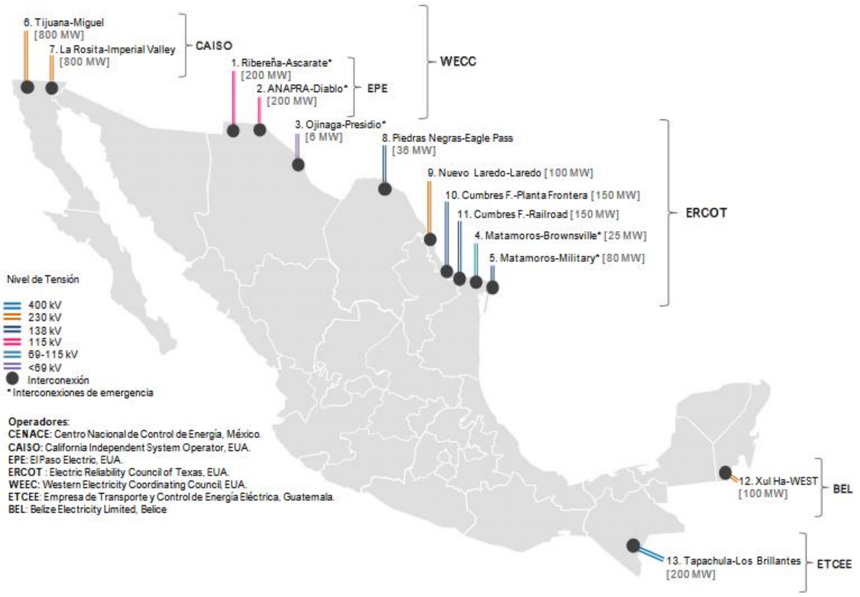

Figure 5: Trans-border transmission connections (PRODESEN, 2016)

Distribution

Energy distribution to the end-users is accomplished through the National Distribution Grid. The distribution grid is composed of 775,483 km of distribution lines, as well as 1.4 million transformers, and substations with an installed capacity of 55,454 MVA in 2015 (PRODESEN, 2016). In the next table we can see a summary of the composition of the distribution grid in Mexico:

Distribution Lines	Length 2014 (km)	Length 2015 (km)	ARC (%)
CFE Distribution	**683,226**	**692,721**	**1.4**
Potential level (34.5 kV)	77,027	79,413	3.1
Potential level (23 kV)	33,170	33,571	1.2
Potential level (13.8 kV)	308,123	311,857	1.2
Potential level (6.6 kV)	129	67	-48.1
Potential level low	264,777	267,813	1.1
Others	**86799**	**82762**	**-4.7**
Total	770,025	775,483	0.7

Table 4: National Distribution Grid (PRODESEN, 2016)

1.2 Problem Statement

The closure of the energy market in Mexico since the 1940´s to foreign investment and the heavy dependence in fossil fuels to power the electric grid, has created financial problems for both PEMEX and CFE, leaving them in a position of disadvantage to keep driving the economy and fulfilling the future energy demands of the world's 15^{th} largest economy. The recent oil crisis is creating a void in the Mexican expense budget for the coming years, and the rising pressure to cut back on CO2 emissions are yielding structural obstacles for the development of the nation.

The Energy Reform was proposed and approved until 2013, which some experts consider to be late by a decade in essence (Reyes-Heroles G.G., 2015). Nonetheless, the Reform will be fully implemented by 2018 and benefits are expected, yet in order to compliment this reform it is imperative to seek for new energy sources that along with the Energy Reform can drive Mexico forward in the 21^{st} century a few steps up into a developed nation.

In respect to renewable energy, Mexico can count on it to be used as a pole of development for its electricity market and act together with the Energy Reform to solve the problem statement. The issue in question is how to correctly implement both the Energy Reform and renewable energy in a country with a few decades of delay in respect to progress on the structure of its energy and electricity market and institutions. Implementing a ground breaking Energy Reform and incorporating renewables seem to be the answer for the problem, yet this will pose a challenge to be discussed and assessed to find a qualitative and quantitative solution on this research, in the form of a positive relationship between consumption of renewable energy and economic growth.

2. Mexico´s Energy Reform: Current policy and expected outcomes

2.1 Historical background

The Energy Reform in Mexico in 2013 is the result of modifying the last reform in respect to the national oil resources administration from 1938, better known as the *Expropiación Petrolera (Petroleum Expropriation).* The use of fossil fuels goes back many centuries in Mexico, even before its birth as a nation. Due to its abundance on fossil deposits, the natural appearance of oil on the surface of Mexico was used by the ancient Mesoamerican civilizations for crafting clay figures and by the Spanish colonizers for medicinal purposes as well as maintenance for ships (Celis Salgado, 1998).

The proper birth of the oil industry in Mexico can be traced back to 1863, when a priest named Manuel Gil y Saenz discovered a surface deposit of oil in the State of Tabasco, in the so called "Mina de Petroleo de San Fernando" (San Fernando Oil Mine). He traded this oil back to the USA, where the industry was booming but he was unable to compete due to the advance of technologies in the USA (Alvarez de la Borda, 2006). Yet the oil reached its destination and the Americans discovered the good quality of the Mexican Oil, which turned the attention of American entrepreneurs to its southern neighbor. The Mexican president at that time, Porfirio Diaz, dictated an accommodating policy for foreign investment on the oil industry in order to boost the industrialization of the economy of Mexico in the early 1900´s. *The Mexican Oil Company* and the *Compañia Mexicana de Petróleo el* Á*guila* dominated the market in the first quarter of the XX century (Alvarez de la Borda, 2006).

After a period of revolution in Mexico (1910-1917), new political leaders emerged in the country that ended a revolt caused by the unfair living conditions of Mexico´s poorest inhabitants. After a period of benefits for the corporations, the new policy in Mexico was to adopt a project for the nation that set as priority the well-being of the Mexican rural population. Mexican president Lazaro Cárdenas, who ran office from 1934-1940, promoted particular expropriating policies that served the goal to procure the well-being of the Mexican population. Besides the Petroleum Expropriation in 1938, he also promoted the *Agrarian Reform*, in which the federal government yielded land for the poor to tend and harvest on (Alvarez de la Borda 2006).

On the 18th of March, 1938 after a series of labor related conflicts between the Mexican oil workers and the foreign corporations, the *Petroleum Expropriation* was enacted and approved. The new law for the exploitation of petroleum in Mexico was incorporated into the article 27 of the Mexican Constitution of 1917, which contains policy in respect to the use of national natural resources. The added paragraph in respect to the petroleum expropriation reads as follows:

"…*In the case of petroleum and solid, liquid or gaseous hydrogen carbides, no concessions will be issued and the respective Regulatory Law will determine the manner in which the Nation will carry out the operations of those products*…" (Carranza, 1917).

Under the presidential decree of the 18th of March 1938, the federal government expropriated unilaterally all plant, equipment, personnel and operations of the foreign oil companies and set a 10-year period for repay of the assets to the affected companies. The result of this was the creation of the national petroleum company, called *PETROMEX*, which was later renamed PEMEX, and became the largest company in the country and in Latin America.

2.2 Energy Reform Legal Framework and Analysis

In this section, a profound presentation and analysis of the Energy Reform of 2013 is structured. All information contained in this paper with respect to the Reform is to be referenced to the current Mexican executive leader, President Enrique Peña Nieto.

2.2.1 Section I: Introduction

The Energy Reform was presented to the Mexican Senate on the 12th of August, 2013 with the main goal to modify the articles 27 and 28 of the Mexican Political Constitution. The reform is based on the following strategic objectives proposed in Section I (Peña Nieto, 2013):

1. Strengthening the role of the State as the rector of the oil industry
2. Economic growth
3. Inclusive development
4. Energy Security of the Nation
5. Transparency
6. Sustainability and Environmental Protection

The proposed Energy Reform is consider to strengthen the role of State and the economic development through the creation of new jobs in the reformed oil industry due to new tentative investments in an open oil sector, promote inclusive development and energy security by increasing the energy and electricity generation capacity of Mexico, and setting new standards in respect to transparency and information access to the public and the intensive incorporation of clean renewable energies into the Mexican electricity market.

2.2.2 Section II: Petroleum and hydrocarbons

The reform states that the exploitation of the nation´s natural resources is a competitive factor that should be exercised by the state to contribute to the economic development of the country. The fact that easy to exploit oil resources in Mexico are becoming scarce, a new approach in terms of policy and administration should be implemented in order to be able to reach the considerable deep-water fossil reserves in the Gulf of Mexico. The reform takes as an example the policies enacted in successful countries in respect to oil extraction such as Brazil, Colombia and Norway (Peña Nieto, 2013).

In regard to the Gulf of Mexico, a reserve shared between the USA and Mexico, a contrast is remarkable as the USA drilled 137 deep-water wells against 6 by PEMEX. In the American market 70 companies participate and share risks in the operations, while in Mexico this task is delegated only to one company. A new approach is needed in this century, since the technology to explore and exploit deep-water reserves is too complex and advanced that falls out of the capabilities of PEMEX. Mexico is faced with the option to follow the trend to open its market to other participants besides PEMEX or leave its reserves unexploited at the moment.

Besides exploitation of oil and hydrocarbons for generating revenue, the energy security of the country is jeopardized by its growing need of energy. Although Mexico produces 2.5 mbd, only 1.2 mbd are refined in Mexico, and the result of this fact is that Mexico must import 49% of its gasoline and diesel from foreign countries. This paradox puts in danger the energy security of Mexico, and new policies are proposed for this purpose.

The proposed reforms in the subject of hydrocarbons state:

1. Eliminate the prohibition of the State to award contracts for the exploitation of hydrocarbons.

By abolishing the clause in article 27 of the prohibition of exploitation contracts to private companies. Still no concessions are granted, meaning that the exploited resource is still property of the state, but revenues from exploitation activities are paid to 3rd parties. We can make a reference to the Norwegian Model of the Petroleum Tax System, with a marginal tax rate of 78%, composed of 25% normal tax on returns for companies plus a special tax of 53% on petroleum activities (Norwegian Petroleum, 2016). With this as a goal, the Mexican government can have tax revenue from foreign companies venturing on extraction activities.

