RENEWABLE ENERGY IN MEXICO: DEVELOPMENT AND OUTLOOK OF PHOTOVOLTAIC (PV) ENERGY

OBNOVLJIVI IZVORI ENERGIJE U MEKSIKU: RAZVOJ I PRIKAZ FOTONAPONSKE (PV) ENERGIJE

José G. Vargas-Hernández [1], Mohamed EL-Shimy [2], Arturo Córdova Rangel [3], Lucija Nađ [4*]

[1] Emmanuel RodolfoAscencio Espinosa. Centro Universitario de Ciencias Económica y Administrativas, Universidad de Guadalajara. Periférico Norte 799, Núcleo Universitario Los Belenes. Zapopan, Jalisco, C.P. 45100, Mexico
[2] Professor of electrical power systems. Electrical Power and Machines Department. Ain Shams University. 1 EL-Sarayt Rd. Abdo-Basha Sq. Abbassia, 11517, Cairo, Egypt
[3] Universidad Politécnica de Aguascalientes. Calle Paseo San Gerardo No. 207, Fracc. San Gerardo . Aguascalientes, Ags., C.P. 20342, Mexico
[4] Environmental engineering, Geotechnical faculty of the University of Zagreb. Hallerova aleja 7, 42000 Varaždin, Croatia
*E-mail adresa osobe za kontakt / e-mail of corresponding author: lucijananad@gmail.com

Abstract: *From the energy resources point of view, Mexico has an advanced worldwide rank in the availability of fossil resources as well as renewable energy resources. The major abundant conventional resources are oil and natural gas while the abundant renewable energy resources include solar, wind, hydro, geothermal, and biomass. Due to the geographical and topological conditions of Mexico, the meteorological conditions of various locations in Mexico are significantly location-dependent. In addition, the potential of the major renewable energy resources (i.e. wind, solar, and hydro) is neither fully explored nor exploited. With a focus of solar-PV energy, this paper analyzes the renewable energy industry in Mexico and investigates the most suitable way for promoting the public policies and finding the absolute advantages. In doing so, the international theories and experiences are considered as a development guide. International experiences show that it is possible to establish 'green energy' markets in which the end users cover their costs. These emerging markets are identified to be highly profitable for both sides i.e. the energy provider and the energy consumers. It can also be seen that government programs are available for supporting these markets; a fact that makes the green energy alternatives tempting for the investment of national and international firms. Some of the data presented in the presented study are based on techniques such as Herfindal-Hirshman Concentration Index (HHI), Pascual concentration indices and game theory.*
Keywords: *Mexico, Renewable Energy, Photovoltaics, Green Energy Markets, Development.*

Sažetak: *Sa stajališta izvora energije, Meksiko je u samom svjetskom vrhu u dostupnosti klasičnih izvora energije, kao i obnovljivih izvora energije. Glavni klasični izvori su nafta i prirodni plin, dok izvori obnovljive energije uključuju energiju sunca, vjetra, hidroenergiju, geotermalnu energiju i biomasu. Zbog geografskih i topografskih uvjeta Meksika, meteorološki uvjeti na raznim lokacijama u Meksiku znatno ovise o lokalnim uvjetima. Osim toga, potencijal glavnih obnovljivih izvora energije (tj. vjetra, solarne i hidro) niti je u potpunosti istražen, niti iskorišten. S naglaskom na solarnu PV energiju, u ovom radu analizira se korištenje obnovljive energije u Meksiku te se istražuje najprikladniji način za promoviranje smjernica daljnjeg razvoja i pronalaženje apsolutnih prednosti obnovljivih izvora energije. Na taj način, međunarodne smjernice i iskustva smatraju se kao dobar vodič za razvoj. Međunarodna iskustva pokazuju da je moguće uspostaviti tržište 'zelene energije' u kojima krajnji korisnici pokrivaju svoje troškove. Takve vrste tržišta u nastajanju identificirana su kao vrlo unosna za obje strane tj. proizvođače energije i potrošače energije. Također se može vidjeti da su državni programi dostupni za podržavanje takvih tržišta; činjenica je da navedeno zelenu energiju čini primamljivom za ulaganja domaćih i međunarodnih tvrtki. Neki od podataka prikazanih u ovom radu temelje se na pokazateljima kao što su Herfindal-Hirshman Koncentracijski Index (HHI), Pascual-ov indeks koncentracije i teorije igara.*
Ključne riječi: *Meksiko, obnovljivi izvori energije, fotonaponski sustavi, tržište zelene energije, razvoj.*

