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Presentation of the Content

In the first chapter we present, *Economic-environmental comparison of an alternative refrigeration system with respect to a conventional refrigeration system applied to the transport of perishables*, by VALLE-HERNANDEZ, Julio, NIETO-PEÑA, Alejandra, MORALES-ORTEGA, Edgar Enrique and ROMAN-AGUILAR, Raul, with ascription in the Universidad Autónoma del Estado de Hidalgo and Universidad Politécnica Metropolitana de Hidalgo, as a second article we present, *Generation of market information of the Mexican Solar Industry under a model of strategic analysis and innovation*, by RODRIGUEZ-CARVAJAL, Ricardo Alberto, ISIORDIA-LACHICA, Paula Concepción, TADDEI-BRINGAS, Jorge Luis and ROMERO-HIDALGO, Jorge Alberto, with ascription in the Universidad de Guanajuato and Universidad de Sonora, as the following article we present, *Economical Feasibility study of a wind system interconnected to the grid for the self-supply at the Universidad del Istmo*, by ESCOBAR-TALIN, Carlitos, DORREGO-PORTELA, José Rafael, IRACHETA-CORTEZ, Reynaldo and HERNÁNDEZ-GALVEZ, Geovanni, with affiliation at the Universidad del Istmo, as next article we present, *Implementation of the economic dispath to optimize the location of the wind parks*, by LÓPEZ-GARZA, Esmeralda, DOMÍNGUEZ-CRUZ, René Fernando, LARA-ALABAZARES, David and ROMERO-GALVÁN, Gerardo, with affiliation at the Universidad Autónoma de Tamaulipas.

Content

Economic-environmental comparison of an alternative refrigeration system with respect to a conventional refrigeration system applied to the transport of perishables

Comparativa económica- ambiental de un sistema de refrigeración alternativo con respecto a un sistema de refrigeración convencional aplicados al transporte de perecederos

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Abstract

The growing demand of food, which cannot always be produced where it will be consumed, has caused the increase of the perishable supply chain in recent years. Most of the transportation and distribution processes of perishable food are carried out by means of refrigerated vehicles, which use vapor compression refrigeration systems powered by a diesel engine. This type of refrigerated transport systems consumes a large amount of fuel, since the cooling system needs additional energy to extract the heat from the refrigerated box, causing an increase in the cost of transporting goods and the emission of greenhouse gases. (GHG). Due to the above, research has been carried out on alternate refrigeration systems, such as the absorption system using thermal energy, with which it could reduce operating costs and the emission of GHG from the truck tract, using waste heat from it. In the present work is carried out an economic-environmental comparison of an alternative refrigeration system with respect to a conventional system, applied to the transport of perishables. This comparison includes the calculation of GHGs and fuel costs, determining the advantages and disadvantages of each of the systems

Refrigerated transport, Energy comparative, Reduction of greenhouse gases

Resumen

La creciente demanda de alimentos, que no siempre pueden producirse donde serán consumidos, ha generado que la cadena de suministro de perecederos aumente en los últimos años. La mayoría de los procesos de transporte y distribución de alimentos perecederos se realiza por medio de vehículos refrigerados, que emplean sistemas de refrigeración por compresión de vapor impulsados a través de un motor diésel. Este tipo de sistemas de transporte refrigerado consume una gran cantidad de combustible, ya que el sistema de refrigeración necesita energía adicional para extraer el calor de la caja refrigerada, provocando un incremento en el costo de transporte de mercancías y en la emisión de gases de efecto invernadero (GHG). Debido a lo anterior, actualmente se han realizado investigaciones sobre sistemas de refrigeración alternativos, como son los sistemas por absorción, que utiliza energía térmica para operar. Este tipo de sistemas de refrigeración podrían reducir costos de operación y de emisión de GHG si utilizaran calor residual del mismo tracto camión. En el presente trabajo se lleva a cabo una comparativa económica-ambiental de un sistema de refrigeración por absorción con respecto a un sistema convencional, aplicados al transporte de perecederos. La comparativa se realiza en base al cálculo de las GHG y los costos de combustible, cada uno de los sistemas.

Transporte refrigerado, Comparativa energética, Reducción de gases de efecto invernadero

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Introduction

The growing demand for food, which can not always be produced where it will be consumed, has caused the perishable supply chain to increase in recent years.

The majority of the processes of transport and distribution of perishable food is carried out by means of refrigerated vehicles, which use vapor compression refrigeration systems powered by a diesel engine.

The number of refrigerated transport units (TRU) in Mexico is estimated at 54,900 according to a study prepared by the Mexican Institute of Transportation in 2015. [Morales Perez, Carmen, et al. (2014). Characteristics of refrigerated transport in Mexico]

These mobile units consume a large amount of fuel, since the cooling system needs additional energy to extract the heat from the refrigerated box. Furthermore, a refrigerated transport unit needs more energy to operate than a similar unit without refrigeration, even with the cooling system off, because the mere fact of having refrigeration machinery and insulating material, the weight of the truck increases considerably.

On the other hand, the cost of transportation of perishable products is directly linked to the consumption and price of fuel. Since conventional refrigeration systems installed in transport units need a large amount of energy, to extract the heat from the box to be cooled and move a greater weight, the fuel consumption is high causing an increase in the cost of transport of goods and in the emission of greenhouse gases (GHG).

The potential of diverse non-conventional refrigeration technologies is currently being studied, which allows the use of alternate energies for their operation, thus reducing the consumption of fossil fuels and the emission of greenhouse gases.

One of these unconventional technologies is absorption cooling that uses thermal energy to operate, this can be solar or process waste heat, which reduces fuel costs and emission of greenhouse gases into the atmosphere.

In the present work, a characterization of two refrigeration systems applied to the transport of perishables is carried out; one with conventional compression refrigeration technology and the other with an alternative absorption cooling technology.

For both cases, a refrigerated truck-type transportation unit is proposed, which transports chicken meat as perishable through an established route. The results show a comparison between the greenhouse gas emissions (GHG) of each of the refrigeration technologies and the economic savings for fuel consumed, one over the other.

Methodology

The comparative study begins with the estimation of the fuel consumption by each of the technologies, for which the refrigeration capacity that one wants to produce and the necessary power supply must be calculated, for the operating temperature ranges. With the estimated fuel consumption, the operating costs and GHG emissions of each refrigeration system are determined.

For the calculation of the heat extracted by the refrigeration system, thermal loads of the product (chicken meat), and thermal load by transmission of walls are considered.

Once the heat to be extracted is obtained, for each one of the refrigeration technologies, an energy analysis is carried out for each of the thermal processes that occur throughout the refrigeration cycles. The analysis is done through mass and energy balances, considering the compositions in the mixtures and the effects of pressure and temperature.

With the energy analysis, the amount of fuel necessary for the operation of each of the systems is determined, and with this the analysis of greenhouse gas emissions (GHG) for the truck tract is carried out.

The calculation of emissions was based on the methodology of standard EN-16258 prepared by the European Association of shipping, transport, logistics and customs services (CLECAT). [EN 16258 (2012) "Methodology for calculation and declaration of energyconsumption and greenhouse gas emissions of transport services"]

In order to carry out a comparison between the resulting greenhouse gas emissions for each refrigeration system, these emissions are calculated for a truck tract with the same characteristics and operating conditions..

Finally, the economic comparison of the fuel consumption is carried out, the results offer an overview of the savings that would be had in an absorption refrigeration system on one of steam compression applied to the transport of perishables in Mexico.

Development

Characterization of the Refrigeration Chamber

The proposed configuration for the refrigeration chamber mounted on a truck tract, can be seen in table 1.

Height	2.5 m.
Width	2.5 m.
Base	14.5 m.

Table 1 Dimensiones de la Cámara Frigorífica
Source: Self Made

The perishable product to be transported is chicken meat, which goes through a pre-cooling process before entering the refrigerated box of the truck tract, at a temperature of 4 ° C.

Inside the refrigerated container the temperature must be kept between 0 and 5 ° C, which is the temperature range for the preservation of the organoleptic properties of chicken meat according to the ASHRAE manual [American Society of Heating, R. a. A. E. (2013). Ashrae handbook: Fundamentals Atlanta].

Based on the above considerations, the operating characteristics of the cold room can be seen in table 2.

Cooling chamber	
Product	chicken meat
Capacity	20 tons
Coolant flow rate	4 m/s
Storage temperatura	3° C
Thermal isolation	Polyurethane

Table 2 Operation characteristics of the camera
Source: Self Made

The ambient temperature during the transfer is considered between 11 ° C and 33 ° C, taking the maximum temperature for the calculation of thermal loads to ensure that the system operates correctly.

Estimation of the cooling capacity

The estimation of the cooling capacity, heat to be extracted from the chamber by the refrigeration system, is made by calculating the thermal loads involved in the process.

In general the system gains heat by the following thermal loads:

a) *Thermal load generated by transmission through walls:*

$$Q = A * U * \Delta T \quad (1)$$

Where:

Q = total heat of transmission through the walls [KW]
A = exhibition area [m^2]
U = Overall coefficient of heat transfer [W/m^2 K]
ΔT= temperature difference [K]

b) *Thermal load generated by product:*

$$Q_{sensible} = m * Cp * \Delta t \quad (2)$$

Where:

$Q_{sensible}$ = Heat extracted [KW]
m = mass of the product [kg/s]
Cp = specific heat above or below the freezing point [kJ/kg K]
ΔT = temperature difference. [K]

The thermal loads by equipment and infiltration are negligible, because the compressor is outside the cooling box and there is no opening of doors during the transfer.