2. Eliminate the exclusive control of the petrochemical industry by the State Company PEMEX by awarding permits for distillation of petroleum products to third parties inside the country.

As a result of the reform, an expected increase on the production of hydrocarbons creates the opportunity for an appropriate growth of the petrochemical industry. Thus, the State also proposes to concede permits to private companies to participate in the complete chain-value of the oil industry and to sell distilled products in Mexico. The main point of this reform section, states that other parties will be able to transport, distribute and sale gasoline, diesel and other hydrocarbons products in Mexico.

Expected benefits

The main expected benefits of the reform in relation to hydrocarbons are:

1. Achieve restitution rates higher than 100% of proven oil reserves in Mexico
2. Increase oil production from 2.5 mbd to 3.0 mbd in 2018 to 3.5 mbd in 2025
3. Increase natural gas production from 5,700 million cubic feet to 10,400 million cubic feet in 2025.

This will in return guarantee energy security for the nation since more supply of distilled products and natural gas will emerge due to competition. Furthermore, the increase in investments will affect positively the GDP and additional revenues will be reinvested in social security and health services, education and infrastructure (Peña Nieto, 2013).

2.2.3 Section III: Electric Energy

The other keystone of the Energy Reform, is the modernization of the electricity sector in Mexico. Mexico has about 98% electricity coverage within its borders (CIA Fact book, 2015). This means that circa 2.3 million Mexicans, still lack access to electric energy. One of the main strategic objectives of the reform is to support inclusive development, and to achieve this purpose the government should provide universal access to electric power. Nevertheless, one of the main complains of the society are the high costs of utilities, especially electric power. As an answer to this concern, CFE has installed policies to subside domestic electric consumption, and by so doing, the company´s equity is decreasing annually. President Peña Nieto takes the example of the USA, where electric power bills are in average 25% less expensive than in Mexico.

CFE financial results are not sustainable, so the Energy Reform proposes to solve the problem by cutting down production costs. The sum of electricity producers in Mexico accounts to 63 Gigawatts of installed capacity. Although CFE is the only company allowed to sell electricity, 36% of produced energy is produced by independent private producers under schemes such as: cogeneration, self-procurement, small production, and own use. Since private investment is allowed into production and the trading of excess output is regulated by CRE (Electricity Regulator Commission), the market has opportunity to grow further.

The main focus of this research is analyzing how incorporating renewable energy in the legal framework of the Energy Reform, can boost the economy. In addition to this reform, in 2012 the *Ley General de Cambio Climático (General Climate Change Law)* was approved. In this framework, Mexico´s set its goals in respect to climate change abatement which are:

- 30% reduction of GHG´s emissions by 2030 and 50% by 2050 (base yr. 2000)
- 35% of electricity supply should come from renewable energies by 2024

In order to achieve these targets, Mexico should start exploiting its potential with renewable energies in coordination with the restructuration of its electricity market and reformation of the State company CFE currently under progress. In 2012, the share of the electric grid powered by renewables was only 18%, so a big challenge lies ahead to reach the 35% share intended to comply with this Energy Reform and the Climate Change Law. In the present, the SEN (Sistema Eléctrico Nacional) is not intended to incorporate a large share of electricity generated from renewable sources, since it was created for the past century to keep up with the demographic growth of the country. The main energy source to date is still fossil fuels to power thermoelectric power plants and the SEN is designed to distribute electricity from this type of infrastructure. The Energy Reform is intended to correct these deficiencies of the SEN by creating a competitive market for renewables in a massive scale through regulation by an independent agent, CRE (Comisión Reguladora de Energía), as well as CELS (Certificados de Energías Limpias) to incentivize companies to earn CELS and trade them in this market.

The implementation of an open whole-sale market to trade electricity with an independent regulating agent, CENACE, has the purpose to select the projects that produce electricity from renewable energy. The focus of the reform is to give priority to the best projects in term of sustainability, meaning that clean energy is sold first. Areas of improvement of the Electric Sector in Mexico include also increase in investments for transmission, as well as maintenance. In respect to distribution, the main challenge is to prevent losses in distribution which account to 15.3% in 2012. So in summary, the challenges and objectives of the Energy Reform with respect to the electricity market are:

- Achieving universal access to electricity in the country
- Switching generation from fossil fueled plants to renewable energy sources (35% by 2024)
- Generate investments for expanding and maintaining the transmission lines

- Achieving a reduction of losses in distribution from 15% to less than 5%
- Setting priorities for selling electricity from renewable sources in the Mexican Electricity Market

The reform proposal with respect to the electricity sector in Mexico is the same as for the petroleum and hydrocarbons, and now with this new law, the government can celebrate contracts with private investors, yet transmission and distribution are still sole responsibilities of CFE. The main difference is that now private companies can sell energy to the public, but using the existing infrastructure of CFE in order to concentrate the operations of the company to activities they can use their current investment and create and promote new ones.

Expected benefits

The Mexican president justifies his reform proposal mentioning some expected benefits of the new policy in the quality of life of the Mexican nationals, some of which are:

- By promoting a new open electricity market, competition will increase the level of service in the electricity market as well as lower prices for the service
- With the CRE, private parties will have certainty they will have access to the transmission network, creating new opportunities for the industry
- Secondary laws will promote the use of renewable energies, thus enabling the country to abide to its 2012 *Ley General de Cambio Climático.*

This Energy Reform is specially focused on a complete face-lift of the 2 largest state-owned companies, by reverting nationalist policies adopted 70 years ago. After it was accepted, the Congress was in charge of enacting the secondary laws added to this Reform proposal and it is expected that by 2018 the reform will be fully embedded in the Mexican economy.

2.3 Summary of the Energy Reform and secondary laws

The green-light given to both, PEMEX and CFE conceding them jurisdiction of awarding contracts to foreign investors, has deeper foundations than those contained in the reform proposal (Peña Nieto, 2013). An energy reform has other consequences in other industries within the economy, and to regulate this subject, the Senate decreed the Secondary Laws for the Energy Reform on August 16, 2014. According to the president of the Energy Commission of the Mexican Senate, David Penchyna, through the correct exercise of these secondary laws, the Mexican economy is expected to grow by 1% additional as percentage of GDP as of 2018 and by 3% additional as of 2025(Penchyna, 2014).

With the approval of the Secondary Laws of the Energy Reform, the government ended a 16-year-old debate in terms of analysis and refusal of reforming the energy sector in the past. Extensive work was done during this time, and to propose a modern legal and operational framework for the Energy Industry in Mexico, the industry leaders and representatives studied and analyzed the energy sectors of 7 different modern economies: UK, USA, Brazil, Colombia, Norway, Canada and Azerbaijan (Penchyna, 2014). The new Energy Sector in Mexico incorporates distinctive traits from each country, notably the example of the Petroleum Fund from the Norwegian Model and the open-market to foreign companies' policy from Brazil.

The Secondary Laws consist of the creation of 9 new laws and the modification of 12 existing laws (Senado de la República, 2014):

Enacted Laws:

1. Hydrocarbons Law
2. Electric Industry Law
3. Geothermic Energy Law
4. Mexican Oil Law
5. Federal Electricity Commission Law
6. Coordinated Regulator Institutions for Energy Administration Law
7. National Agency for Industrial Security and Environmental Protection for the Hydrocarbons Industry Law
8. Hydrocarbons Revenues Law
9. Mexican Petroleum Fund Law

Modified Laws:

1. Foreign Investment Law
2. Mining Law
3. Public-Private Associations Law
4. National Water Law
5. Parastatal Institutions Law
6. Acquisitions, Leases and Services for the Public Sector Law
7. Public works and related services Law
8. Organic Law of the Federal Public Administration
9. Federal Law on Rights
10. Tax Coordination Law
11. Federal Budget and Fiscal Responsibility Law
12. General Law on Public Debt

Reviewing in this research all of them individually is not the main purpose, and for sake of analyzing all the legal and technical aspects of this set of laws the next table show the main impacts of the Energy Reform and the Secondary Laws packages and relate each key impact to a certain law (Zenteno, 2014).

Impact	Analysis Sector	Related Law
Opening of the oil and gas market to foreign investment and private investors	Hydrocarbons	Hydrocarbons Law
Celebration of Oil Contracts with third parties	Hydrocarbons	Hydrocarbons Law
Occupation of third parties land premises for exploitation purpose with a fee of profit going to the landlord	Hydrocarbons	Hydrocarbons Law
Allowance of *fracking* practices to extract shale oil and gas	Hydrocarbons	Hydrocarbons Law

Opening the electricity market, meaning third parties can generate and sell electricity to the public, competing against CFE	Electricity	Electric Industry Law
Permits to generate and resell electricity awarded by the recently created CRE	Market Regulator	Coordinated Regulator Institutions for Energy Administration Law
New electricity market regulators, CRE and CNH (National Hydrocarbons Commission), will coordinate with the federal government	Market regulators	Coordinated Regulator Institutions for Energy Administration Law
Different gasoline stations brands arriving the country by 2017, ending the PEMEX monopoly	Hydrocarbons and State Productive Companies	Hydrocarbons Law and Mexican Oil Law
Setting millionaire fines to petrol stations dispatching incomplete fuel liters to end-users	Hydrocarbons	Hydrocarbons Law
As of 2018, the price of gasoline and diesel will be allowed to float and be determined by the market. Presently it is determined by the Mexican Administration for budget planning	Hydrocarbons	Hydrocarbons Law
Electricity fees will go down as a consequence of the competition of the new entrants in the market	Electricity	Electric Industry Law
The corporate structure of PEMEX and CFE will be modified and be more like	State Productive Companies	Parastatal Institutions Law

a private corporation structure, still they will be State Productive Companies		
The State will take some part of the labor and pension fund liabilities of both CFE and PEMEX to help them reform	State Productive Companies	Parastatal Institutions Law and Federal Budget and Fiscal Responsibility Law
The relationship with labor union will be modified to accept the liability of the State on pension funds, namely the labor conditions for retirement will change and a private individual account shall be used from now on	State Productive Companies	Parastatal Institutions Law and Federal Budget and Fiscal Law
The MPF (Mexican Petroleum Fund) is established as a trust fund to administer the revenues from the assignation of exploitation contracts to private companies. If revenues from petroleum activities exceed 4.7% of the GDP, then the excess is saved in the fund as reserves.	Petroleum Fund	Mexican Petroleum Fund Law

Table 5: Analysis of Energy Reform's Secondary Laws

The main objective of this research is to investigate how incorporating renewables into the Mexican electricity market will impact the economic growth of Mexico in the framework of the Energy Reform. For this reason, from now on the main line of investigation will be focused on the Electricity Industry Law from the Secondary Laws. In the next section, an insight into the Mexican economy and its key parameters is presented, in order to set the ground for the analysis on the opportunities with renewables.