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Pregledni rad / Review paper

1. INTRODUCTION

Currently, the renewable energy (RE) sources occupy an increasing space in the energy landscape, and global economics. All developed countries and developing countries are changing their energy policies for the development of technologies that provide economic growth, and can meet the demands of its population. The technologies that use renewable energy are currently experiencing the highest growth rate in the world.

Mexico is no exception of the international trend. Over the last decade till now, the energy reform led to the development of the energy sector.

Currently, there are 10 major private companies engaged in the production of renewable energy. The business of these companies with the Federal Electricity Commission (CFE) is as direct producers, and/or production equipment providers (also for individuals). Mexico has initiated a way to diversify fuels used in electricity generation for enhancing the energy mix.

The intensive use of fossil fuels has impacts on the energy security by the volatility of prices and availability of fuels. In addition, the use of fossil fuels degrades the environment and health due to the emission of greenhouse gases. Due to these reasons, Mexico (legislators and government) has recently developed various policies, laws, rules and regulations to promote the rational use of non-renewable resources and increase the implementation of energy sources that cause less environmental impact, such as renewable energy. In the latter context, it is found that the use of solar energy could play an important role.

Various energy planning documents developed and /or supported by several national and international organizations and actors (such as the Ministry of Energy (Secretaria de Energía), bilateral cooperation agencies, research centers, NGOs, associations and representatives of civil society and private industry) have highlighted the enormous potential for Mexico to take advantage of the solar resource. The proposed applications of the solar energy include heating and cooling applications as well as electricity generation.

In the case of electricity generation, international experiences show that PV systems require some form of intervention by the authorities conducting energy policy to overcome the obstacles and create a market that will accelerate their development.

2. OBJECTIVES

This paper analyzes the renewable energy industry in Mexico, specifically solar energy and photovoltaic (PV) technologies. Although it is a new industry and an emerging market in Mexico, it is a significantly growing market. Therefore, the renewable energy in Mexico can be considered as a potential business of a high economical viability. The period of analysis oscillates between 2000 and 2013.

This work focuses on the review and analysis of the renewable energy sectors from the points of view of the operation of the technologies, its applications, its current market, and their chronological development, and the foreign and national investment as well as the sale and production of the solar-PV equipment. The present study investigates these aspects using techniques such as Herfindal-Hirshman Concentration Index (HHI), Pascual concentration indices, and game theory.

The research questions are: What are the main features of the RE market in Mexico? What is the industry outlook considering development and production? And who are the major investment companies in the photovoltaic industry in Mexico?

3. BACKGROUND

According to the National Association of Solar Energy (ANES), until 2006, virtually the applications of solar-PV systems installed in Mexico include off-grid applications, rural electrification, communications, and water pumping and cooling. However, from the year 2007 there are records of grid-connected applications. This trend has continued in subsequent years. For example, in 2011, 94% of the 3.5 MWp installed in that year were grid-connected. **Fig. 1** shows the evolution of the installed capacity and power generation with solar-PV systems in Mexico.

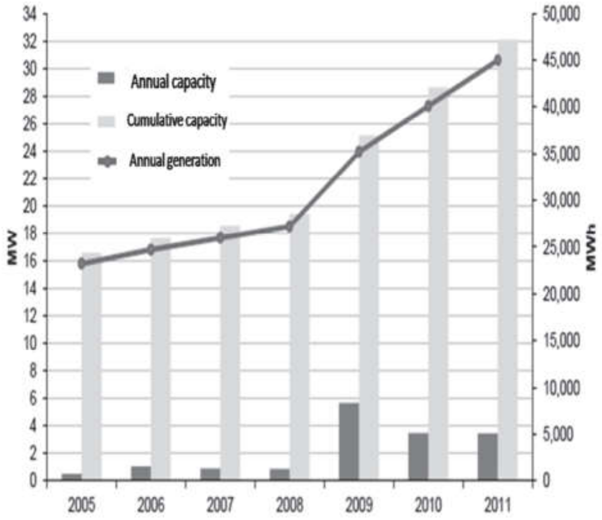

Figure 1. Evolution of the installed capacity and power generation with solar-PV systems in Mexico. (SENER2012)