The total thermal load, which defines the amount of heat that is extracted from the cooling chamber, is given by the following equation:

$$Q_{Total} = Q_{\,producto} + Q_{trasm\,por\,paredes} \quad (3)$$

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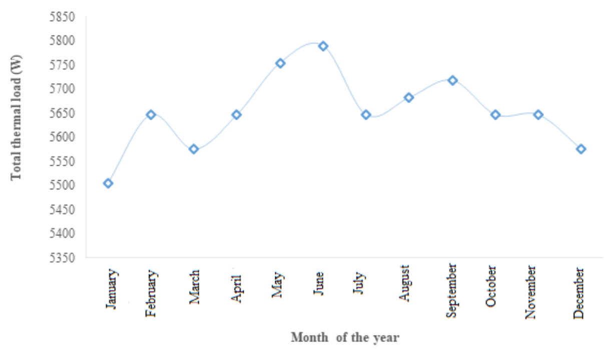

Graphic 1 Total thermal load to be removed throughout the year
Source: Self Made

Figure 1 shows the behavior of the total thermal load that must be extracted from the refrigerated chamber in each month of the year. The largest amount of heat to extract is in the month of June, due to environmental conditions, and is 5.79 KW.

Energy Analysis of refrigeration cycles

a) Steam compression refrigeration cycle

A simple refrigeration cycle by heat compression is composed of four components: evaporator, compressor, condenser and expansion valve. Figure 2 shows the diagram of this cycle.

The heat to be extracted from the refrigerated chamber enters the evaporator, where it evaporates the flow of refrigerant flowing in a closed circuit. The refrigerant vapor enters the compressor increasing its pressure and increasing the condensation point, in order to be condensed at room temperature and transfer heat to the outside of the cycle.

The coolant flow, a steam-poor mixture, enters the expansion valve where it lowers its pressure and lowers the boiling point. The low pressure refrigerant enters the evaporator to extract the heat again and complete the cycle.

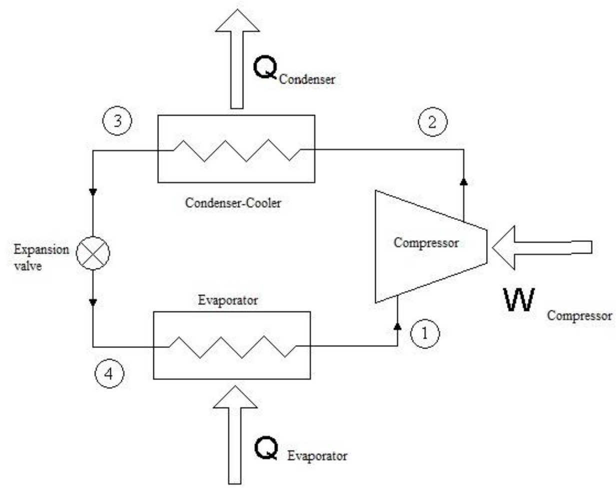

Figure 1 Simple compression refrigeration cycle
Source: Cengel, Y. A.; Boles, M.A.: Termodinámica. Mc Graw-Hill, 1996

The refrigerant that is considered in the analysis is R-404A, refrigerant belonging to the range of Hydrofluorocarbons, which is one of the most used for refrigeration in the transport of perishables.

The energy consumption is obtained from the work done by the compressor (W), through the mass flow and the enthalpies of the refrigerant at the inlet and outlet of the compressor.

Table 3 shows the results of the thermodynamic design for the refrigeration system at the proposed operating conditions.

Points	Place	P (kpa)	T (°C)	h (KJ/KG)	S (KJ/Kg K)
1	Evaporator outlet	519.36	-5	363.28	1.6102
2	Compressor output	1743.2	43.583	386.52	1.6102
3	Capacitor output	1743.2	38	256.84	1.909
4	Expansion valve outlet	519.36	-5	256.84	

Table 3 Thermodynamic analysis of the compression cooling system
Source: Self Made

The mass flow and compressor work are calculated by the following equations:

$$\dot{m} = \frac{Q_H}{h_{out\ comp} - h_{out\ evap}} \quad (4)$$

$$W_{comp} = \dot{m}\,(h_{out\ comp} - h_{in\ comp}) \quad (5)$$

Where:

Q_H = Total thermal load. [KW]
$h_{in\ comp}$ = Enthalpy to the compressor inlet. [kJ/kg]

$h_{out\ evap}$ = Enthalpy at the entrance of the evaporator. [kJ/kg]
$h_{out\ comp}$ = Enthalpy at the compressor outlet. [kJ/kg]

To determine the electrical consumption of the refrigeration installation, the electric efficiency of the compressor must be taken into account, which is generally between 85% - 95%. [American Society of Heating, R. a. A. E. (2013). 2013 Ashrae handbook: Fundamentals Atlanta].

In this case, an electric efficiency of 90% was considered. Finally, the Coefficient of Operation (COP) of the system was calculated, this is the relation between the total thermal load extracted by the system [kW], and the power [kW] consumed by the compressor, which is given by:

$$COP = \frac{Q_{total}}{W_{compresor}} \quad (6)$$

Table 4 shows the results of the energy analysis of the vapor compression refrigeration system.

	Storage chamber
Thermal load	5.79 kW
Mechanical power of the compressor	1.13 kW
Electric power	1.26 kW
COP	4.58

Table 4 Energy consumption of the compression refrigeration system
Source: Self Made

b) Absorption cooling system cycle.

A system by absorption has the same components as one by vapor compression, where the refrigerant flows through a condenser, an expansion valve and an evaporator, except that the compressor is replaced by the assembly of an absorber, a pump, a generator and an expansion valve.

In the generator there is an increase in the temperature of the refrigerant-absorbent solution due to the heat transferred from a thermal energy source, producing a separation by evaporation of the refrigerant due to a lower miscibility than that of the absorbent fluid, leaving in the generator a liquid solution poor in refrigerant.

The refrigerant released in the gaseous state passes to the condenser where it is condensed, and then to the expansion valve where it undergoes a pressure drop.

The coolant-poor solution flows into the absorber, where it absorbs the refrigerant through an exothermic reaction.

The solution leaves the absorber and is compressed with a pump, where it increases its pressure taking it back to the generator and starts the cycle again. The work consumed by the cycle is only that which is necessary to operate the pump.

For the comparison, a simple regenerative absorption system with a binary NH3 / H2O mixture was considered, as shown in Figure 2.

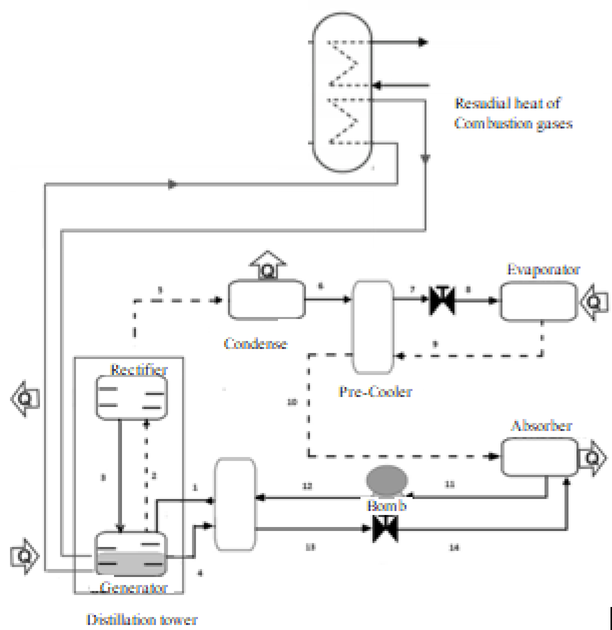

Figure 2 Absorption cooling system
Source: Self Made

This system includes a pre-cooler between the evaporator and the absorber, since it has a better thermal performance than one without regeneration.

The operating conditions of the absorption system must be those necessary to maintain the same heat extraction in the refrigerated chamber as obtained by the vapor compression system.

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The thermodynamic analysis of the absorption cooling system was carried out by mass and energy balances in each element of the cycle, for which the EES (Engineering Equation Solver) program was used to access the thermodynamic properties of the ammonia-water mixture of a simple and exact way. Table 5 shows the equations to determine the energy flows in each element of the system.

Component	Symbol	Equation
Evaporator	Q_E	$\dot{m}_{10}(h_{11}-h_{10})$
Absorber	Q_A	$\dot{m}_{12}(h_{12}-h_1)+\dot{m}_{10}(h_{11}-h_{10})+\dot{m}_{10}(h_1)+\dot{m}_6(h_1)$
Condenser	Q_C	$\dot{m}_7(h_7-h_8)$
Generator	Q_G	$\dot{m}_4(h_4)+\dot{m}_3(h_3))+\dot{m}_{14}(h_{14})$
Rectifier	Q_R	$\dot{m}_7(h_7)$
Solution pump	W_{hp}	$\dot{m}_1(h_2-h_1)$

Table 5 Energy flows in each component of the SRA
Source: Self Made

The energy balance is satisfied by the following equation:

$$Qg + Qe + Wp = Qa + Qc + Qr \quad (7)$$

The results for the energy balance of the refrigeration system per single effect absorption cycle, shown in Table 6, were obtained based on the ASHRAE method, where the following considerations are taken:

- System without pressure changes, except in the expansion valves and in the pump.
- In points 1, 4, 8, 11 and 14 it is considered saturated liquid, in 12 and 13 saturated steam.
- Heat losses or gains are not considered through the different components of the system and the ducts.
- The process in the expansion valves is considered iso-American.

Component	Symbol	Power (kW)
Evaporator	Q_E	5.79
Absorber	Q_A	8.21
Condenser	Q_C	5.53
Generator	Q_G	8.82
Rectifier	Q_R	.889
Solution pump	$\mathbf{W_{hp}}$	**.023**

Table 6 Results of thermodynamic analysis of the refrigeration system by absorption
Source: Self Made

Costs and emissions of greenhouse gases from refrigeration systems

To carry out the economic-environmental analysis, it was estimated the amount of fuel that both refrigerated apicado systems would consume. Table 7 shows the diesel fuel consumption for different types of refrigerated vehicles by compression, which use HFC 404a as a refrigerant, according to the Economic Committee of Internal Transportation of the United Nations (ATP).