3. Mexico´s economic background: energy production and consumption

3.1 Primary Economic and Demographic Indicators

Mexico is to date the world´s 15th largest economy and 2nd in Latin America, and it is expected to be well into the top ten within the next 30 years. The optimistic forecast is based mostly on macroeconomic indicators such as Foreign Direct Investment, strategic trade deals and its demographic bonus. Nevertheless, as a developing economy, it still faces the challenges of modernizing its primary institutions, investment in education and in research and development. In terms of territory, it is ranked as the 13th largest nation in terms of area, which relates directly to its considerable natural resources. In terms of population, as of 2015 Mexico had 127 million inhabitants (INEGI, 2015).

Figure 6: Mexico seen from space, satellite image (INEGI, 2015)

Mexico is part of the OECD, and the primary economic indicators and statistics are audited by this organization and presented on the following table:

Indicators	**Mexico**	**OECD (avg.)**	**Unit**
Production and Income			
GDP	1.144 trillion	1.43 trillion	$ USD

GDP per capita	18,078	40,552	$USD
Household disposable income growth	3.2	2.57	Annual %
Economic growth			
GDP growth	2.5	2.2	Annual %
Economic structure: share of value added to GDP			
Agriculture, forestry, fishing	3.3	n.a	%
Industry including energy	***27***	***n.a***	***%***
Construction	7.4	n.a	%
Trade	25.5	n.a	%
Information, communication	2.3	n.a	%
Finance and insurance	3.7	n.a	%
Real Estate	11.2	n.a	%
Professional, scientific, support services	6.4	n.a	%
Public admin., defense, education, health, social work	11	n.a	%
Others	2.1	n.a	%
Government deficit and debts			
Government deficit	0.1	-1.62	% of GDP
Government debt	49.2	89.7	% of GDP

Trade			
Imports	33.5	29.2	% of GDP
Exports	32.4	29.1	% of GDP
Prices and interest rates			
Inflation rate	2.7	1.35	% annual growth
Inflation rate: energy	2.5	-0.6	% of annual growth
Energy supply and prices			
Total primary energy supplies	187.8	93.52	Mtoe
TOES per unit of GDP	0.1	0.12	Toe per 1000 USD
Renewable energy	17 165.3	14 110	Ktoe
Average electricity price to end-user	55	38	USD/MWh
Environment			
Municipal waste per capita	360	516.3	Kg
CO2 emissions from fuel combustion	3.8	8.08	Tonnes per capita
Employment			
Employment rate 25-54 yrs	70.8	65.7	%
Unemployment rate	4.3	7.3	%
Research and development			
Gross domestic expenditure on R&D	10 434	29 070	million USD

Population			
Total population	121	34.7	Million people
Population growth	1.1	0.53	% of annual growth
Youth population, less than 15 yrs	28	18.4	%
Fertility rate	2.2	1.7	Children/woman

Table 6: Mexico V.S. OECD average key socioeconomic factors (OECD, 2015)

As it can be seen, industry including energy has the largest share of value added to Mexico's GDP, so it is essential to keep the energy industry on pace with the modern geopolitical and economic trends. Furthermore, energy is the engine for the industry, so in summary for Mexico's economy to bloom, energy is the most important sector to date (OECD, 2015).

According to economic institutions, Mexico is going through tough economic challenges at the moment. Due to the low oil-prices, and the general downturn in economy, Mexico now relies on private internal consumption as means of economic growth that went down from 2.5% to 2% in the last quarter and it is expected to continue its descend next years. As a result, the Mexican government is taking monetary and fiscal policies to shield against these developments and the strong depreciation of the MXN against USD in the last 2 years. In the past 10 months, interest rates have gone up from 3.5% to 5.25% to hedge against this depreciation as a strategy to wait out until the results of the increase in competitiveness for Mexican exports is experienced. In the short term a decrease on aggregate demand is to be expected due to the external shocks the country's economy has been facing, yet the structural reforms, including tax and energy reforms aim to create bases for sustained growth in the medium term (World Bank, 2016).

With an unclear panorama in respect to the recovery of oil-prices and a set of newly implemented structural reforms, a sound strategy for coming years would be to invest heavily on the energy sector, which as stated before, is the main engine for the industry and Mexico's GDP.

3.2 Mexico´s energy demand and production

Mexico's economy expanded at a considerable rate during the first decade of the 21st century. So did its energy demand. Since 2000, the demand for energy has increased by 25% at a similar rate to accumulated economy expansion (IEA, 2016). This means that energy intensity has not increased much in the country as it did in other economies. The energy intensity in Mexico for 2014 was **0.168 toe/ $1000 usd.** In comparison to other OECD members, the energy intensity is about 40% lower to the average, which implies that energy demand and use is set to rise in the near future for Mexico.

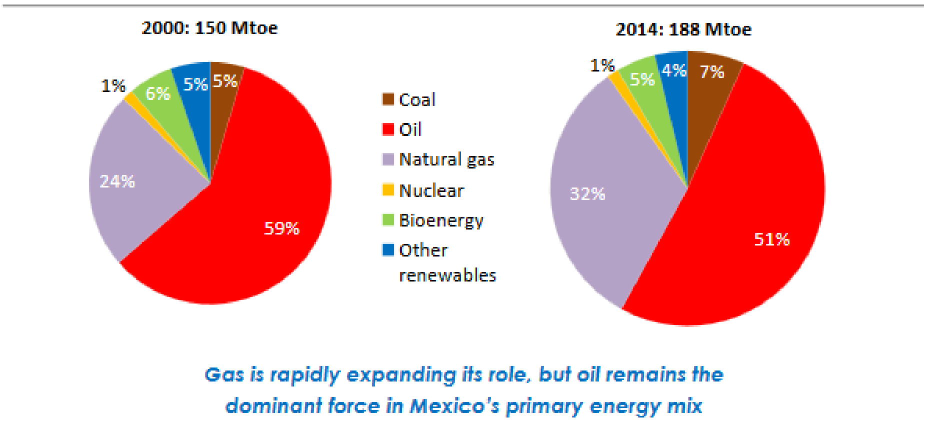

Figure 7: Energy Demand by Fuel (IEA, 2016)

As shown in figure 7, we can see that oil still takes the largest share for primary energy demand in the country and the increase of natural gas is considerable, for this, the Energy Reform contemplates both type of fuels for future investments. Nevertheless, renewables take up to 9% presently, and it is expected to grow to fulfill the ambitious goal to reach 35% of the energy mix for electricity by 2025 as set by the National Energy Strategy (ENE, 2013). Both combining the goals and interests of the Energy Reform and the ENE 2013-2027, the underlying principle is that although Mexico will require more energy to grow, its energy intensity increase will be delivered by renewable energy in the medium run and it will exploit its fossil fuel potential in the short term. Mexico's energy sector contribution to the GDP is roughly 8% (OECD, 2015), and the government bears interest to grow this share as other developed nations.

3.2.1 Energy demand by sector

A first step to understand how renewables can become a trident of economic progress for the country, is to take a look to its demand by sectors. Renewable energy can be used efficiently in the building and industry sectors with the use of solar panels, but for other sectors such as transport is not as easy to implement a new strategy based on renewables since there are barriers for electricity use considering it is necessary to change all transport means to electric motorized vehicles.

In Mexico, 40% of the energy demand comes from the Transports sector, Industry takes 28% of the demand and Building sector only 20% (IEA, 2016). Energy demand increase for the transport sector can be related to the increase of car ownership in the nation, since vehicle stock rose by 250% in the last 15 years (IMM, 2015). Due to its large reserves of fossil fuels, this demand is fulfilled by the use of oil fuels in Mexico. In respect to the Industry Sector, the rise has been more moderate at only 14% (IEA, 2016) since 2000 mainly because the energy intensity of industries globally has fallen due to increased efficiencies in the production processes of manufacturing companies. Furthermore, energy demand increase in the industry sector although not as large as in the transport sector, has played a key role in the country. Since NAFTA was signed, many manufacturing companies from the USA and car makers from around the globe have come to Mexico due to its low labor wages.

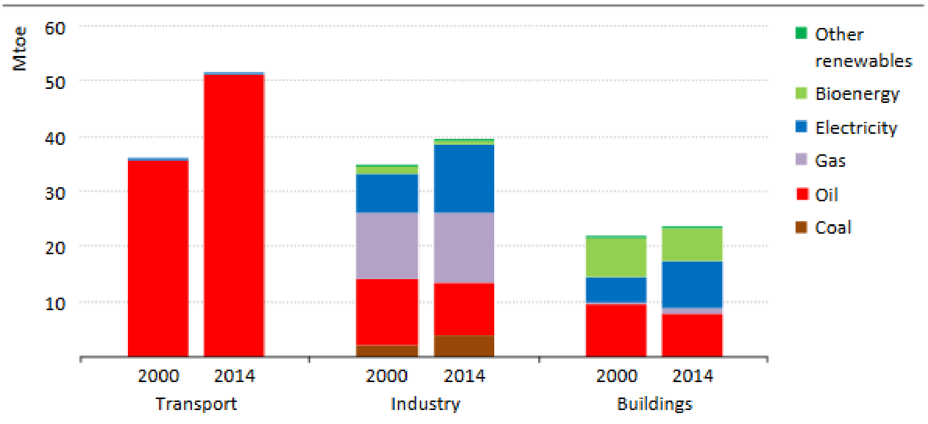

Figure 8: Energy Demand by Sector and fuel (IEA, 2016)

In respect to the building's sector, increase in consumption is only 10% (IEA, 2016), which can be traced back to the change from using biomass (wood) for heating houses to the use of electric energy. Nevertheless, increase in this sector is possible as increase in wages are expected.