As shown in the **Fig. 1**, the annual installed capacity (off-grid and grid-connected systems), shows a fluctuating behavior in the period 2005 – 2011; however, in cumulative terms, the installed capacity is increased from 16.5 MWp to 32 MWp while the annual electricity generation increased from 23,235 MWh in 2005 to 44.974 MWh in 2011. Therefore, the cumulative capacity and cumulative energy show increasing trend.

4. DESCRIPTION OF TECHNOLOGY

Till the middle of previous century, the use of solar energy to generate electricity materialized its first applications mainly during the early space race between the U.S. and the former Soviet Union. The phenomenon that is considered as the origin of photovoltaic was observed by first time over 100 years ago. This phenomenon is called 'photovoltaic effect'. **Fig. 2** illustrates the basic concepts of the photovoltaic effect. **Fig. 3** illustrates the construction of solar-PV arrays.

The solar-PV cell presents the main item. Cells are grouped together to form the solar-PV modules (or panels) which is the usually available commercial units. A solar-PV generator is constructed by externally connecting several modules by wires. Details about the development of photovoltaic materials, characteristics, and solar-PV generators for off-grid and grid-connected applications can be found in (EL-Shimy M, and Abdo T, 2014; and EL-Shimy M, Nov. 2015).

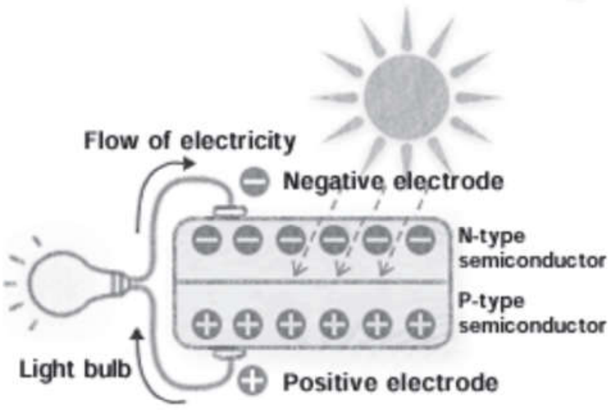

Figure 2. Main concepts of photovoltaics (Solar pool tech)

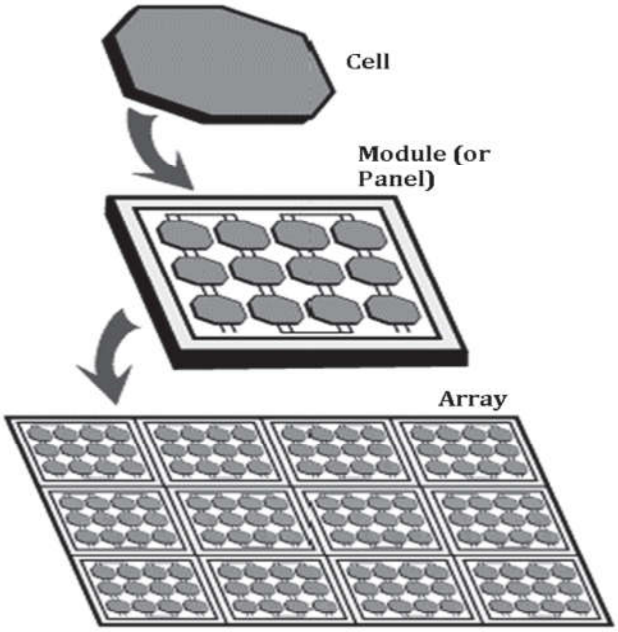

Figure 3. Assembly of a PV module (Organización Anes)

Since the CFE as well as other grids delivers AC electricity to their loads such as homes while the solar-PV modules produce DC electricity, inverters are needed for transforming the DC electricity to AC electricity as specified by the grid. It should be noted that the connection of a PV array with the grid requires other components such as power conditioning, filtering devices, metering instruments, and protection devices. Although the lifetime operation and maintenance (O&M) costs of solar-PV systems are low while their initial costs are significantly high in comparison with other power generation technologies. Therefore, the contribution of initial costs in the Levelized Cost of Energy (LCOE) is very high in comparison with the contribution of the O&M costs. Consequently the O&M costs are virtually null in comparison with the cost of electricity generation. From trend of costs point of view, it is found that the investment and the generation costs decline and it is expected that these costs continue to significantly decline.