Type of refrigerated vehicle	Fuel consumption per 100 km	Consumption percentage of the cooling system
	l/día	%
Van (7.5-17 ton)	26.9 – 31	18.9
Rigid vehicle (17-25 ton)	38.2	19.5-24.2
Articulated vehicle (<25 ton)	36.2	15.6

Table 7 Fuel consumption of refrigerated vehicles
Source: (Energy Efficiency in Transport Refrigeration in: Proceedings, International Congress of Refrigeration, Beijing, China, Paper)

The fuel costs for refrigerated transport units that operate, with refrigeration system by compression, and with refrigeration system by absorption, are calculated from equations (8) and (9), respectively.

$$Costo_{FRC} = C_{100Km} * D * P_f \quad (8)$$

$$Costo_{FRA} = (1 - C_{RC})C_{100Km} * D * P_f \quad (9)$$

Where: C_{100Km} is the fuel consumption per 100 km, D the distance traveled in Km, P_f the price of fuel and C_{RC} the fraction of fuel consumed by the compression refrigeration system.

Greenhouse gas emissions (GHG) are estimated from direct or indirect fuel consumption. Fuel consumption depends mainly on the design and quality of the cooling system, the insulation qualities of the refrigerated chamber and the operating practices. Direct fuel emissions depend on the type of vehicle, the load, the distance and the amount of fuel used (TTW), while the indirect emissions come from the production of the fuel, and play an important role when the carbon inventory is produced for transportation services (WTW).

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From the equations (10) and (11) the GHG emissions are estimated for both refrigerated transport systems.

$$G_T = F * g_T \quad (10)$$

$$G_W = F * g_W \quad (11)$$

Where: G_T and G_W are the direct and indirect GHG emissions, respectively. F is the fuel consumption in liters, g_T the factor of direct emissions in kg of CO_2 emitted and g_W the emission factor is indirect in kg of CO_2 emitted.

The conversion factors necessary to calculate the emissions are taken from the methodology EN 16258, and are shown in Table 8.

Greenhouse gases	
TTW	WTW
kg CO2e/l	kg CO2e/l
2.67	3.62

Table 8 Factores de converción de GHG
Source: Standard EN 16258 "Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services"

Results

To estimate the economic cost of fuel consumption (diesel), we considered a refrigerated truck tract with a performance of 36 liters per 100 km (Table 6).

Where the refrigeration system consumes 15.6% of the total fuel, so the absorption refrigeration system, including the work of the pump, would save 4.9 liters of fuel per 100 km.

On the other hand, according to the study of C RepICE, A. Stumpf, it is proposed that refrigerated transport travel approximately 400 km per day, operating the vehicle 260 days a year, resulting in 104,000 km per year.

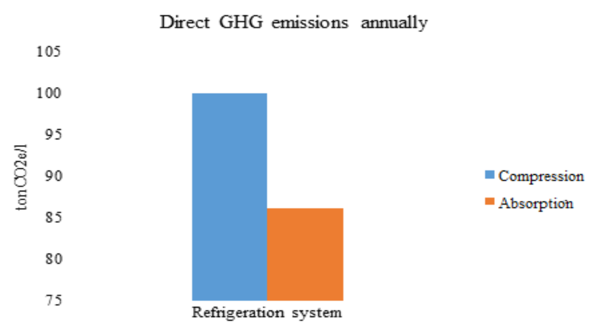
Table 8 shows the economic comparison between compression refrigeration (SRC) and absorption (SRA) systems.

	SRC		**SRA**	
Weather	Fuel (Lt)	Fuel cost ($)	Fuel (Lt)	Fuel cost ($)
Day	144	2,880	124.13	2,482.56
Week	720	14,400	620.64	12,412.8
Month	3,120	62,400	2689.44	53,788.8
Year	37,440	748,800	32,273.28	645,465.6

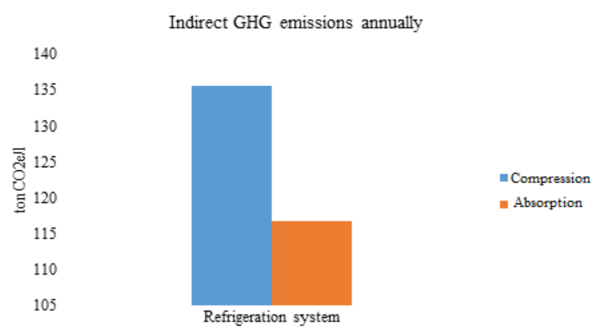
Table 9 Economic analysis of cooling systems (Considering diesel price at $ 20 lt)
Source: Own Elaboration

In the table it can be seen that annually the use of an absorption refrigeration system saves approximately $ 103,344 pesos for fuel (diesel).

Graphs 2 and 3 show the direct and indirect emissions, obtained from the fuel consumption per year, of two articulated trucks; one with compression cooling system and the other with absorption cooling system.



Graphic 2 Comparison of GHG direct annual emissions of articulated trucks with absorption and compression refrigeration systems
Source: Self Made



Graphic 3 Comparison of indirect annual GHG emissions from articulated trucks with absorption and compression refrigeration systems
Source: Self Made

From the results, shown in graphs (2) and (3), we can see that an absorption cooling system applied to the transport of perishables stops emitting about 34 tons of CO2 into the environment; 15 tons directly and 21 tons indirectly.

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Conclusion

Absorption refrigeration systems are currently being considered as an alternative to reduce greenhouse gas emissions, by incorporating solar thermal energy into the refrigeration industry.

However, absorption cooling is not limited to the use of solar energy, since it can occupy residual heat as an energy source. A diesel engine usually has a thermal efficiency of 30%, which means that 70% of the fuel's energy is lost in the form of heat. The recovery of only a small portion of this wasted energy would be enough to cover the refrigeration requirements of an articulated transport.

The use of waste heat to feed the absorption refrigeration system of articulated trucks would significantly reduce the amount of greenhouse gases emitted into the environment, approximately 11 million tons of CO2 per year, considering the approximately 50,000 refriged trucks reported by the company. Mexican Institute of Transport in 2015.

In addition to reducing emissions, the recovery of recurrent heat would also have an economic impact on the cost associated with the use of fuel, estimated at approximately $ 100,000 pesos per year for each refrigerated truck tract.

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Generation of market information of the Mexican Solar Industry under a model of strategic analysis and innovation

Generación de información de Mercado de la Industria Solar Mexicana bajo un modelo de análisis estratégico e innovación

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Abstract

The Mexican solar industry is being born because the existing mainly serves the commercialization of imported technology. Currently initiatives have been developed that seek to create this industry in Mexico, one of them is the Mexican Center for Innovation in Solar Energy, this Center was created in 2013 where the academic and research sector was invited to propose projects that could reach the market and generate innovation, giving way to a Mexican solar industry. The progress of this project is reflected in the generation of industrial property but without really addressing market needs, this is due to the fact that there is little formal and validated information that helps to make the best decisions to the academics who are conducting this research and to the sector. productive that motivates investment in these technologies. Derived from the above, this project strategically acquires the relevance to be able to provide information to the actors that are building the nascent solar industry. An analysis of the state of the art and the technique was carried out on market information generated regarding the solar industry in a global manner. The global information was analyzed and a study framework was proposed for the Mexican solar industry.

Solar Industry, Solar Market, Suply Chain

Resumen

La industria solar mexicana esta naciendo pues lo existente atiende principalmente a la comercialización de tecnología importada. Actualmente se han desarrollado iniciativas que buscan crear esta industria en México, una de ellas es el Centro Mexicano en Innovación en Energía Solar, este Centro fue creado el año 2013 donde se convocó al sector académico y de investigación a proponer proyectos que pudieran llegar al mercado y generar innovación, dando paso a una industria solar mexicana. El avance de este proyecto se refleja en la generación de propiedad industrial, pero sin atender realmente las necesidades de mercado, esto debido a que existe poca información formal y validada que ayude a tomar las mejores decisiones a los académicos que están realizando estas investigaciones y al sector productivo que motive la inversión en estas tecnologías. Derivado de lo anterior este proyecto adquiere de manera estratégica la relevancia para poder brindar información a los actores que están construyendo la naciente industria solar. Se realizó un análisis del estado del arte y la técnica sobre información de mercado generada referente a la industria solar de manera global Se analizó la información global y se planteó un marco de estudio para la industria solar mexicana.

Industria Solar, Mercado Solar, Cadena de Proveeduría

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Introduction

Solar energy is the most generated source on earth, with approximately 885 million TWh falling on the surface of the planet each year, 6,200 times the primary commercial energy consumed by humanity in 2008 (SENER, 2017).

Global spending on renewable energy is breaking the trillion dollar barrier over the next few years, so nanomaterials are in commercial development as a means to reduce costs and make these sources of energy competitive. Achieving considerable progress in wind and solar energy, fuel cells, thermoelectric, batteries and supercapacitors, which today materialized into tangible products. Nanocoatings are enabling new paradigms in energy-friendly and low-cost energy conversion and storage systems (Nanocoatings, 2014).

The Secretariat of Energy (SENER), (2017) defines photovoltaic solar cells and modules as solid state semiconductor devices that convert sunlight into direct current electricity. It is important to mention that a cell is the minimum unit to acquire the energy of the sun and in which electric power is generated, while a module or solar panel is an array of cells with the objective of obtaining greater electrical power generation.

There is a wide range of photovoltaic materials available around the world and can be categorized by crystalline silicon technology, thin film technology and emerging technologies. The cells of crystalline silicon (c-Si) occupy 90% of the total produced, the rest are called "thin film" ("thin film").

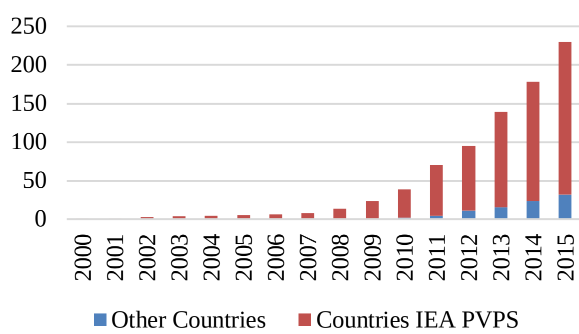
The solar light on impacting the semiconductor, there is the transfer of electricity through the union between two layers, thus obtaining direct current. The greater the intensity of the light, the greater the flow of electricity. It is important to mention that a photovoltaic system does not require bright sunlight to function, this is due to the phenomenon of reflection of sunlight, which also on cloudy days, energy is obtained.