3.2.2 Energy production in Mexico

Mexico is the 10th largest oil producer in the world, and during the last 30 years of the 20th century it was the engine that moved Mexico from an agrarian society to an industrialized country. As mentioned before, the *Petroleum Expropriation* was a key event, since Mexico used its treasured resource to grow internally. Since globalization started to be a reality, Mexico lagged behind in terms of capacity and technologies to keep exploiting its oil fields and as of the last decade, this has started to be a problem for the nation.

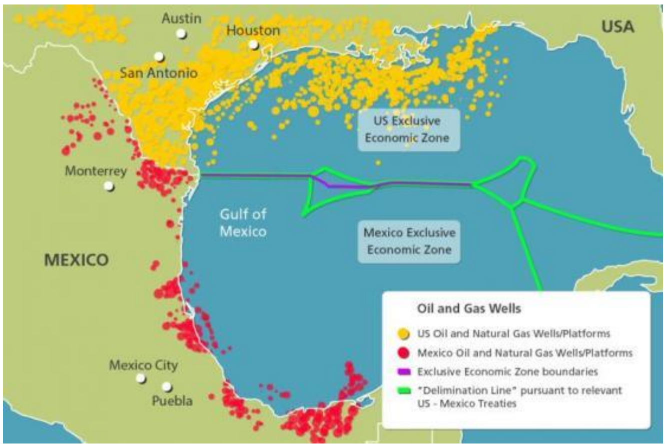

Figure 9: Oil and gas wells comparison USA-Mexico (Oil and Gas 360, 2015)

As shown in figure 10, since its peak of 3.8 mbd in 2004, oil production and exports have been declining at a disturbing rate mainly due to the depletion of its main oil-field, Cantarell, in the Gulf of Mexico.

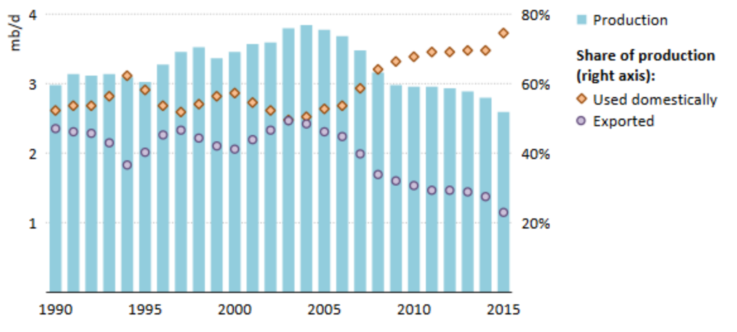

Figure 10: Oil production and exports (IEA, 2016)

Although Mexico has proven reserves in deep-water and non-conventional fossil fuels, PEMEX's lack of competence on the subject and an increase on domestic demand of oil have jeopardized the country's ability to export crude oil. Oil exports have fallen from 1.9 mbd to

1.2 mbd in 10 years. Even though oil exports are falling, the economy is still growing due to the government's right move into attracting FDI, in particular within the automotive industry which has exceeded its share to GDP to that of the energy industry. A substitution from energy exports to car manufacturing has been enough to keep relative economic stability to the nation, yet in order to grow on all axes of development a new strategy is defined with the Energy Reform.

In respect to natural gas, mentioned before as an increasing primary energy source, the panorama is similar to that of oil, since 75% of Mexican gas production is related to oil production as associated gas (IEA, 2016). Natural gas production output has decreased by 18% from its peak in 2010 to 42 bcm. As with the case of oil, Mexico's gas resources are enough to supply its demand for the resource as its shale-gas resources were assessed to be the 6th largest in the world by the US Energy Information Agency (USEIA, 2015). Unfortunately for Mexico, again its lack of competence in energy exploitation and administration has led to the preference of importing natural gas at competitive prices from USA's neighboring states, meeting 40% of the country's demand for the fuel (IEA, 2016).

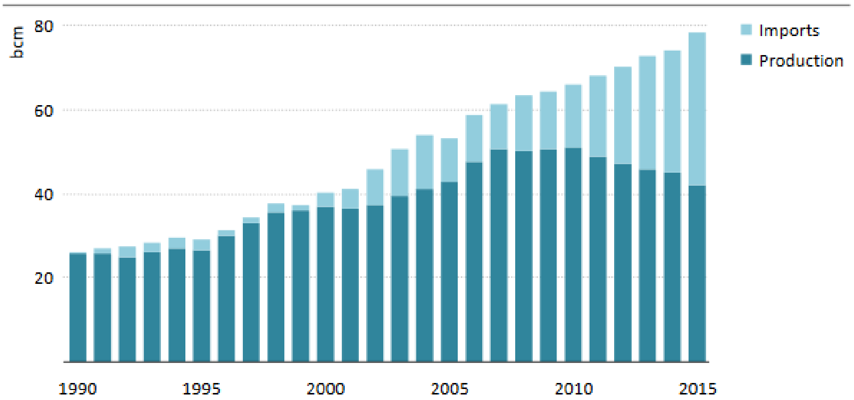

Figure 11: Natural gas production and imports (IEA, 2016)

The main problem with Mexico and its energy industry is simple: **Mexico is a net exporter of energy commodities at low prices, but is a net importer of energetics at higher prices.** Imports for gasoline, diesel and ready for use LNG account the country high costs for utilities and costs for transportation. The abundance of energy resources did not solve the energy problem for the country, in addition to old policies with nationalistic dyes.

Mexico has another window of opportunity to solve its energy problem and to boost its economy. It’s called renewable energy, and yet again its central location within the tropics has conceded Mexico a privileged position in terms of solar, geothermal, and wind energy. The Energy Transition Law of 2015, in addition to the Electricity Law from the Energy Reform’s secondary laws, provide the necessary legal framework for the implementation of an energy strategy based on renewables.

In 2016, two electricity auctions were held by the country and 4.9 GW of new capacity was awarded in the form of long-term contracts, mainly focused on solar PV and wind energy technologies (IEA,2016). Mexico’s solar potential has been estimated at around 5.5 kWh/m2/d by the Ministry of Energy (SENER, 2012), in its publication *Renewable Energies Perspectives 2012-2026*.

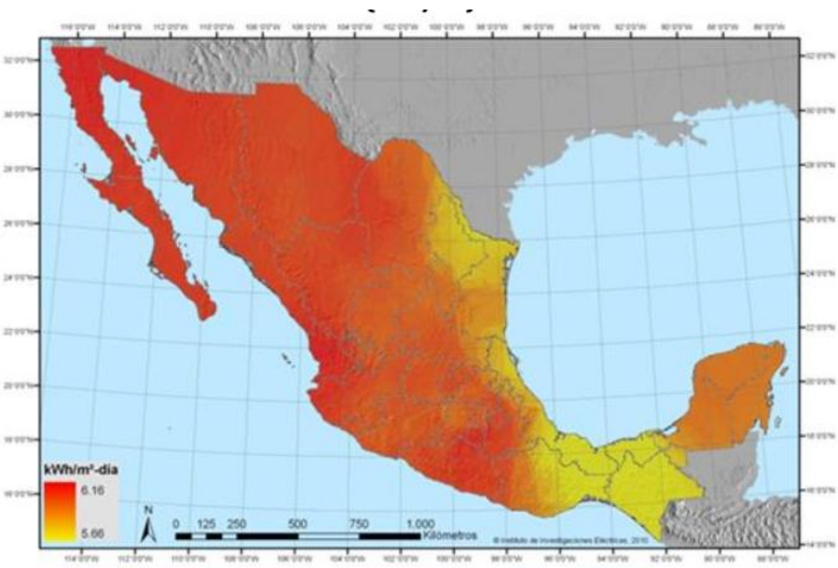

Figure 12: Average daily solar radiation kWh/m2/d (IEE, 2010)

In respect to wind energy, the country has a capacity of 71,000 MW considering 20% utilization factors (IIE, 2010).

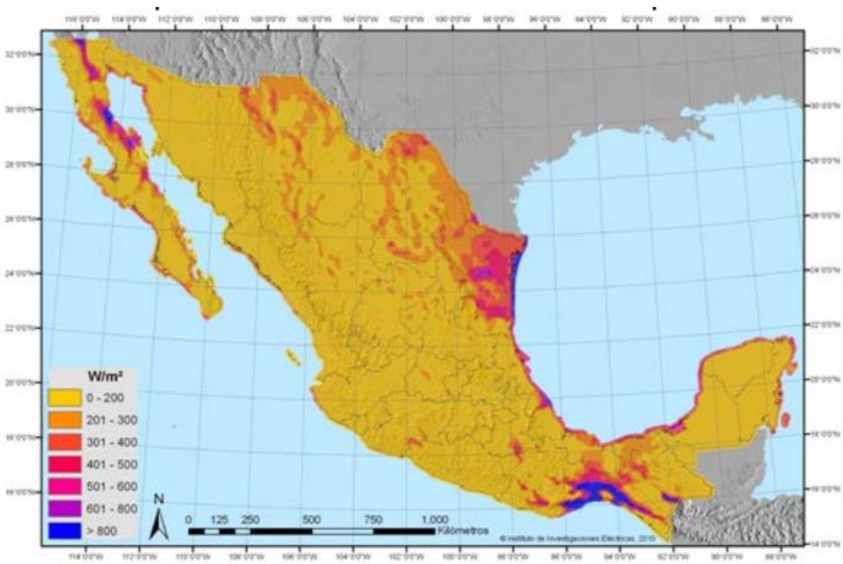

Figure 13: Wind potential density at 80 m height (IIE, 2010)

Geothermal energy doesn't fall behind and experts estimate potentials of 10,000 MWe in the country (Adame, 2010).

Figure 14: Mexico's geothermal resources (IIE, 2010)

In figure 14, the orange dots represent detected geothermal anomalies, the black triangle symbolize sites already being exploited and the blue triangles are fields with evaluated potential.