Details about the modeling, and evaluation of the LCOE of solar-PV systems can be found in reference (Said M, EL-Shimy M, and Abdelraheem M A, 2015). From the point of view of the lifetime of solar-PV modules, it is shown in (EL-Shimy M, and Abdo T, 2014) that the lifetime is highly dependent of the technological characteristics of the solar-PV materials. For example, the average lifetime of Mono-Si modules is 41 years while it is 30 years for Poly-Si modules. The average lifetimes of the major second generation modules are 19 years, 37 years, and 18 years for a-Si, CdTe, and CIS modules respectively.

There are two markets that can harness solar energy for electricity generation: the grid-connected or off-grid (autonomous isolated) systems. These two markets are described in the following subsections.

4.1. Grid-connected systems

The grid-connected systems are mainly utilized in urban or rural areas, which are interconnected to the National Electricity System (SEN). These systems consist of the following components (**Fig. 4**): (1) PV panel or array; (2) Inverter; (3) Other interconnecting devices that include protection, measurement, switches, protection, and bidirectional meter.

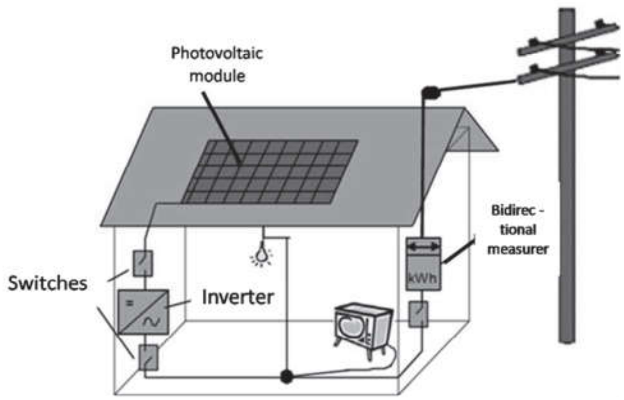

Figure 4. Example of grid-connected solar-PV system. (CONUEE/ GTZ, 2009 Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ))

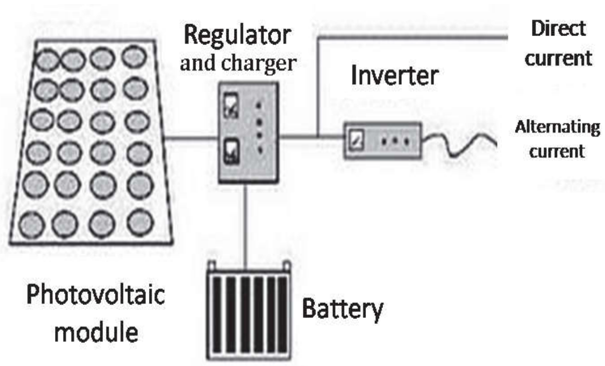

Figure 5. Off-grid solar-PV system

4.2. Isolated or off-grid systems

Isolated or off-grid systems can be found in rural or isolated areas, where it is not economically feasible to construct a grid interconnection with SEN. These systems consist of the following components (**Fig. 5**): (1) PV panel or array; (2) Battery bank and battery charger; (3) Interconnecting and protecting devices; (4) Inverter which required for supplying AC loads and can be excluded if the loads are DC.