A photovoltaic system takes advantage of incident solar radiation, to directly generate electricity in the form of direct or direct current.

When referring to photovoltaic technology all the components of the physical system that converts solar energy into electrical energy are integrated (SENER, 2017).

In the report of REthinking Energy 2017 it is mentioned that worldwide, photovoltaic solar energy; its photovoltaic capacity increased from 40 GW in 2010 to 219 GW in 2015, accumulating approximately 20% of the new installed capacity for electricity generation (SENER, 2017).

By the end of 2015, according to the International Energy Agency, installed capacity continued to increase to reach 227 GW of photovoltaic systems around the world (SENER, 2017), see Figure 1.



Graphic 1 Evolution of photovoltaic installations (GW)
Source: Trends in photovoltaic energy, SENER (2017 p.22)

This work shows an analysis of the market information available in Mexico, as well as the development potential of a nascent solar industry, making a study of the value chain, and not only focusing on the manufacture and installation of photovoltaic devices, but also a analysis of the potential of the technological developments of two national projects such as the National Laboratory of Concentration Systems and Solar Chemistry (LACYQS) and the Mexican Center for Solar Energy Innovation (CeMIE-Sol).

There is also an analysis of the industry installed in the State of Sonora, which shows the potential to be integrated into the value chain of this industry, and stop relying on technology acquisitions, this derived from the facilities that will be made emanated of the energy auctions that SENER has competed.

Theoretical framework

The energy sector has become a condition for the economic growth of the countries, due to the close relationship that exists between the growth of the gross domestic product and the energy demand of each country. The increase in the standard of living of the population has generated a persistent increase in energy demand.

The finite nature of resources has forced us to seek greater efficiency in the production and use of energy, as well as to develop the potential of the use of non-fossil energy sources.

In this context, the use of renewable energies appears as an element that contributes to increasing the country's energy security, by diversifying its energy matrix in the face of the expectation of higher prices and the volatility of conventional energy sources (IEA, 2011), as well as how to mitigate greenhouse gas emissions and the serious consequences of climate change from the use of fossil fuels.

An energy balance provides a simple representation of an energy system using the basic ideas of accounting and is one of the basic frameworks for the analysis of energy systems, is a tool that has been used since the fifties in the United States and continues to be an essential part of energy planning today, mainly in models with an econometric approach (Bhattacharyya and Timilsina, 2009).

The energy balance represents the flow from the energy supply, the transformation to secondary energies, and the final demand, by sector and by type of energy, for this information to be able to monitor the energy needs in a region (Adams and Shachmurove, 2007).

Bazán and Ortiz (2010) describe the energy system in general and the parts that make up this system as: demand, which in the balance is detailed by sector, subsector, end uses and equipment; transformation, where an evaluation is made detailed structures for the generation of secondary energy, such as refineries, power plants, etc.; and supply of primary energy, simple representation of renewable and non-renewable resources that are used as supply.

According to the National Inventory of Renewable Energies (INER), Mexico has abundant resources for the generation of energy from renewable sources, with a proven potential of up to 13,167 GWh / year, estimates that increase substantially if reserves are considered probable, as indicated in table 1.

Potential of Electrical Generation with Renewable Energies (Gwh / Year)

Resources	Geothermal	Mini hydraulics	Wind	Solar	Biomass
Possible	16,165	-	87,600	6,500,000	11,485
Probable	95,569	1,805	9,597	-	391
Probable	892	1,365	9,789	542	579

Table 1 Prospective of Renewable Energies 2013-2027
Source: National Inventory of Renewable Energies, SENER

Solar Manufacturing

The potential of manufacturing components for the solar industry is very great since it has a highly developed industrial ecosystem, this derived from a large number of companies that have integrated supply chains in other industries such as medical, automotive, electrical, electronic, aerospace and others.

Together with a good industrial ecosystem, technological scientific initiatives have been developed, such as the National Laboratory of Concentration Systems and Solar Chemistry (LACYQS), a project funded by the National Council of Science and Technology of Mexico and led by the Institute of Renewable Energies of the University Autónoma de México, in this project the University of Sonora actively participates being the headquarters of the Experimental Field Installation of Central Tower (CEToC) of this national laboratory.

The LACYQS project, which frames several important linking results, has developed several technologies that have been protected through patent applications, which have been sought to be transferred to the productive sector to impact on economic development and generate mitigation impacts greenhouse gases, because when they are adopted they stop consuming fossil fuels for the production of electrical energy.

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In this sense, the technology that has been transferred to a local company dedicated to the automotive sector, whose expertise is the work of metalworking, manufactures solar tracking structures of two axes, which opens a business unit dedicated to the manufacture of fixed structures and solar tracking to serve the photovoltaic and solar power concentration market, since it serves both solar technologies.

This shows the potential of the scientific developments carried out by universities and research centers.

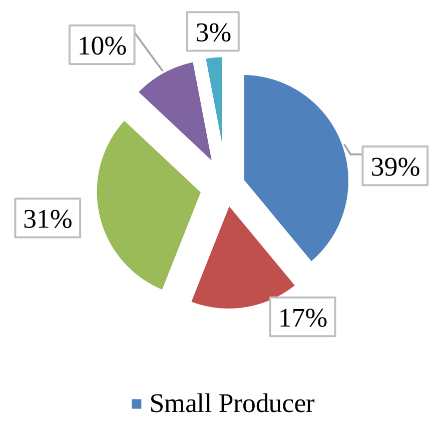
Another of the projects that have been generated nationally, are the initiatives of the Mexican Centers in Innovation in Energy, Solar, Wind, Geothermal, Ocean, among others, with the financing of the Energy Sustainability Fund, of the Secretariat of Energy in Association with the National Council of Science and Technology (CONACYT).

In particular, the Mexican Center for Solar Energy Innovation (CeMIE-Sol) has promoted 22 strategic projects, as shown in Table 2.

# of Project	Project name
P03	Production of solar electricity using parabolic disk systems, from photocells
P16	National Inventory of the Solar Resource (Map of the Solar Resource)
P21	National Inventory of the Solar Resource (Map of the Solar Resource)
P22	Design and development of photovoltaic devices in CIACYTUASLP: based on cubic InGaN and multi-band cell structures of GaNAs
P25	Development of prototypes of CdTe / CdS photovoltaic modules in an area of 100 cm2 with efficiency in the range of 10%, and associated systems for its manufacture for efficiency in the 10% range, future technology transfer
P26	Processing of solar cells of CdS / Cu (InGa) Se2 and CdS / Cu2ZnSnS4 for their technological transfer to the industrial sector
P27	Development and manufacture of solar cells modules of TiO2 sensitized with dye (DSC) and quantum dots (QDs), and of photovoltaic organic (OPVs)
P28	Nanotechnology applied in the development of thin films and prototype solar cells
P29	Development of a national laboratory for the evaluation of the compliance of modules and components of photovoltaic systems and installations LANEFV
P31	Advanced nanostructured materials for high efficiency organic / inorganic hybrid photovoltaic cells
P32	Nanoantenas thermoelectric with high efficiency for the use of solar energy
P35	I+D of solar cells with novel materials
P37	Development of new photovoltaic devices and semi-superconducting materials
P39	Development of a permanent inventory of PV systems installed at the national level
P50	Low-capex manufacturing routes coupled to heat treatments for high performance of novel thin film materials

Table 2 Strategic projects driven by the CeMIE-Sol
Source: Own Elaboration from. PROMÉXICO, 2018

In Mexico, there is an installed capacity per modality as shown in Figure 2.



Graphic 2 Installed capacity of Photovoltaic Energy by mode (MW)
Source: PROMÉXICO, 2018

Value chain of the photovoltaic industry

Regarding photovoltaic technology, we have the following supply chain that can be seen in figure 1, this chain poses as a challenge to develop Mexican interconnected investors, since the tracking and fixed structures can be manufactured and serviced by Mexican companies.

In terms of electrical equipment, there are already several Mexican companies that will provide the materials to the plants that could be developed. Photovoltaic panels are a technology that requires large investments to produce them, so it is better to import this technology, although there are Mexican companies that are manufacturing panels.

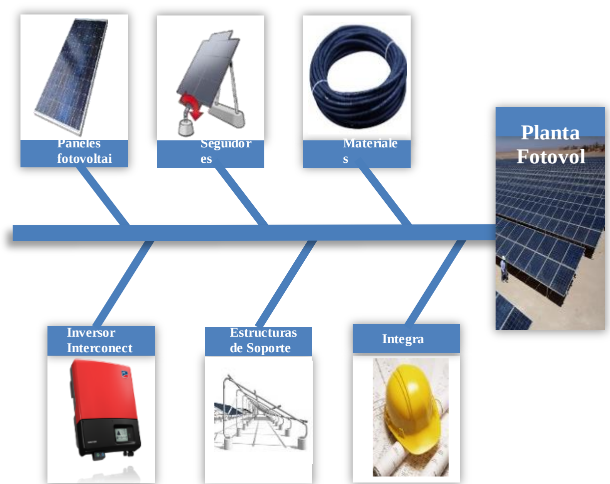


Figure 1 Value chain of the photovoltaic industry
Source: Own Elaboration

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When presenting this analysis of supply chains in photovoltaic technology it is clear that the great opportunity for Mexican companies to generate products such as: solar tracking structures, electrical materials, investors and microinverters, marketing of photovoltaic panels, development of new materials, integration and engineering in large-scale and residential generation projects among others. Each of these links have a national and international market value that is growing due to the number of facilities projected in Mexico and the World.