Renewable energy potential is large as can be seen on the last figures, and solar potential in particular is estimated to be double than that of Germany (IEA, 2016), whose installed capacity is around 38 GW ranking 1st in the world. Because of this, the solar potential for energy in Mexico is worth enough to drive an analysis of its own and its positive impact on the economy.

Although the energy potential lies there, the story in terms of production is different. In terms of solar energy production, the installed capacity in Mexico is around **32 MW** mainly used for rural electrification, energy supply in the residential sector and water pumping (SENER, 2012). In terms of wind power generation, as of 2011 the country had in total 86.8 MW installed capacity (SENER, 2012). As of the geothermal energy capacity, Mexico is already in mature terms of installed capacity with 38 units of geothermic generation with a total capacity of 886.6 MW of electric power (SENER, 2012).

4. Renewable Energy Potential in Mexico: The opportunity with solar energy

4.1 An introduction to solar power

Solar power consists of using the energy in form of radiation coming from the sun caused by nuclear fusion processes of hydrogen nuclei transforming into helium in its surface. Due to several factors, solar power is yet a small portion of the renewable energy market mix, yet as of 2011 it is the fastest growing technology of all renewable sources (Narbel et al., 2014). Therefore, this means that in the near future the development of this technology will be exponential and betting for its use in Mexico can yield satisfactory results.

4.1.1 Different technologies options

There are 3 basic processes or technologies to transform solar radiation into energy (Narbel et al., 2014):

1. Passive solar power (PSP)
2. Concentrated solar power (CSP)
3. Solar photovoltaics (PV)

Passive solar power

Passive solar power is thermal energy created by setting panels of black absorbing material which encompass channels for water. Thus, it is an absorption process in which the black material absorbs solar radiation and transfer it to the water in form of heat and the differential of temperatures between the panel and the environment creates power following the next model:

$$P_{in} = c_1 A I_{sun}$$

$$P_{out} = c_2 \Delta T$$

Where *Pin* is the solar power into the absorbing material, *Pout* is the power transferred to the water from the conversion process of radiation to heat, *c1* and *c2* are material constants, *A* is the area of the absorbing material, *Isun* is the incoming flux from the sun and *ΔT* is the temperature gradient in the system.

Passive solar power receives its name because it is a passive energy conversion process without any chemical reactions for the production of energy in form of heat. This solar technology is mainly used for purpose of generating heat for warming water for domestic use in the buildings sector and no other relevant applications are considerable since the temperature reached is not enough to produce steam and move a motor turbine.

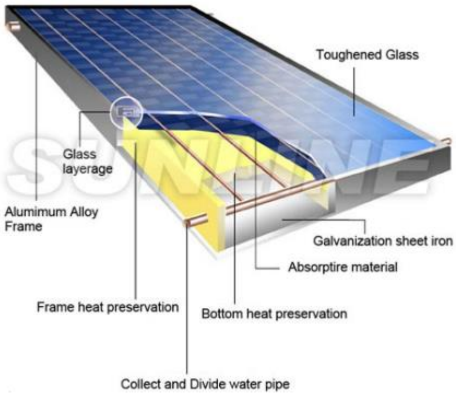

Figure 15: Scheme of a PSP unit (Hansen, 2016)

Concentrated solar power

The technology of concentrated solar power is a variation of passive solar power in which a set of mirrors are laid in order to concentrate the solar radiation into a focal point containing the fluid, similar to the magnifying glass principle. With this technology, the fluid (water) can be brought up to more than hundred degrees and thus steam can be used to power a turbine to generate electricity. Nevertheless, assembling the mirror system is expensive and the efficiency of the mirror system is not optimal. Also, as the system now consists of the mirror system and the engine, the total efficiency can be defined as:

$$\epsilon_{CSP} = \epsilon_{mirrors} * \epsilon_{engine}$$

Where ϵ_{CSP} is the efficiency of the system, $\epsilon_{mirrors}$ is the efficiency of the mirror assembly and ϵ_{engine} is the efficiency of the steam turbine engine to convert steam to electricity.

In common practice, efficiencies of 25% are common for this type of systems, but can be higher by improving the efficiency of the mirror system, yet the price tends to increase.

Figure 16: Example of a CSP power system (Hansen, 2016)

Solar photovoltaic

The principle behind solar PV is based on the physics principle of the excitation of the electrons of the atoms constituting the panel's materials (Si) by the photons contained in solar radiation. If the photons can excite the electrons on the panel materials, these electrons can in exchange generate an electric current. The potential for electricity can be defined as:

$$H_f = E_f - E_i$$

Where *Ef* and *Ei* represent the final and initial energy states of the current generating materials. With respect to the efficiency of the system it is a constant of the material's efficiency, depending *W* weakly on *T* temperature and *C* cloud coverage.

$$\epsilon_{PV} = \epsilon_{material} W(T, C)$$

The most commons materials, Silicon based, have efficiencies of about 20%, yet other more sophisticated materials can reach efficiencies between 40%-50%.

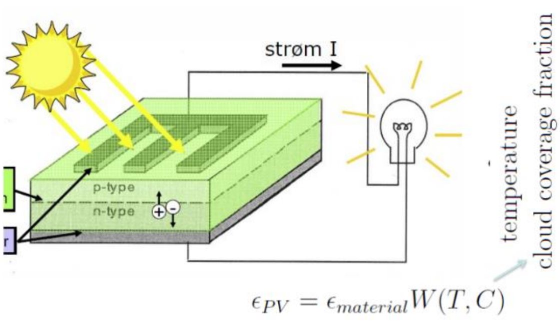

Figure 17: Scheme of PV cell (Hansen, 2016)

4.1.2 Requirements, considerations and costs

The main requirement to deploy correctly any of the 3 types of technologies is land area, since in order to generate a considerable amount of power a large extension of land is needed to absorb the solar radiation. In terms of capital costs, CSP is the cheapest of the 3 and around 1 GW of installed capacity is installed worldwide, mainly in Spain (Narbel et al., 2014). In respect to solar PV, by the end of 2012 around 102 GW of installed capacity was set worldwide mainly in Germany, Spain, Japan and Italy. The main challenge for solar PV is to reach grid parity, but once it does (experts predict it can be as soon as 2020), a solar energy revolution is expected worldwide. In terms of costs, solar technologies such as CSP and PV are capital intensive since 80%-90% is needed upfront for the solar systems to be built and installed. In the next table we can see a summary of the levelized costs of energy for CSP and PV power plants:

Technology	LCOE minimum(eurocents/kWh)	LCOE maximum(eurocents/kWh)
CSP	13	17
PV	13	34

Table 7: LCOE for CSP and PV (Narbel et al., 2014)

Levelized Costs of Energy, *LCOE*, is an approach used to compare between energy sources on a unit cost basis over the lifetime of different energy technologies/projects (Narbel et al., 2014). The 3 main elements evaluated under this approach are: capital costs, operation and maintenance costs and fuel costs. It is a widely used tool for economic assessment and forecasting of energy projects and for the sake of research purposes, all energy costs for the economic modelling on section 6 come from a LCOE approach.

4.2 Solar Power in Mexico

4.2.1 Current status

Solar PV

Last year Mexico experienced a boom with respect to its installed capacity of solar PV systems, adding just in 2015 100 MW to reach 260 MW total capacity. Just for reference, in 2011 the capacity reached was just of 32 MW (SENER, 2012). Solar PV systems in Mexico are mainly targeted to rural electrification and residential buildings demand complementation. This large boom was thanks to the implementation of regulatory instruments by CENACE to allow for interconnection of solar PV systems to the CFE's electric distribution grid, as well as tax deductions for investments on plant and equipment for solar PV.

Figure 18: Solar Farm Aura Solar 1, largest in LA in Baja California Sur, Mexico (CONACYT, 2014)

Concentrated Solar Power

Regarding CSP, the development of this technology is yet to be exploited in the country since to date there is only one CSP plant in Mexico, in the Northwestern state of Sonora in combination with a CC electric plant. The project named, *171 CC Agua Prieta II*, is a hybrid system compromising a CC plant (447 MWe) and a thermo- solar farm with parabolic channels with an output of 14 MWe (SENER, 2012) set to start operations in April 2016.

Figure 19: Agua Prieta Hybrid Power Plant (CFE, 2015)

4.2.2 Potential Use

Mexico is located between latitude 14°-33° N, which means it is within the solar belt region of earth. Average solar radiation is in the order of 5.5 kWh/m2/d which is one of the highest in the world. In the next table we can see solar radiation as a function of time of year:

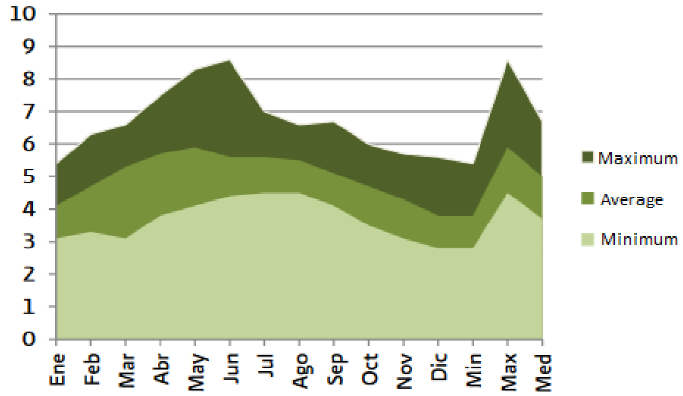

Figure 20: Daily solar radiation month average (SENER, 2012)

The Institute for Energy Investigations, IIE, conducted research on the penetration of the CSP technologies in Mexico within a 5 years' timeframe (Ramos, 2010). The research establishes 3 scenarios: Low, medium and high penetration scenario. The research's results are:

- Low penetration: Parabolic plate plants to substitute internal combustion machines.
- Medium penetration: Central receptor and parabolic channel plants to cover for additional power demand and withdrawal of conventional sources plants of CFE.
- High penetration scenario: Central receptor, parabolic channels and plates facilities to cover for 30% of CFE's demand.