Unlike conventional energy sources, some renewable energy sources are characterized by high variability and intermittency (EL-Shimy M, May 2015; EL-Shimy M, Nov. 2015). Consequently, electrical energy storage is essentially required in isolated systems that supply off-grid non-deferrable loads for providing the required instantaneous power balance. There are a variety of energy storage options (EL-Shimy M, Nov. 2015). The use of batteries is common in small-scale systems while R&D efforts are currently focused on finding techno-economically energy storage for large-scale and bulk energy applications. Probably, the hydrogen-based energy storage systems as well as the pumped hydro storage system show competitive viable bulk energy storage in the future. On the other hand, there is a class of loads that are deferrable such as irrigation water pumping systems (EL-shimy M, 2013). These loads do not require a precise instantaneous energy balance. Therefore, electrical energy storage is not required for these kinds of loads. Sometimes hydraulic energy storage is used in solar-PV supplied irrigation water pumping systems for energy security purposes rather than power balance requirements. As shown in **Fig. 5**, isolated systems are not usually equipped with energy measuring devices.

5. INDUSTRY OF SOLAR ENERGY IN MEXICO

Mexico is among the most attractive five countries worldwide for solar-PV projects; however, Mexico is still behind China and Singapore, because they are part of the Sun Belt region. The Sun Belt countries are located within latitudes + -35 with respect to the Equator and they exhibit higher levels of solar and sunlight radiation in comparison with the rest of the planet; however, there are areas where the solar irradiance is greater than 5kWh per m² in Mexico (**Fig. 6**). Market attraction also includes other factors such as market potential, politics, business environment, financial stability and renewable energy policies. The size of the electricity market, its projected growth in electricity consumption in the next two decades and the competitive cost of PV technology also coverage electricity networks and the ease of power distribution are among the others the market attractiveness reasons.

Currently, Mexico has an installed capacity of 33 MWp of solar-PV systems. The main applications are rural and industrial electrification. In addition, there are several construction and development projects of this kind that would have an installed capacity of 39.1 MWp. In late 2011, a Spanish company called Siliken invested in a photovoltaic power project in Durango called La Manzanadel Sol. The project has 100MWp of installed capacity and it is now in its first stage and it is estimated that would be increased to a total of 400MWp in the five years after its initiation (**Fig.** 7).

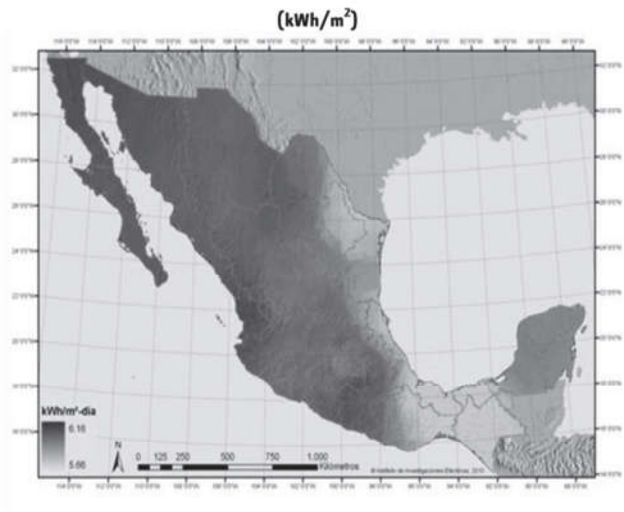

Figure 6. Annual average global solar radiation over Mexico (IIE)

Photovoltaic solar plants for electricity generation				
Central	Current status	Installation capacity (MW)	Location	Type of service
Contracts of small and medium scale	In preparation	32.0	-	Private
Central Piloto, Santa Rosalia	In preparation	1.0	Baja California South	Public
Total	-	33.0	-	-
Photovoltaic proyect, Durango	To start with operations	0.5	Durango	Private
Photovoltaic proyect (self-supply)	In construction	3.8	Aguscalientes	Private
Photovoltaic proyects (small plant)	In construction	29.8	Jalisco	Private
Central Piloto, Cerro Prieto	In construction	5.0	Baja California	Public
Total		72.1		

Figure 7. PV centrals in México (CFE)

6. MARKET STRUCTURE

6.1. Major PV companies in Mexico

Mexico is the leading supplier of photovoltaic modules in Latin America, with an annual production capacity exceeding 276 MWp still above countries such as Chile, Brazil and Argentina. Among the leading developers of photovoltaic are: Abengoa, Abener, Del Sol Systems, Microm, Iberdrola and Silken.