Characterization of Sonoran companies with potential for integration into the value chain of the solar industry

A survey was carried out of the Sonoran companies dedicated to the metal-mechanic manufacturing for the automotive and aerospace industry. The following were found: 61 companies (see table 3) dedicated to this line of business, with diverse capacities and clients, the most consolidated serving as a priority to the automotive sector, offering several products and services. These 61 companies are distributed in the state of Sonora, with their main activity distributed as follows:

Location	What is the main activity of the Company			Total
	Production	Sales and / or trade	Service	
Hermosillo	61.1	5.6	33.3	100.0
Cd. Obregón	7.7	7.7	84.6	100.0
Navojoa	10.0	0.0	90.0	100.0
Guaymas - Empalme	0.0	0.0	100.0	100.0
Nogales	50.0	12.5	37.5	100.0
Total	27.9	4.9	67.2	100.0

Table 3 Classification of companies by municipality and main activity
Source: Own Elaboration

The composition of its sales is presented as follows (see table 4).

What percentage of your sales are	What is the main activity of the Company			Total
	Production	Sales and / or trade	Service	
Local	61.4	78.3	87.1	79.5
Nationals	10.3	11.7	8.7	9.3
Foreign	28.4	10.0	4.3	11.3

Table 4 Percentage of sales and main activity
Source: Own Elaboration.

As can be seen, the highest concentration of sales are local, with the solar industry turning out to be a potential, as it would allow it to export its production to the US border states with Mexico.

The level of education of the employees of these companies is varied as presented in table 5.

Percentage of employees and level of education	What is the main activity of the Company			Total
	Production	Sales and / or trade	Service	
Without studies	0.6%	4.3%	0.1%	0.5%
Primary school	6.9%	14.5%	6.6%	7.1%
Secondary school	22.3%	24.8%	36.4%	31.9%
High school	24.9%	4.3%	17.2%	18.7%
Technical	24.4%	39.5%	24.7%	25.4%
Bachelor's degree completed	16.4%	12.6%	13.2%	14.0%
Postgraduate	4.4%	0.0%	1.7%	2.3%

Table 5 Percentage of employees according to level of education
Source: Own Elaboration

Being the highest concentration staff with baccalaureate and technical level, however, the level of undergraduate and graduate is present and concentrates a good percentage of employees in the production area.

The composition of its clients currently served is as follows (see table 6).

Customer relationship	What is the main activity of the Company			Total
	Production	Sales and / or trade	Service	
Percentage of National Clients	64.2	83.3	84.3	78.6
Percentage of Transnational Clients	35.8	16.7	15.7	21.4

Table 6 List of customers with company activity
Source: Own Elaboration

Where it is seen that national clients are the ones that occupy the highest percentage of clients, this is due to the type of clients they currently manage, that if they turn to the solar industry, the composition will change since the largest consumer of solar technology is the United States, and the products and / or services that these companies can attend are the metalworking for fixed structures and solar tracking.

Among the products and services that companies registered as their main ones, a total of 70 was obtained, since not all companies already have on the market the results of the approved projects or because they still do not obtain profits and therefore do not consider them your main products / services.

Some of the products mentioned by the companies whose main activity is production are instrumentation, equipment installation, pre-cooling systems semifix and others. Likewise, the service companies had answers such as services to instruments and equipment, consulting services, preventive and corrective maintenance, among others.

Linking companies with the academy

Table 7 shows the companies that have had links with higher education institutions (HEIs) and / or Research Centers (CIs).

It shows how the Sonoran companies decide to have links with IES or CI outside of the state because there is no State of Sonora institution.

Name of the institution outside of Sonora with whom you have links	Main activity of the Company		Total
	Production	Services	
Center for Industrial Engineering and Development (CIDESI)	0	1	1
Advanced Materials Research Center (CIMAV)	0	2	2
Postgraduate School (COLPOS)	1	0	1
National Institute of Cardiology	0	3	3
National Institute of Astrophysics, Optics and Electronics (Inaoe)	1	0	1
National Institute of	0	3	3
Nutrition			
National Polytechnic Institute	2	1	3
Veracruz University Institute	0	3	3
University of Development (udd)	1	0	1
National Autonomous University of Mexico	1	0	1
La Mar University	1	0	1
Polytechnic University of Sinaloa	1	0	1
Total	8	13	21

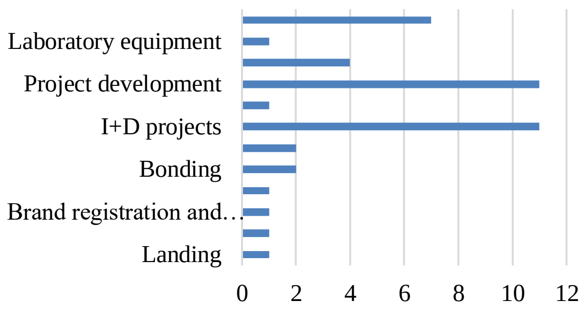
Table 7 Linking IES or CI with companies
Source: Own Elaboration

The linkage activities that have been carried out for these companies are principally the development of services, which are provided by the different laboratories of the IES or CI (see Table 8).

Reason	Production	Services	Total
Technical Capabilities	0	7	7
Laboratory equipment	0	1	1
Product development	1	3	4
Project development	16	12	28
Thermal / Mechanical Engineering	0	1	1
Practitioners	5	2	7
I+D projects	10	1	11
Technological Transfer and Biotechnology	2	0	2
Bonding	2	0	2
Software development	1	0	1
Brand registration and patent initiation	1	0	1
Home	1	0	1

Table 8 Linkage activities by quantity and type of companies
Source: Own Elaboration

Other linking activities are shown in figure 3. The R & D projects and product development are the activities that are carried out most between the companies and the IES or CI.



Graphic 3 Other bonding activities
Source: Own Elaboration

Methodology to be developed

With the previous characterization, what can be observed in the State of Sonora is a business ecosystem with important links with the academy, with strong capacities for the development of new products and with export capacities.

These companies have technically well-trained employees, and the lack of skills or competences solves them with the link with the IES and CI.

In this way, integrating into the productive chain of the solar industry, it is potentially a step that has to be taken, derived from the prospects for growth of the photovoltaic solar energy sector that, if not served by national companies, will be occupied by transnationals, as has happened in other industries.

With the reform of the energy law, the forms that limited the growth of the market have been modified, opening the possibility of being able to generate and market in an open market, although the transmission lines will be mostly from the Federal Electricity Commission (CFE) (see Figure 2).

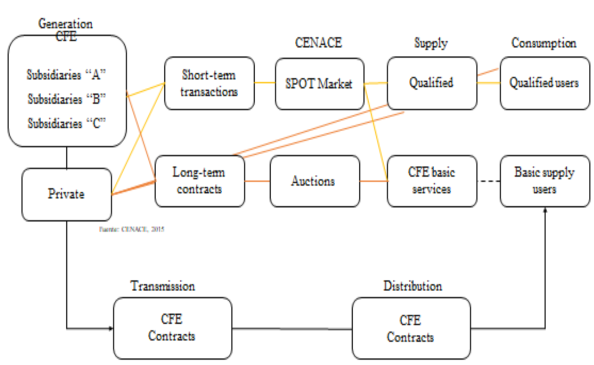


Figure 2 New model of the electric industry in Mexico
Source: CENACE, 2015

The LTE and the LIE -which are set as minimum goals for the participation of clean energy in the generation of electric power 25% for 2018, 30% for 2021 and 35% for 2024- are key instruments for the impulse of the generation of electricity from clean energies.

These country goals will make it possible to comply with the policy on the diversification of energy sources, energy security and the promotion of clean energy sources. (PROMEXICO, 2018).

In the year 2016 in Mexico permits for generation were granted as shown in table 9.

No.	Central	Federal entity	Scheme	Authorized capacity (MW)	Authorized energy (GWh)	Entry into operation
1	Autoabastecimiento renovable, S.A. de C.V.	Aguascalientes	Self-supply	0.8	1.8	2011
2	Coppel, S.A. de C.V.	Sinaloa	Self-supply	1.0	2.3	2014
3	Generadora Solar Apaseo, S.A.P.I. de C.V.	Guanajuato	Self-supply	1.0	2.1	2013
4	Plamex, S.A. de C.V.	Baja California	Self-supply	1.0	1.9	2014
5	Iusasol Base, S.A. de C.V.	Estado de México	Self-supply	0.9	1.9	2015
6	Iusasol 1, S.A. de C.V.	Estado de México	Self-supply	18.3	37.2	2016
7	Santa Rosalía (CFE)	Baja California Sur	Generation	1.0	2.0	
8	Cerro Prieto (CFE)	Baja California	Generation	5.0	11.0	2012
9	Servicios Comerciales de Energía S.A. de C.V. (Aura Solar)	Baja California Sur	PP	30.0	86.0	2012
10	Tai Durango Uno, S.A.P.I. de C,V,	Durango	PP	15.6	32.4	2013
11	Tai Durango Dos, S.A.P.I. de C,V,	Durango	PP	6.3	12.1	2016
12	Tai Durango Tres, S.A.P.I. de C,V,	Durango	PP	3.5	6.8	2016
13	Tai Durango Cuatro, S.A.P.I. de C,V,	Durango	PP	6.3	12.1	2016
14	Tai Durango Cinco, S.A.P.I. de C,V,	Durango	PP	30.0	57.9	2016
Total				**120.7**	**267.5**	

Table 9 Permits granted during the year 2016 in Mexico for power generation
Source: Energy Regulatory Commission

In Mexico, auctions have been carried out by SENER so that companies can generate energy and sell it to the CFE. The National Center for Energy Control (CENACE) shows the information of the energy auctions presented in table 10.