With respect to solar PV systems in Mexico, SENER conducted a study with PWC (SENER, 2012) in order to assess the potential for PV systems penetration in the Mexican electricity market. The conclusions are that by 2017, solar PV systems will be competitive in economic terms for end-users, and by 2020 an expected total installed capacity of 1500 MW can be reached. The economic impacts of this development are assessed to be able to reach a positive impact on the GDP of $31,400 million MXN, 12,400 new direct and indirect jobs, $2,600 million MXN of tax revenue for the State and furthermore, a reduction of 2% in the distribution losses for CFE and a contribution of 2% of the GHG emissions reduction (SENER , 2012).

5. Integrating renewable energy into the mexican electricity market

5.1 Basic principles of integrating renewables into the energy mix

In principle, energy systems around the world began liberalizing in the last decade of the 20th century (Morales et al., 2014). Energy production by conventional fuels such as oil, gas, coal, etc. is deterministic in its nature, meaning that the output of power depends primarily on the will of the operator to run the power plant, considering fuel supply is not compromised. One can control the rate of production and accommodate to shifts on power demand, which is a key advantage of the conventional power plants.

On the other side, power production by the major renewable sources such as solar and wind power is stochastic intrinsically, meaning that it is not possible to control the pace of power production since the energy source is intermittent by nature, causing shifts with the power demand by the consumers. Thus, although the source can be readily available in some areas, it is still a challenge to incorporate renewable energy into electricity markets and reach grid parity (Morales et al., 2014).

Basically, until the technology for electricity storage advances to a level in which several days or even months of production and subsequent demand can be stored, integration of renewable energy into the markets should be accomplished by finding the optimized generation mix. Yet another challenge rises when trying to find the *perfect energy mix*, namely by mixing energy from conventional fuels and renewable sources, the efficiency of operation of conventional plants is diminished due to the added uncertainty and loss of economies of scale of power plants (Morales et al., 2014). Therefore, a general model or equation for the integration of renewables is not plausible since the integration of new sources is affected directly by the policies of the specific electricity markets worldwide.

With all the challenges posed to integrating renewables into the markets the question in place is: **Why integrate renewable energy in the electricity market offer?** The automatic answer for this is *Climate Change*. The concern that this issue has generated is already shifting many policies that concern the industry and day by day more countries have in their agenda integrating renewables as a way of reducing GHG emissions. Key drivers such as the Kyoto

Protocol or the UN Paris Agreement are shifting the largest economies to issue policies towards the *green revolution*. As a consequence, energy projects involving renewable energy are being prioritized and receiving State support. Furthermore, integrated renewable energy into electricity markets get prime sell positions, or the so called *merit-order* effect (Morales et al., 2014). This means *green electricity* is sold first and drag the price for kWh down due to supply and demand effects. On the contrary, when production of green electricity is low, the prices go up as a consequence.

Integrating renewable energy is a challenge posed to all actors involved in the market: the regulating bodies or State in a centralized market, the producers of electricity and also for the end-users or consumers. A fully integrated market depends on the 3 parties involved to reach a successful integration of new energy sources into the grid for several reasons. In the case of the regulators, they should incentivize the production of renewable energy to meet global policies with respect to Climate Change. The electricity producers bear most of the pressure to balance the energy mix and keep operations on the profitable side while following the policies proposed by the Regulators. Lastly, consumers pay for the result and if higher prices result as a consequence of shielding the environment from further damage they should either pay the end-price or change their consumptions habits to keep a relatively affordable price for their energy needs.

Different tools exist for each actor to participate on the integration of renewables into the markets. In the case of regulating bodies or States, the most common approach being used is the Renewable Portfolio Standard, *RPS*, which in essence is setting a target for renewable energy in the mix and letting the market find the cheapest way to get there (Komor, 2004). An RPS is composed of the assignation of the target to the producers and the task to generate the green electricity and a penalty for not achieving the goal. It is the simplest approach to ensuring that renewable energy capacity is built and has the approval of many political leaders worldwide (Komor, 2004). Additional to an RPS, the so-called *Green Certificates* can help achieve the integration of clean energy. Green certificates are the tradable *green currency* exchanged between producers and regulating bodies to achieve their RPS goals. It is a measure of how green the production is and this added value is traded among the actors involved on a RPS scheme to make ends meet.

For the case of the electricity generators, the tools involved in the energy mix management for the market are: mathematical and probabilistic modelling of the demand and supply of renewable energy, balancing the markets by using the day-ahead market approach, and implementing the so-called *virtual power plants* (also commonly known as aggregators) with the results of modelling and forecasting (Morales et al., 2014). The future of electric grids and markets seem to lie on the hands of virtual power plants, which in essence are the digital coordination of several energy plants from different energy sources into a coordinated transmission and distribution grid that take into account the forecasted demand and supply of electricity (Morales et al., 2014).

Least but no last, the contribution that the end-users can make to the correct integration of renewables is related to the intermittency of these sources. The concept of *demand response*, is basically the interaction between the consumers and an intelligent grid manipulated by a virtual power plant. This interaction will consist on a dynamic pricing scheme of electricity for the end-users meaning that when prices are higher the users will be warned and a *demand response* will be to moderate the consumption of electricity. Thus, when the production of electricity from renewable sources is low due to intermittency of the source, the virtual power plant will send the signal to the integrated grid and to the end-user's terminal warning him that if he turns on the switch now he will pay a more expensive utility bill in the coming month (Morales et al., 2014). This concept is already being used by Uber® with its dynamic pricing scheme whenever the supply of cars available is short, increasing the offer price.

5.2 Renovated mexican electricity market

Before the energy reform, CFE had no competition in terms of electricity trading in the country. Although there were other actors generating the power, they were forced to sell their output to CFE in order for the State company to resell it to end-users. With this framework, competition was obstructed and as a result Mexicans payed higher electricity bills than the Americans. The pre-reform Mexican Electricity market can be summarized by the following diagram:

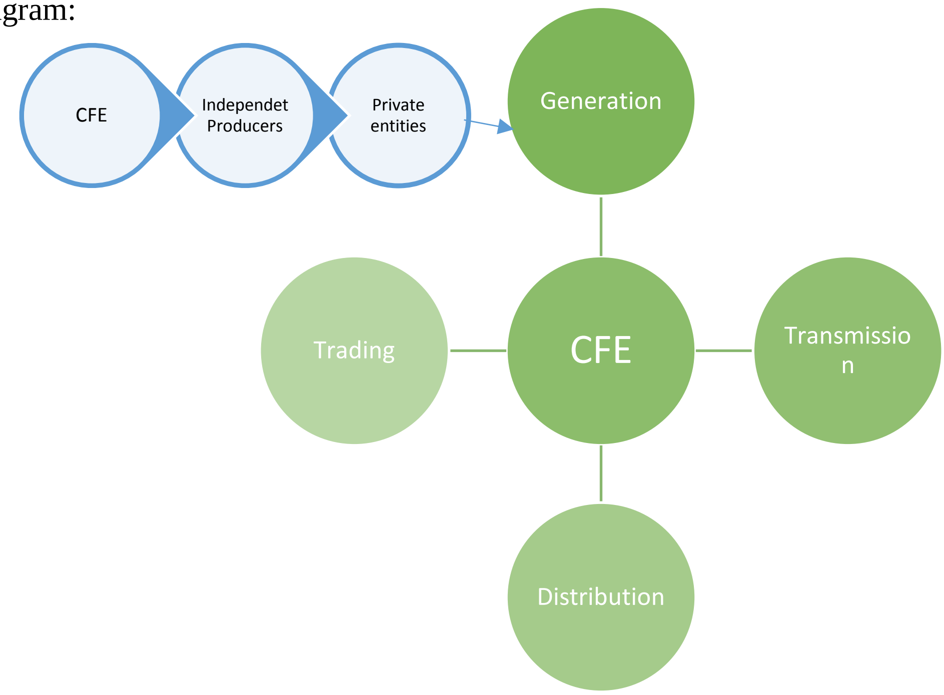

Figure 21: Pre-reform Mexican electricity market (CFE, 2014)

As shown above, in the generation activities, independent producers where companies venturing in the market to generate electric power under a certain contract with the commitment to sell the output to CFE at a certain price. Private entities such as companies could also generate electricity with their facilities for their own consumption as to incentivize industrial activities with lower prices for electricity. Nevertheless, if they had excess power they were not allowed to make a profit by selling it to third-parties. They had to sell only to CFE under a small scale production contract at a price determined by CFE.

With the Energy Reform of 2013, and the secondary law of the Electric Industry, the path is set for competition and for the integration of renewable energy into the Mexican electricity market.

The main advantages of the new Electric Industry Law are the following (Peña Nieto, 2013):

- Conditions for egalitarian competition are set for all energy producers in the market.
- Investments in clean energy are accelerated as well as the rate of decommissioning of obsolete plants.
- Electricity generators can celebrate contracts with end-users and trade their product in the Whole-sale electricity market.
- The State maintains its exclusivity within nuclear power generation and the resource.

In respect to electricity transmission and distribution, the responsibility of the grid administration will remain within the State's domain, yet external parties can contribute with their technology and experience in the extension activities of the grid and be able to assess CFE to optimize the grid and reduce losses in transmission and distribution.

In order to administer the recently launched Mexican whole-sale electricity market in early 2016, the federal government founded the CENACE with the following scope of responsibilities:

- Control of the electricity grid and of the National Electric System, in charge of procuring access to all generators.
- Quality assurance of the generating plants in order to maintain competitiveness within the market.
- Planning of the transmission grid accordingly to the forecasted demand growth.
- Establishing the policies with respect to the concession of interconnection rights to all generators.