In Mexico there are plans for operating power plants using the solar-thermal high-concentration; however, in the state of Sonora is developing the project 171 CC Agua Prieta II, by CFE that consists of a combined cycle hybrid system: 477 MWe, and a thermal solar field of trough parabolic channels with a power of 14 MWe. It is expected that this plant enter into operations soon (**Fig. 8**). The growth power generation and the energy mix for years 2000 to 2013 are illustrated in **Fig. 9.**

Potential growth of solar thermal energy in Mexico		
Region	Stage	Potential (MW)
North	Low	0
	Medium	816
	High	1,413
	Low	417
Northwest	Medium	837
	High	1,431
Total	Low	471
	Medium	1,653
	High	2,844
Source: IIE.		

Figure 8. Growth potential of solar thermal energy in Mexico (IIE)

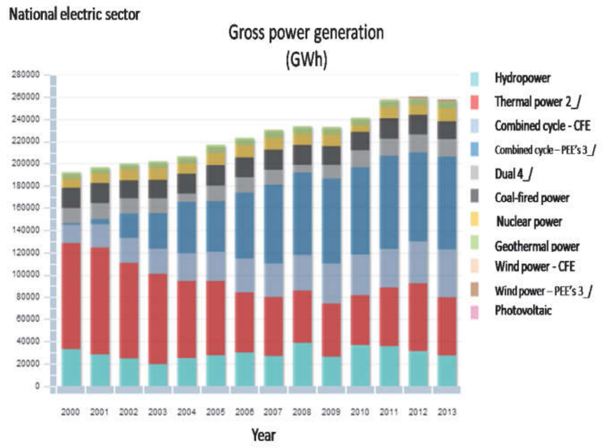

Figure 9. Gross Power Generation (SENER)

Table 1. Companies by number of employees

Strata	Economic units	Total Gross production	Intermediate consumption	Total ex-penses by consumption of B and S	Total invest-ment	Gross census aggregate value	Total remunera-tions	Total reve-nues
Total	65	450968876	233857943	298861814	29504562	217110933	35520658	522313705
From 0 to 2	5	10284205	8485161	8486788	-32356	1799044	300	10451433
3-5	1	2100	1157	1186	0	943	0	2100
6-10	1	92538	79036	79036	0	13502	1021	92538
11-15	3	620686	620686	494161	20	4119	0	97966
16-20	3	99667	95548	94112	20		0	
21-30	2	2859872	2132179	2132179	47609	727693	0	2580730
31-50	12	33293082	24408760	24409601	-127987	8884322	53907	30346885
51-100	1	243083	220004	233195	0	23079	0	243083
101-250	1	536132	231202	311708	1417	304930	49448	430398
251-500	2	20050472	11308700	12706982	119680	8741772	100219	1561760
501-1000	7	35295345	15597663	18240301	1771641	19697682	1691959	24897558
1001 and more	27	347591694	170804372	231672565	27593151	176787322	33623804	451020425
Total	65	450968876	233857943	298861814	29504562	217110933	35520658	522313705

Table 2. Concentration indexes

Strata	Economic units	Participation/ Market share	%	P²(HHI)	HH	ID(HH²)
Total	65	1				
From 0 to 2	5	0.022804689	2.2804689	0.000520054	0.000855074	7.31E-07
From 3 to 5	1	4.66E-06	0.0004657	2.17E-11	0.608197431	0.369904115
6-10	1	0.000205198	0.0205198	4.21E-08	6.92E-08	4.79E-15
11-15	3	0.001376339	0.1376339	1.89E-06	3.11E-06	9.70E-12
16-20	3	0.000221006	0.0221006	4.88E-08	8.03E-08	6.45E-15
21-30	2	0.006341617	0.6341617	4.02E-05	6.61E-05	4.37E-09
31-50	12	0.073825676	7.3825676	0.00545023	0.008961285	8.03E-05
51.100	1	0.000539024	0.0539024	2.91E-07	4.78E-07	2.28E-13
101-250	1	0.001188845	0.1188845	1.41E-06	2.32E-06	5.40E-12
251-500	2	0.044460878	4.4460878	0.00197677	0.00325021	1.06E-05
501-1000	7	0.07826559	7.826559	0.006125503	0.010071569	0.000101437
1000-and more	27	0.770766482	77.076648	0.59408097	0.976789672	0.954118064
Total	65	1	100	0.608197431	1.608197431	1.32421522