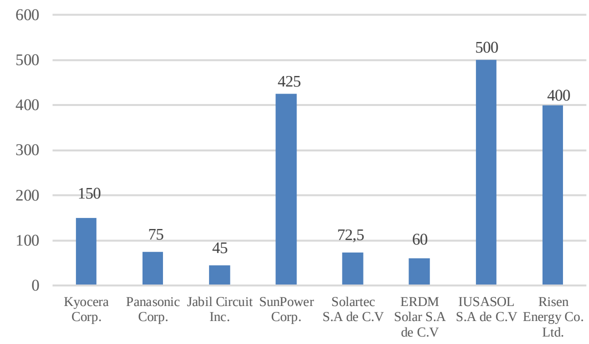
First Auction	Second auction
	- Acciona (180 MW)
	- Ienova (41 MW)
- Sunpower (100 MW)	- Zuma Energy (148 MW)
- Enel (787 MW)	- OPDE (112.17 MW)
- Recurrent (63 MW)	- Fisterra Energy (125 MW)
- Sunpower (500 MW)	- Gestamp Solar (X-Elio) (150 MW)
- Jinko (188 MW)	- ENGIE (126 MW)
- Alter Enersun (30 MW)	- Ienova & Trina Solar (100 MW)
- Thermion (23 MW	- Fotowatio Renewables (300 MW)
	- Hamwha Q-Cells (101.08 MW)
	- Alten Renewable Energy (290 MW)
	- EDF (90 MW)

Table 10 Information about energy auctions
Source: CENACE

The new installed capacity of photovoltaic solar energy will be concentrated mainly in seven states of the country: Coahuila, Aguascalientes, Yucatan, Sonora, San Luis Potosi and Chihuahua, which will cover, overall, 93% of the new capacity resulting from the first and second auctions (3,310 MW); the remaining 7% will be installed in the states of Jalisco, Morelos, Baja California and Baja California Sur (see Figure 3).

Figure 3 Location of projects to develop derived from energy auctions
Source: Solar Industry, 2018

In addition to the above, in Mexico there is an installed capacity of photovoltaic panel factories as shown in Figure 4.



Graphic 4 Installed capacity of photovoltaic panel manufacturing
Source: PROMÉXICO, 2018

Results

In this work we have shown in a general way the predicted energy production potential in Mexico, this denotes a growing market in the coming years.

This market demands inputs that must be provided by companies that are integrated into the value chain of the solar industry; In this sense, an analysis and characterization of companies from the north of Mexico, the state of Sonora was carried out, selecting a sample of those that can be users but also have the capacity to integrate into the value chain of the solar industry.

Added to this is the impact of public policies regarding energy generation, where Mexico has acquired an international commitment to produce a high percentage (30% to 35% by 2030) of the energy used in the country with renewable sources, giving a great opportunity to solar energy.

SENER has competed several auctions of energy production and in Mexico there are at least 18 projects to be installed that total 3,454.25 GW in the coming years, giving the opening of the market on a large scale.

Acknowledgement

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Conclusions

The analyzed companies have the capacity to develop the knowledge and skills to be able to diversify their turn and to attend quickly the business that the solar industry means.

Failure to do so will happen as in other industries, where transnational companies come to meet the needs, and Mexico would be only a consumer of foreign technology.

The projects of scientists and technological development that are being carried out by the IES and CI, give a great opportunity to generate technology and frontier knowledge to meet the needs of the solar industry.

The companies have taken confidence with the IES and CI, so that they have the conditions to generate this ecosystem of innovation and technological development, in order to generate social, environmental and economic benefits that take the Mexican solar industry to a position competitive, and that later is exporting technology to the world.

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Economical Feasibility study of a wind system interconnected to the grid for the self-supply at the Isthmus University

Estudio de viabilidad económica de un sistema eólico interconectado a la red para el autoabastecimiento de la Universidad del Istmo

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Abstract

Wind energy is one of the renewable energy sources that has experienced a constant growth worldwide. Currently, this source of energy is part of electricity markets in many countries, being China, United States and Germany the leading countries in installed capacity. In México there have been important advances and the total installed capacity already exceeds 4 GW, being the self-supply scheme one of the most used. The region of Isthmus of Tehuantepec is the main scenario for wind projects in the country, due to the great wind potential available. In this region, UNISTMO is located, an institution of higher education that has three university campuses: Tehuantepec, Ixtepec and Juchitán. This university is currently supplied with the electric power supplied by CFE, however, it has resources such as wind and solar that could be used to produce part or all of the energy consumed. For this reason, in this work the simulation, optimization and study of sensitivity of a wind system interconnected to the electric network at Campus Juchitán are carried out, considering variations in certain technical-economic variables.

Renewable energy, Electrical markets, Economical study

Resumen

La energía eólica es una de las fuentes renovables que ha experimentado un constante crecimiento a nivel mundial. Actualmente, esta fuente de energía forma parte de los mercados eléctricos en muchos países, siendo China, Estados Unidos y Alemania los países líderes en capacidad instalada. En México se han dado avances importantes y la capacidad total instalada ya supera los 4 GW, siendo el esquema de autoabastecimiento uno de los más utilizados. La región del Istmo de Tehuantepec es el principal escenario de los proyectos eólicos del país, debido al gran potencial eólico con el que dispone. En dicha región se encuentra localizada la UNISTMO, una institución de educación superior que cuenta con tres campus universitarios: Tehuantepec, Ixtepec y Juchitán. Esta universidad se abastece actualmente de la energía eléctrica que le suministra CFE, sin embargo, cuenta con recursos como el eólico y el solar que podrían aprovecharse para producir una parte o la totalidad de la energía que consumen. Por dicha razón, en este trabajo se realiza la simulación, optimización y estudio de sensibilidad de un sistema eólico interconectado a la red eléctrica en el Campus Juchitán, considerando variaciones en ciertas variables técnico-económicas.

Energías renovables, Mercados eléctricos, Estudio económico

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Introduction

Recently the demand for energy has reached very high levels, the main reason for this is the rapid increase in urbanization, neighborhoods, the built environment, public transport and services. Nowadays, due to the economic and political conditions of the modern world, there is a rapid development of the renewable energy system in Mexico and even though it is not so good, it is around 0.74% of the total generation (AMDEE, GWEC 2017). But the goal of the Mexican government is to generate 25% by 2018, 30% by 2021 and 35% by 2024 of total energy by renewable system. As a result, Mexico installed the 478 MW capacity to reach a total of 4,005 MW by the end of 2017, supplying approximately 4% of the country's electricity (GWEC, 2017). As far as wind energy has shown a rapid growth in recent years, and today is the technology with the most competitive price in most markets around the world.

Several countries are showing a boom in this technology, such as Argentina, or in South Africa, which has a surprising return. For its part, Mexico is experiencing spectacular growth. This development behavior is due to several factors, mainly to energy policies (SENATE) which mandates the execution and coordination of the Special Program for the Use of Renewable Energies (SPURE) that is being promoted worldwide to generate electricity through clean energies, the objective of reducing environmental damage, incentives, and the technical maturity that this technology has obtained (Dennis *et al*., 2012; Wais, 2017).

Regarding renewable policies, in many countries they are ceasing to be tariffs established by the government and are beginning to be competitive auctions with long-term energy purchase agreement (PPA) for public-scale projects. (https://www.iea.org/renewables/).

One relevant fact is that the Energy Reform of Mexico introduced the tender for wind energy and other renewable energies, the last of which resulted in a record price of US $ 0.017 / kWh for projects, which has already attracted more than US $ 7.6. Investment bn The auctions held so far are historically lower prices, setting new world records and demonstrating the competitiveness of wind power in the country.

In addition, the Mexican wind market is not only about long-term auctions, since there are also new regulations that allow contracts with large consumers in the private sector. This helps extend the social and economic benefits of renewable energy development throughout the country.

The trend in prices is improving, which is why the use of wind turbine technologies is motivated in places where energy demand is really important, so much so that nowadays the economic viability of several sites for the production of electricity at low cost, either for electricity supply or for sale to the network.

The development of wind energy in Mexico has been complex and controversial; The great increase in wind energy in Oaxaca has created social conflicts, which could even stop the development of wind projects in the region (Huesca-Pérez, 2016; Juárez-Hernández et al., 2014). Within this sector, Oaxaca is the best-known state in the country because of the wind power that is delivered to the country every year (AMDEE), thanks to the wind potential of the Isthmus of Tehuantepec, particularly in La Venta, which has become a stage of the wind projects, despite the controversies and the public resistance to the wind developments that have taken place when planning the projects (Pasqualetti, 2011).

In this work the economic study is carried out using the software HOMER PRO (Hybrid Optimization Model for Electric Renewables), whose main interest is to analyze the profitability of the installation of a wind turbine or wind turbine of 660 kW or Gamesa of 2 MW for the purpose to supply electricity to the Juchitán campus or, if necessary, the three campuses of the Universidad del Istmo (UNISTMO) located in Santo Domingo Tehuantepec, Ixtepec and Juchitán de Zaragoza. After making various analogies regarding various variables such as: wind speeds, interest rate, initial capital, costs by O & M, etc., the conclusion of this investigation is expressed.

Methodology

The study was conducted using the HOMER PRO (HOMER) model. HOMER (http://www.nrel.gov/homer/) is a program for the optimization of hybrid electric power generation systems based on renewable sources (Türkay, 2011, Sahoo, 2015).

The program can optimize hybrid systems composed of photovoltaic generator, batteries, wind turbines, hydraulic turbine, AC generator, fuel cell, electrolyser, fuel tank and bidirectional AC-DC converter. The charges can be AC, DC and / or hydrogen charges, as well as thermal loads.

This model performs three fundamental activities: **simulation, optimization and sensitivity analysis**. In the simulation process, it models the operation of a particular system configuration every hour of the year, to determine its technical feasibility and its cost in the useful life. In the optimization, it simulates many different configurations in the search for the one that satisfies the technical constraints at the lowest cost. In the sensitivity analysis, it performs multiple optimizations under a range of assumed changes in input variables (costs, average demand, average wind speed, interest rates, life of the project or components, height of the wind turbine hub, others), to measure the effects that these changes cause on the functioning of the system. The optimization determines the optimal values of the variables over which the system designer has control, such as the combination of components that make up the system and the size or quantity of each. In contrast, the sensitivity analysis helps to assess the effects of uncertainties or changes in variables over which the designer has no control, such as those mentioned above. (Lambert et. al.).