With this new scheme, the energy prices will be set by the market operations between the producers, traders and qualified users (large scale consumer such as multinationals, steel companies, etc.), the transmission and distribution prices will be set by the CRE. For basic users such as households, only CFE will procure the electricity supply and the prices will be dictated by the Ministry of Finance to correspond accordingly with the State budget. The Electric Industry Law from 2014, has the premise to separate in legal terms all the market activities like generation, transmission, distribution and trading in order to maintain any conflicts of interest away from the market and to assure the transparent and efficient functioning of the industry. This law sets a milestone in the openness of the electric industry in terms of competition, but also in terms of energy sources since newcomers are benefited by preferential trading of their electricity if it is generated from clean sources. So the new companies entering the market are more attracted to generate better profits offering the country green electricity, since their offer is bought first by CFE or allowed for sale to qualified users. In order to clarify the structure of the new Mexican electricity market, the following diagram is offered:

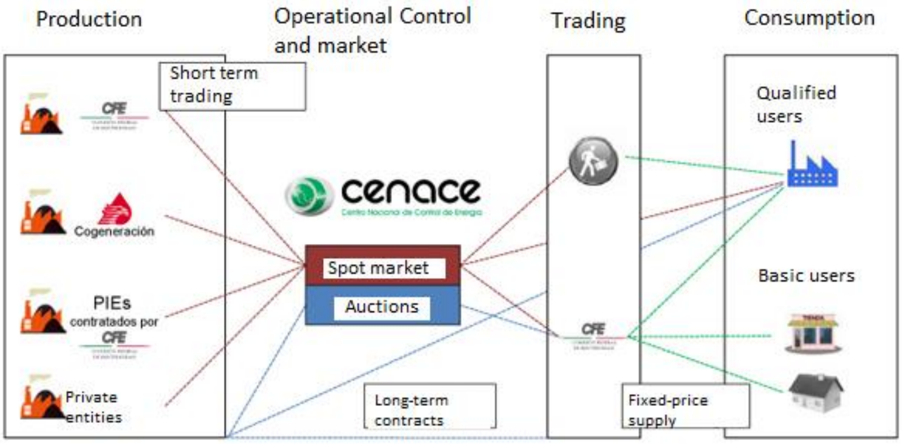

Figure 22: Mexican Electricity Market Post-reform (CENACE, 2014)

In terms of sustainability, the Electric Industry Law is coordinated with the National Energy Strategy and the National Strategy for Renewable of the SENER. The 3 pillars for developing a strategy based on renewables are:

Green certificates

The government will take a classic approach by establishing a RPS scheme, which set the goal of 35% of renewable in the electricity generation from clean energies. This will be exercised by the trading of CELS or *green certificates* among the players of the electricity sector.

Interconnection and transmission for clean energies

The producers of green electricity will have priority and support to connect to the transmission and distribution grid. Also, the planning by the CRE will contemplate the interconnection of remote plants in areas of high potential of renewable energy into the transmission grid.

Distributed generation

In terms of distributed generation (generation by small parties), rules will be enacted in order to allow for the immediate interconnection to the grid to the owners of solar PV panels and other technologies. Also, these parties will be able to sell power to CFE at regulated prices or sell to the other electricity traders at market prices.

6. Economic modeling: Mexico's growth forecast integrating renewable energy

6.1 Impact of renewable energy in world economies

Renewable energy as a concept has been developed for contribution to sustainable development in terms of energy security and access to rural populations and mitigation to climate change. Nevertheless, with the further development of the technologies involved in renewable energy generation, cost for the energy from clean sources has become competitive in economic terms and can compete against energy from traditional sources. With this, governments and experts have started studying the contribution of renewable energy to economic development of nations, in terms of the added-value of the production from clean sources plus the jobs created from this booming industry (Greenpeace, 2014). Thus, the contribution to sustainable development now encompasses all axes, from environmental, social and economic perspectives.

In the last years, several studies conclude in a positive correlation between the increase of GDP and consumption of renewable energy. For example, in 2009 a study by P. Sardosky encountered a positive relationship between the GDP per capita of 18 emerging nations and the increase in consumption of renewables (Sardosky, 2009). In 2010, a study by Apergis and Payne found a positive correlation between consumption of renewable energy and economic growth taking into consideration 20 OECD nations during the 1985-2005 period (Arpegis and Payne, 2010).

This relationship of causality is not exclusive of emerging nations, since developed nations also boost their somewhat stagnant economies by consuming renewables. A study by Tugcu in 2012, show the same behavior with the G7 economies (Tugcu et al., 2012). In mature economies, innovation is a key driver into further development of the economy where all other industries are mature and growth is not significant. Thus, some experts believe in what is called the *green revolution*, as contrast to the industrial revolution which lead Europe and the world to development as we know it (Greenpeace, 2014). Together with the *IT revolution*, this new approach to energy production and consumption will likely be the driver of sustainable development in the 21st century.

California, the largest state of the U.S. in economic terms, which by itself is the world's 5th economy, navigates accordingly to its innovative spirits being the world capital of IT, and aims to have 50% of electricity from renewable energy by 2030 and increase by two-fold energy efficiency in buildings (Koronowski, 2015). The bill SB350, called *The Clean Energy and Reduction Act*, was approved in September 2015 by the California State Assembly and with this California demonstrates to be the world leader in solving the climate change crisis by setting a landmark legislation.

With all these precedents, Mexico lies within a window of opportunity for sustainable economic growth. Normally Mexico is a country that grows year by year, yet this fact is not enough to turn Mexico into a developed nation since growth is polarized between the population (income disparity) and the rate of growth (2.5%) is not enough to cope with decades of delay with respect to developed nations and the still growing population (1.1%). Country leaders are aware of this situation and have set in effect a series of reforms in the last 4 years, not only the Energy Reform (focus of this paper), but also the Tax Reform, Education Reform, Telecommunications Reform and the Transparency reform are within the most important ones. In the next sections, an assessment of the economic impact of incorporating renewable energy (focus solar PV) will be set and discussed by proposing different scenarios in terms of penetration of this energy source.

6.2 Summarized collected data from analysis and research

In the research, we came to the following findings for the growth forecast of the economy:

Factor	Key finding
Increase in electricity market	6% per year
GDP Increase by overall reform	1% additional by 2018, 3% additional by 2025
Mexican GDP	$1.144 trillion USD
Mexican Energy Market Share of GDP	8% of GDP
Discount rate	5.25%
Mexican GDP annual growth	2.5%
Average electricity price to end consumer	$1,100 MXN/MWh or $55 USD/MWh (EIA, 2016)
Average electricity production price	$1,400 MXN/MWh or $70 USD/MWh (CFE, 2015)
LCOE for Solar PV in Mexico	$1,000 MXN/MWh or $50 USD/MWh by 2020 (EMIS, 2015)
Exchange rate MXN to USD	$20 MXN to $1 USD (BANXICO, 2016)

Table 8: Summarized data for analysis of economic modelling

With the recent oil-prices crisis, the Energy Reform loses some attractiveness in terms of Hydrocarbons input to the economic development of the country, therefore the focus of this research and the next economic modelling is on solar PV, a booming industry in the country. Using the Production Approach Methodology to measure GDP approved by INEGI, Mexico's statistics institute, different scenarios of solar PV area coverage and electricity production will be measured in terms of the added-value to the GDP.

As seen from table 8, currently Mexico is heavily subsidizing electricity prices by 30%. A total of 100,000 million MXN (5 billion USD) are taken from tax revenue to subsidize electric tariffs in the country. Such a State's interference in the price is detrimental to an open electricity whole-sale market, which started early 2016 in Mexico. In comparison to OECD countries, electricity in Mexico is 44% more expensive even considering the heavy subsidies (CFE, 2014). If solar PV capacity is installed, with a matching production price to sale price, the 30% subside will become the added-value to Mexico's GDP and that is the key measurement of success the author is looking for in this paper.

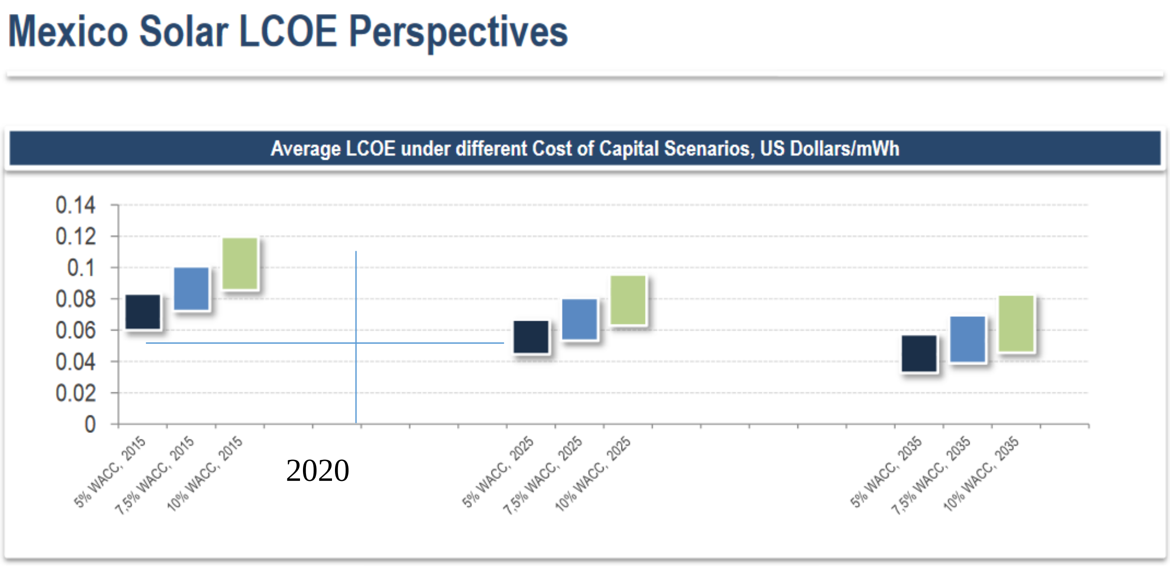

Figure 23: Mexico Solar LCOE Perspectives (EMIS, 2015)

From Figure 13, we can roughly estimate a LCOE of $0.05 USD/kWh for solar PV in 2020, considering that for solar PV projects WACC is by practice equal to the discount rate in Mexico (5.25%). For analysis purposes, the author shall consider a substitution of a fraction of power production of Mexico (309,553 GWh in 2015 from table 1), by solar PV production considering the average annual daily solar radiation in the country (5.5. kWh, figure 12) considering a standard plant utilization factor of 0.207 (SENER, 2012). To proceed with this economic modelling, the author assumes that all other economic, social, political and geographical factors remain constant.