6.2. Share of renewable energy companies

Table 1 shows the number of companies participating in the market for year 2009. It can be depicted that for this year there are 65 companies involved in this market segment. Gross production for year 2009 amounted to a total of 450,968,876 units, with a total investment of 29,504,562 bp generated a total income of 522 313 705 million. The given the figure shows that there are 27companies that dominate this market with 77.07% of it.

6.3. Concentration index segment

Table 2 shows the participation of companies in the renewable energies sector in 2009. In addition, there are evaluations of the *Herfindal-Hirshman Concentration Index* (HHI) which were also calculated by size of enterprise. The data give an HHI of 0.60 that is a monopolistic competition because 27 of the 65companies control the market hogging the 77.07% of the market and leaving only one 22.93% for all other companies.

Nonetheless, the economic theory tells that the market tends to be from monopolistic to oligopoly due to the size of companies and the influence they have in the market competition (**Table 2**).

The considered market is relatively new and little taken into account is a tempting niche for the large firms because consumers are almost all the same, houses, apartment buildings, hospitals, businesses, hotels, sport clubs, government projects, solar parks and even the producers themselves would benefit because costs would be lowering. It is known that the solar energy market in Mexico ascents amount millions of dollars, of which 30 belong to photovoltaic. Since it is an emerging market that is relatively new, it is extremely profitable for all companies making the development and growth of this focus solely on their production costs, and market strategy.

7. COSTS

Based on a recent data of the average costs of solar-PV systems (Said M, EL-Shimy M, and Abdelraheem M A, 2015), **Table 3** summarizes the investment as well as the O&M costs for grid-connected and standalone solar-PV generating systems. The table also shows the costs of DC and AC systems.

The costs of grid-connected solar-PV systems in Mexico are dependent on their capacities. In late 2011, SENER and GTZ conducted a survey to stakeholders and actors in the country to determine these costs. For the residential sector where the average investment for PV systems with a capacity between 0.24 kWp to 1.65 kWp is U.S.$ 4,851/ kWp with levelized costs of U.S.¢17.8/kWh. Meanwhile, the costs for systems with capacities between 2kWp to 10kWp are reduced to U.S. $3,000 /kWp - 4,200/ kWp and levelized generation costs range from U.S.¢10.9/kWh (Mx$1.3) to U.S. ¢15.4/kWh (Mx$1.8). By early 2014 these costs were reduced to 1100 U.S. $. In comparison with the average international costs of solar-PV systems (**Table 3**), it is clear that the costs offered in Mexico are smaller with a decreasing trend. It is estimated that the average life span of photovoltaic panels is 25years useful to 100% and up to 35years total lifetime. In addition, it is estimated that the initial investment is recovered in the medium term between 3 and 6 years after purchase.

8. REGULATORY FRAMEWORKS FOR RENEWABLE ENERGY

Currently, the following legal and regulatory instruments allow the use of solar-PV grid connection.

Table 3. Costs of solar-PV systems

DC No Sun Tracking		
Grid-connected	4,630	US$/kWp
Standalone	4,030	US$/kWp
O&M	30	US$/KW-year
Inv replacement	0	US$/W-10year
AC No Sun Tracking		
Fixed grid-connected	4,824	US$/kWp
Fixed standalone	4,524	US$/kWp
O&M	40	US$/KW-year
Inv replacement	0.194	US$/W-10year
AC Single axis tracking		
Fixed grid-connected	5,204	US$/kWp
Fixed standalone	4,904	US$/kWp
O&M	55	US$/KW-year
Inv. replacement	0.194	US$/W-10year
AC Two axis tracking		
Fixed grid-connected	5,784	US$/kWp
Fixed standalone	5,484	US$/kWp
O&M	55	US$/KW-year
Inv. replacement	0.194	US$/W-10year

8.1. General Law on Climate Change

On June 6, 2012, this law was published in the Official Gazette Diario Oficial de la Federación, which has among its purpose to ensure the right to a healthy environment and to establish the occurrence of powers of the three branches of government in the development and implementation of public policy on two guiding themes: Climate change adaptation and mitigation of emissions and greenhouse compounds.