Figure 1 shows the scheme of the wind system studied, which included the possibility of installing either Vestas wind turbines of 660 kW or Gamesa of 2 MW. This was done for comparative purposes, in such a way that one could choose between one and the other through the optimization process; the previous subject to restrictions in the power sale capacity to CFE.

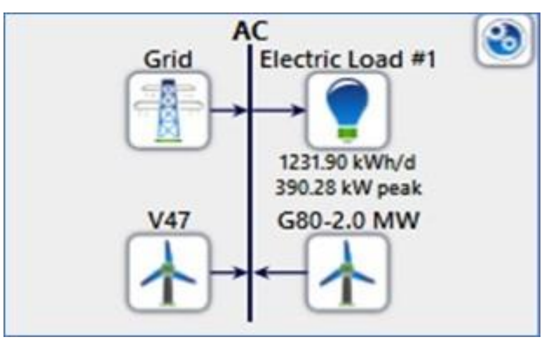


Figure 1 Scheme of the wind system studied
Source: HOMER PRO

The idea of including several values for the capacity to sell energy to CFE (sensitivity), is to see how this affects the level cost of the energy produced. This analysis is justified by the fact that, in Mexico, CFE does not pay for surplus energy that the system delivers, but under the self-supply scheme only makes a balance between what is delivered and what is purchased from the network (charges the difference between said amounts). Therefore, this analysis seeks to minimize surplus energy as it does not imply additional income for the university.

Table 1 shows all the sensitivity variables used: sales capacity; discount rate; rate of inflation; and daily energy consumption. The values of daily energy consumption consider: a university campus (1232 kWh / d); two campuses (2460 kWh / d); and three campuses (3700 kWh / d).

The value of a campus' consumption is derived from load studies conducted at the Tehuantepec campus, using a Fluke brand energy quality analyzer. The other two values are estimated.

Sensitivity variables			
Capacity to sell to the network (kW)	Nominal discount rate (%)	Rate of inflation (%)	Daily energy consumption (kWh)
25	8	6	1232.00
50	6	4	2460.00
100			3700.00
			500.00

Table 1 Sensitivity variables used
Source: Data taken from HOMER PRO

The meteorological information used consisted of wind speed data, recorded at 32 m SNS every hour, in an anemometric station located next to the Juchitán campus.

Regarding the sale and purchase prices of electric power to CFE, these were considered equal. It was taken into account that UNISTMO pays its electricity service to CFE under the HM tariff, which differentiates consumption in three periods: base, intermediate and peak. The prices for each period change by season of the year and apply to certain periods of the day. For this reason, a series of 8760 data were constructed with the prices of electricity for each hour of the year.

This series was imported from the HOMER and it is visualized in figure 2.

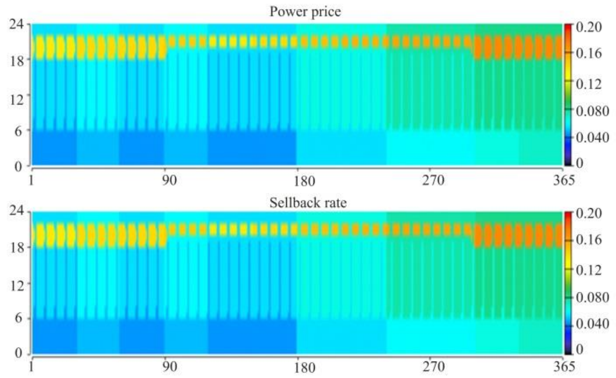


Figure 2 Variation in energy prices according to the HM tariff
Source: HOMER PRO

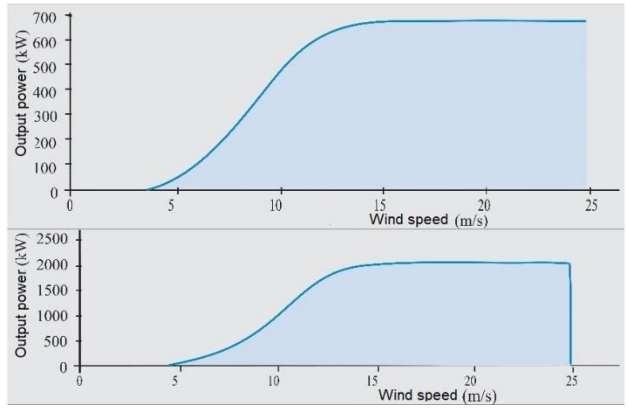
The costs considered for the wind technologies were the following:

1. Capital cost: 800 USD / kW.
2. Annual operation and maintenance costs: 2% of the capital cost.

The duration of the project was considered equal to the life time of the wind turbines (25 years), with which the residual value of the same is zero.

Figure 3 shows the proposed site for the installation of the wind turbine, at the Juchitán campus of UNISTMO. This campus was chosen because it is located in one of the most important wind resource sites in the country; where the largest Mexican wind farms are installed.

Figure 3 Place of location of the wind turbine on the Juchitán campus of the UNISTMO
Source: HOMER PRO



Graphic 1 Power curves of the Vestas V47-660kW and Gamesa G80-2MW wind turbines
Source: HOMER PRO

As can be seen in Table 2, the configuration that includes a Gamesa G80-2MW wind turbine is located behind the one that considers only the electricity grid. That is, in the life cycle of the project (25 years) it would be preferable to continue consuming 100% of the electric power from the network instead of interconnecting a 2 MW wind turbine.

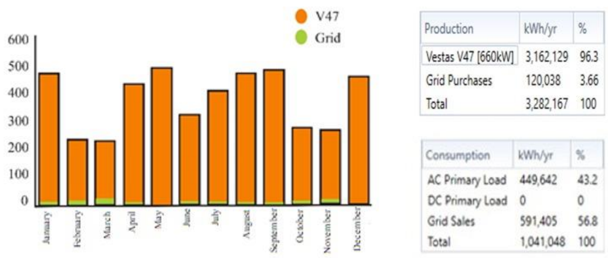
This is because the scheme that has been evaluated is self-supply, where the surplus energy does not imply additional income.

Architecture	Costs				System
Wind turbine	COE ($)	NPC ($)	cost of operation	Initial capital	Renewable fraction
Vestas 660kW	0.0065	0.13M	-26,595	0.66M	88.5
Red	0.0722	0.64M	32,486	0	0
Gamesa 2MW	0.0608	1.36M	-12,234	1.60M	92.6

Table 2 Results of the optimization
Source: Data taken from HOMER PRO

If it were the case of an independent production system or another where additional income is obtained by selling energy, then the behavior would be different and surely the G80 wind turbine would be preferable instead of the network or the V47 wind turbine.

However, under the conditions already described, a Vestas V47-660kW wind turbine would be enough to generate 100% of the consumption of the Tehuantepec campus.



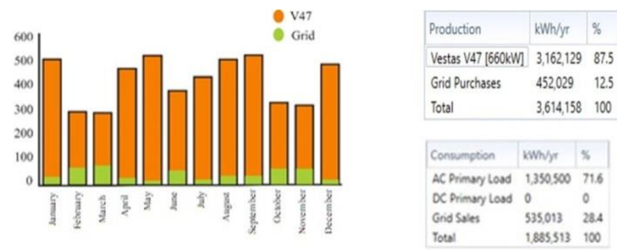
Graphic 2 Monthly energy balance produced by the wind turbine and purchased from the network (case of a university campus)
Source: HOMER PRO

The Vestas wind turbine would have a capacity factor of 54.7%, which is very high due to the potential of the available wind resource (9.57 m / s at 32 m SNS). The annual energy delivered would be 3162.13 MWh, while that purchased from the grid would be 120.04 MWh. It would be necessary to buy this amount of energy to the grid even though the total wind production is higher than the annual consumption, which is 449.64 MWh, due to the intermittency of the wind (not in all the hours of the year the production of the wind turbine equals or exceeds consumption).

However, since the energy sold to the grid (591.40 MWh) exceeds the power purchased, then the wind turbine would be supplying 100% of the demand and would also have an excess of production.

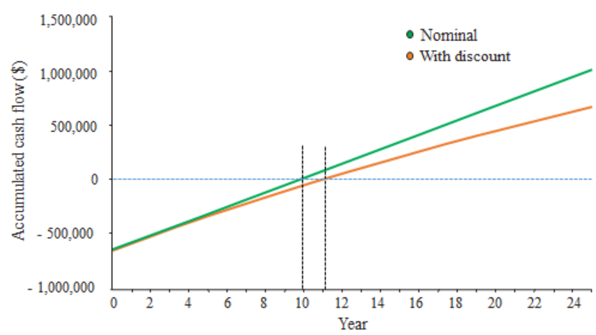
For those cases in which the electrical demand of the other two university campuses would also be met, the optimal system would continue to be wind power interconnected to the grid with a V47 wind turbine. Only by adding one or two more campuses, then it will be necessary to buy more energy from the network.

For example, for two campuses the total annual energy consumed (898 MWh) continues to be less than the annual production of the wind turbine; and for the three campuses the total annual consumption (1350.5 MWh) would also be lower. In all cases the production of the aerogenreador exceeds the demand.



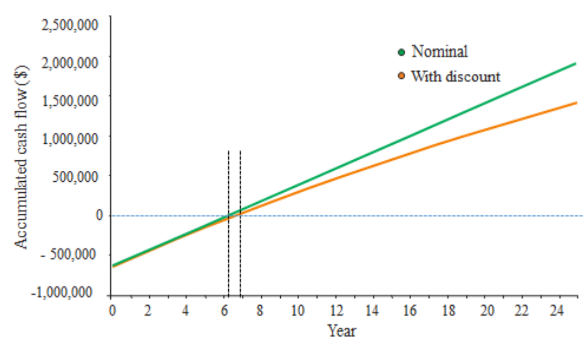
Graphic 3 Balance of monthly energy produced by the wind turbine and purchased from the network (case of the three university campuses)
Source: HOMER PRO

If we compare graphs 2 and 3 we can see that the amount of energy purchased from the network is higher in the second case, but the amount of energy sold continues to exceed the amount purchased.