6.3 Methodology

The methodology to be used is the one approved by the Mexican government to measure its GDP and growth (INEGI, 2015):

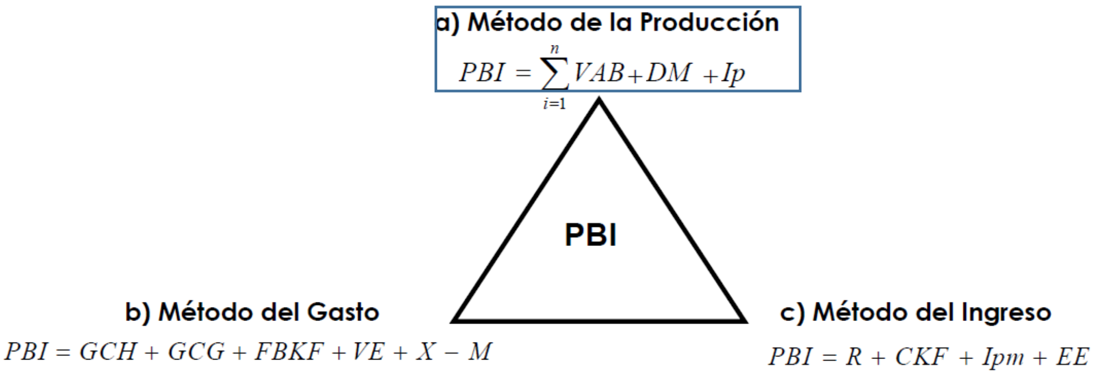

Figure 24: GDP Measurement Methodologies (INEGI, 2016)

The Production Approach (Método de la Producción) formulation in English reads as follows:

$$GDP = \sum_{i=1}^{n} GVA + IR + T$$

where

GVA= Gross Value Added of Production

IR= Import Rights of production

T= Revenue from taxes

n= number of production units (45 for the case of Mexico)

To calculate the Gross Value-Added from electricity production, the standard formulation for the production approach is:

$$GVA = GVP - IC$$

Where

GVP= Gross Value of production at market price

IC= Intermediate Consumption (costs of production)

For the analysis of impact on GDP, the remaining 44 production units in Mexico are considered constant, thus the formula for our analysis becomes:

$$GDP = GVA + IR + T$$

For the case of solar PV electricity production, we have that IR=0, since electricity is produced to be consumed internally in the country. Also, according to the Mexican Law on Income Tax, article 40, fraction XII all investments on plant and equipment for the production of clean energy are 100% tax-deductible (LISR, 2016). Thus, by having a sound financial planning, solar PV electricity producers can avoid paying any taxes on their production. Therefore, we can consider T=0 in our new formulation to be written as:

$$GDP = GVA = GVP - IC$$

GVP becomes then the actual price of electricity production in Mexico, \$70 USD/MWh (see table 7) and *IC* will be the forecasted LCOE for solar PV in 3 years from now, considering that the current production price from conventional sources remains constant. Thus, IC= \$50 USD/MWh (see table 7). Consequently, the Gross Value-Added from electricity production, *GVA*, is equal to \$20 USD/MWh.

$$GVA = GVP - IC = \$20\ \text{USD/MWh}$$

Finally, to measure the total GDP increase due to the *GVA*, we propose 3 different penetration scenarios: 10%, 25% and 50% of total electricity production from solar PV technology. For each of them, an area requirement will be discussed in the next section in terms of feasibility and location in Mexico.

7. Results and conclusions

Scenario 1, 10% of electricity production from solar PV

Factor	Amount	Unit	Amount2	Unit2
Total electricity production	309,553	GWh		
Fraction from solar PV	30955.3	GWh	30955300	MWh
Land area of Mexico	1.973	million km2	1.973E+12	m2
Average annual solar radiation	5.5 kWh/m2		0.0055	MWh/m2
Total theoretical potential (100% usable area)	10851500000	MWh	10851500	GWh
Average plant factor	0.207			
Total potential	2246260500	MWh	2246260.5	GWh
Ratio potential to electricity production	7.256464967			
Total area required for scenario 1	27189547650	m2	27189.548	km2
Percentage area required/total area Mexico	1.4%			
Size of Sonora, mexican northern dessert state	179503	km2		
Ratio required area to size of Sonora	15%			
GVA from Solar PV Electricity Production	$ 20.00	USD/MWh		
Total GVA from scenario 1	$ 619,106,000.00			
Mexico's GDP	$ 1,144,000,000,000.00	USD		
GVA to GDP ratio	0.054%			

Table 9: Scenario 1

Scenario 2, 25% of electricity production from solar PV

Factor	Amount	Unit	Amount2	Unit2
Total electricity production	309,553	GWh		
Fraction from solar PV	77388.25	GWh	77388250	MWh
Land area of Mexico	1.973	million km2	1.973E+12	m2
Average annual solar radiation	5.5 kWh/m2		0.0055	MWh/m2
Total theoretical potential (100% usable area)	10851500000	MWh	10851500	GWh
Average plant factor	0.207			
Total potential	2246260500	MWh	2246260.5	GWh
Ratio potential to electricity production	7.256464967			
Total area required for scenario 1	67973869126	m2	67973.869	km2
Percentage area required/total area Mexico	3.4%			
Size of Sonora, mexican northern dessert state	179503	km2		
Ratio required area to size of Sonora	38%			
GVA from Solar PV Electricity Production	$ 20.00	USD/MWh		
Total GVA from scenario 1	$ 1,547,765,000.00			
Mexico's GDP	$ 1,144,000,000,000.00	USD		
GVA to GDP ratio	0.135%			

Table 10: Scenario 2

Scenario 3, 50% of electricity production from solar PV

Factor	Amount	Unit	Amount2	Unit2
Total electricity production	309,553	GWh		
Fraction from solar PV	154776.5	GWh	154776500	MWh
Land area of Mexico	1.973	million km2	1.973E+12	m2
Average annual solar radiation	5.5 kWh/m2		0.0055	MWh/m2
Total theoretical potential (100% usable area)	10851500000	MWh	10851500	GWh
Average plant factor	0.207			
Total potential	2246260500	MWh	2246260.5	GWh
Ratio potential to electricity production	7.256464967			
Total area required for scenario 1	1.35948E+11	m2	135947.74	km2
Percentage area required/total area Mexico	6.9%			
Size of Sonora, mexican northern dessert state	179503	km2		
Ratio required area to size of Sonora	76%			
GVA from Solar PV Electricity Production	$ 20.00	USD/MWh		
Total GVA from scenario 1	$ 3,095,530,000.00			
Mexico's GDP	$ 1,144,000,000,000.00	USD		
GVA to GDP ratio	0.271%			

Table 11: Scenario 3

For a reference location, Sonora was selected as being a dessert state in Northern Mexico, where conditions exist for installation of solar PV capacity for feasibility of the research. From the 3 different scenarios, an area approximates to 15%-75% the size of Sonora is needed to produce the required electricity premise. In the last scenario, 75% can seem like a large number, yet Sonora has 2 neighboring states, Chihuahua and Coahuila similar in size and meteorological conditions, therefore a rough estimate would be to occupy 20% of the land area of each state with the solar panels facilities to comply with the 50% share of total power production from solar PV. In terms of feasibility, occupying 20% of dessert like states seem likely, yet a profound feasibility study for these scenarios is not within the scope of the research. Also, it will be important to assess the environmental impact on flora and fauna by the installation of solar panels on such large areas, yet it is not in the scope of this research. The plant utilization factor of 0.207 is from other solar PV projects currently in operation in the State of Sonora (SENER, 2012), so with respect to the intermittency of the power source, this proposed factor covers for basic feasibility purposes.

In economic terms, the economic modelling results show that a positive economic impact is to be expected with the incorporation of solar PV electricity in Mexico, ranging from 0.05%-

0.271% of additional GDP annual growth. Comparing to the actual GDP of 2.5% annual growth, in scenario 3 around 10% additional GDP growth can be expected by going solar in Mexico.

Additional scenarios can be proposed accordingly in terms of a sudden reduction of the LCOE of solar PV electricity due to a sudden break-through in panel technology, and the increase in the contribution to the Added-Value can go up further. For example, considering a 50% reduction in the LCOE of solar PV due to a fall in the capital costs (panel prices) or improved efficiencies, the projected contribution of solar PV electricity in Mexico can go up to 0.5% of additional GDP annual growth. Considering that electricity production is just 1 out of 45 production units in Mexico, the findings of the economic modelling for this unit of production are encouraging for the country. According to the experts, and increase of 3% additional GDP growth by 2025 can be expected by the overall effects of the Energy Reform and with respects to the results of this modeling we can conclude they go in line with what the experts are forecasting.

In economic terms, a switch to solar PV in Mexico seems convenient. Furthermore, the environmental relief of this change of energy source is the other good side of the story. Mexico's goal of incorporating renewable to its energy mix by 35% by 2025 can be easily met with the strategy proposed in this paper. By so doing, the country can stop contributing to CO2 emissions to the environment, where nowadays Mexico is the 7th CO2 polluter in the world.

The author recognizes the limits within the scope of this research, since switching to solar PV in 10, 25 or 50% of total electricity production can be deemed difficult in terms of investments, construction and installation of the capacity and political will. Yet is the aim of the author to show a clear panorama of the energy sector in Mexico and its whole potential in terms of sustainability.

In conclusion, the research show that renewable energy can be a factor for economic growth for a country such as Mexico, with focus on solar power. Also, the impact of the Energy Reform is the key to trigger the necessary market conditions for this to happen soon enough to take advantage of the opportunity window for the privileged location of the country. Furthermore, research threads in other renewable sources such as wind or geothermal power can be conducted in order to fill the gap and to study the possibility of a 90-100% of energy generation with renewable sources in Mexico and asses the overall impact on the economic growth.

Finally, the research and analysis results show that the thesis proposed was met, since a deep study and interpretation of the Energy Reform together with economic modelling and forecasting applying a methodology to find the economic impact of renewable energy on economic development show qualitatively and quantitatively this proposed relationship.

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