8.2. Law on the Use of Renewable Energies, Financing of Energy Transition (LAERFTE), and its regulations

In late 2008, this law was published in the Official Gazette Diario Oficial de la Federación, which has the purpose to regulate the use of renewable energy for electricity generation for purposes other than the provision of public service. Its regulation was published in the Official Gazette of September 2, 2009, including more specific areas for compensation of renewable energy projects.

8.3. Interconnection Agreement for Renewable Energy and Power Cogeneration System in Small and Medium Scale

On April 8, 2010, the Energy Regulatory Commission (CRE) published these model contracts in the Official Gazette, and is intended to establish the rights and obligations of a user that connects a source of renewable energy to the

SEN. These interconnection agreements are based on the principle of "net metering".

8.4. Interconnection Agreement for Renewable Energy of Collective Source or Collective System in Small Scale Cogeneration contract (to be published by the CRE)

This type of contract applies to everything related to Small Scale generation described in the previous paragraph. With the characteristic that the collective source of electricity generation belongs to a group of generators, besides, the energy generated by the collective source. It is divided, for billing purposes, between the owners depending on the percentage of investment made by each of the owners.

Since PV systems can reduce or stop suddenly generate electricity, for example, partially cloudy days, it is also necessary to establish a series of technical rules to avoid discomfort or harm to other users. For this, the CRE and CFE have developed a specific regulatory framework for interconnection technologies based on renewable sources such as photovoltaic systems:

1) Specification for low voltage interconnection of photovoltaic systems with capacity up to 30 kW (CFE G0100-04).
2) Annexes to the Interconnection Agreement in Medium Scale: Characteristics of measuring equipment and communication (Annex E-RMT) and technical requirements for interconnection (Annex ERD-T).
3) General Rules for Interconnection to SEN or permit generators with renewable energy or efficient cogeneration (published in the Official Gazette by the CRE, the May 22, 2012).

In a graphical form, **Fig. 10** shows how the composed the regulatory and policy framework for PV in Mexico which consists of the following legal structure. In addition to public institutions (CRE and CFE) there are private institutions for issuing standards in the electricity sector such as the National Association for Standardization and Certification of the electricity sector that have issued Mexican Standards.

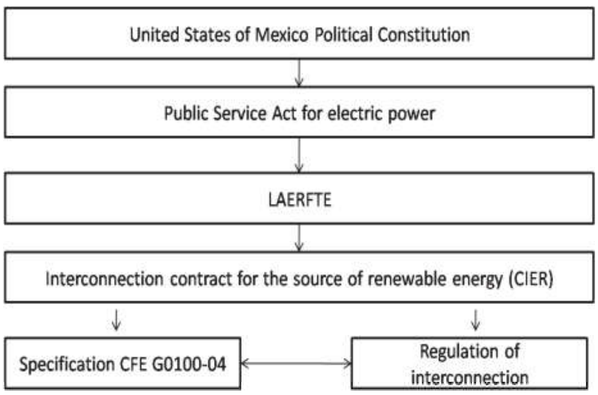

Figure 10. Legal structure (PROSOLAR SENER)

9. CONCLUSIONS

In the presented work, the growing behavior of the renewable energy market in Mexico is observed. The potential of the emerging market is identified. The main focus is placed on the solar-PV energy sector. Mexico is considered one of the most attractive countries to invest in this sector being considered as the 5th country with more possibility of development. Also it is seen that the HHI for 2009 is 0.60 which tells that it is a monopolistic competition with a tendency to be oligopoly. The profitability of the sector is abundant; generating profits of more than double the investment for businesses.

It is shown that the investment for consumers becomes profitable from the 3rd or 6th year, with investment costs below the international average values. Within the regulatory framework also there is a growing legislative restructure that encourage the development in different ways for both the private and the public sectors.

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