Graphic 4 Accumulated cash flow (case Tehuantepec campus)
Source: HOMER PRO

The accumulated cash flow in figure 4 shows that the period of recovery of the investment would be 11 years if only the supply of electricity to the Tehuantepec campus were considered. However, if the system considers the self-sufficiency of the three campuses, the recovery period would be approximately 7 years (figure 5).



Graphic 5 Accumulated cash flow (case of three campuses)
Source: HOMER PRO

Regarding the sensitivity analysis, the influence of electricity consumption and sales capacity on the network was analyzed in the optimal system type (figure 4). As can be seen, most of the area is occupied by the wind system interconnected to the network (wind turbine V47-660 kW).

However, for small values of sales capacity and lower consumption than the Tehuantepec campus (1232 kW / d), the optimal system is the electricity grid. The latter would also happen for consumption slightly higher than those of said campus and network sales capacities below 40 kW.

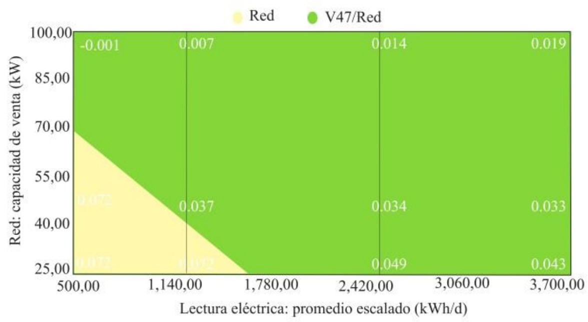


Figure 4 Optimal system type for different consumption values and capacity to sell energy to the network
Source: HOMER PRO

It should be noted that the Gamesa G80-2 MW wind turbine was not optimal for any of the possible combinations of the two sensitive variables of Figure 4. It should also be noted in Figure 4, that for the same value of energy consumed (horizontal axis) the level cost of energy (values superimposed in the area of the graph) decreases with the increase in sales capacity (vertical axis). The latter is because the increase in sales capacity would imply more energy sold to CFE.

What is indicated in the previous paragraph indicates the need to establish public policy measures in the energy sector that facilitate the commercialization of surplus energy that takes place in systems distributed under self-supply schemes.

Conclusions

The study shows the technical-economic feasibility of interconnecting wind turbines to the electric grid in the Juchitán campus, to supply the entire UNISTMO with electricity.

The existing wind potential allows to obtain wind turbine capacity factors above 50%, which means that wind turbines even lower than the MW of power are capable of supplying large amounts of electricity to the UNISTMO.

The sensitivity analysis carried out demonstrates the need to implement public policy measures that encourage the use of wind technologies for energy self-sufficiency. Low levels of electric power sales capacity can make systems such as those studied unprofitable, compared to the conventional electricity grid.

It should be noted that this study is preliminary, since there has been no optimization in the selection of the wind turbine most suitable for the site; Take into account, for example, aspects of turbulence and wind gusts that could reduce their useful life. This should be part of later studies.

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Implementation of the economic dispath to optimize the location of the wind parks

Implementación del despacho económico para la localización óptima de parques eólicos

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Abstract

The supply of electrical energy must be guaranteed in a sustainable way due to the depletion of non-renewable resources, as new alternatives for renewable resources, known as clean energies. As a concrete case, for the state of Tamaulipas, previous studies have been carried out that indicate its enormous potential for the installation of the wind parks. This paper presents an analysis of the efficient management of electricity production through the generation of clean energy, such as wind energy. This analysis is carried out under the economic dispatch scheme, proposed as a problem of minimization of energy at the time of transmission. The mathematical model, formulated through a linear programming scheme and considering the real variables, allows to find the optimal location of a wind park in order to maximize the generated energy, showing the real generation capacity. The analysis realized has the advantages of being a method that yields the best solution for the linear optimization model, unlike the heuristic methods that only look for a solution that is closest to the optimum.

Economic Dispatch, Linear Programming, Optimization

Resumen

El abastecimiento de la energía eléctrica se debe garantizar de una manera sustentable y debido al agotamiento de los recursos no renovables, se han buscado nuevas alternativas a partir de recursos renovables, conocidas como energías limpias. Como caso concreto, para el estado de Tamaulipas, se han realizado estudios previos que indican su gran potencial para la instalación de parques eólicos. En este trabajo se presenta un análisis de la administración eficiente de la producción de energía eléctrica mediante la generación de energía limpia, como la eólica. Dicho análisis se realiza bajo el esquema de despacho económico, planteado como un problema de minimización de pérdidas de energía al momento de la transmisión. El modelo matemático, formulado a través un esquema de programación lineal y considerando variables reales, permite encontrar la localización óptima de un parque eólico con el fin de aprovechar al máximo la energía generada, logrando mostrar la capacidad real de generación. El análisis realizado posee las ventajas de ser un método que arroja la mejor solución por el hecho de ser un modelo de optimización de programación lineal, caso contrario de los métodos heurístico que solo buscan una solución la cual es la más cercana a la óptima.

Despacho Económico, Programación Lineal, Optimización

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Introduction

Energy is the ability of a body or system to develop a certain work, these forms of energy can be kinetic, thermal, solar, light, hydraulic, wind, atomic, and electrical energy according to Roldan (2008). Currently, electric power is present in the daily life of the human being, and as fossil fuels are exhausted, as well as its high and increasing cost each day, they provoke the interest of searching for new alternatives to take advantage of resources energetics.

The methodology of the economic dispatch provides a way to supply the demand for electric power, optimizing the available generation resources. An administrative approach to the economic dispatch arises when dealing with the problem of locating a new generation plant through economic dispatch, resulting in an optimal location.

Theoretical fundament

Exhaustion of non-renewable resources

Electricity is of utmost importance in our society, due to the countless applications in all areas of life as mentioned by Hall (2013) is industrial, commercial, communications, and residential uses.

This electric power according to Villarrubia (2012) is generated from non-renewable resources and renewable resources, which must be guaranteed in a sustainable way in Mexico and is defined within the 2013-2019 development plan, which refers to to use in renewable energies, to increase competitiveness and have greater economic and social development. Currently, most of the energy consumed in the world is of non-renewable origin according to the report on Renewable Energies: The world situation: (2018), where it is mentioned that only 26.5% of the energy generated is through renewable resources.

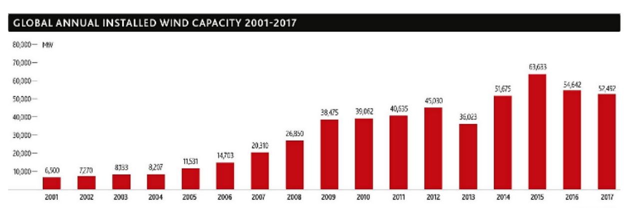
Studies of the energy sector, such as that of the International Energy Agency: World Energy Otlook (2006) and of the European Commission World Energy, Technology and Climate Policy Outlook WETO 2030 (2007), coincide in their projections of a depletion of resources not renewable as fossil fuels and coal for 2030 and uranium according to Dittmar (2011).

Due to the depletion of non-renewable resources begins to develop systems or devices for the use of alternative sources of energy known as renewable energy such as: solar, wind, biomass, hydraulic, geothermal, and obtained by the oceans according to Roldan (2013).

Wind energy: viable alternative in Mexico

Wind power, as defined by Spinadel (2015), comes from the sun due to changes in pressure and temperature in the atmosphere that cause the air masses to move and generate wind. This, allows to be taken advantage of by the wind turbines that transform the kinetic energy of the wind to produce the necessary mechanical work to generate electricity. In its beginnings it was used in irrigation and milling, as well as to operate water pumps at the beginning of the 17th century.

Until the early twentieth century was when the wind was used to produce electricity, but the low cost of coal and fossil fuels made them more in demand. As a result, the development of its technology was halted, and as a result of the oil crisis of the 70s, it promoted alternative energies such as wind power. According to Han (2005) and Fernández (S / F) the pioneering countries in the use of this technology were E.U and Europe. From the 21st century, wind energy has had great development as shown in Chart 1, with the main current producers China, U.S., Germany, India and Spain according to the Global Wind Energy Report 2018 (GWEC 2018).



Graphic 1 Evolución de la capacidad de energía eólica instalada en el mundo
Source: Global Wind Statistics 2017

In Mexico wind energy has advanced very slowly, currently there are several wind farms in different states with a total capacity of 4005 MW according to the Mexican Wind Energy Association in 2018 (AMDEE 2018). In Figure 1, the distribution of wind farms installed in Mexico reported until 2018 is shown.

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Figure 1 Wind farms installed in Mexico
Source: AMDEE 2018

Different studies such as those of the Tech4 CDM Project (2009), Calderón (2008), Gorrochotegui (2006) and Coronado (2005), to name a few, have identified different areas with wind potential to produce electricity.

In particular, one of them is the coastal area of Tamaulipas, the mentioned references indicate that the points with the greatest potential are in Matamoros, Soto la Marina and Altamira as shown in Figure 2.

Figure 2 Wind power density in Mexico
Source: SENER 2014

The incorporation of new electric power generation centers to the central network; brings with it new challenges among them the efficient use of all resources, so it is important to resort to the implementation of optimization techniques that allow the strategic location of energy generation nodes to be identified.

Operations research

Decision making in real problems is complex, especially due to the large number of variables involved. For the resolution of these problems, the use of quantitative models is fundamental and, according to González A. and García G. (2015), this branch of mathematics is known as Operations Research.

A mathematical model can generate endless solutions, but the optimal solution that is generated will be one that improves feasible solutions.

Its main feature is that all the variables involved in the system must be represented by linear functions. The linear programming model consists of three basic components:

1. The variables of non-negativity.
2. The goal, which is the goal that is to optimize, either maximize or minimize resources.
3. The restrictions that must be met, these can be due to the limitation of resources.

Economic Dispatch

The operation of an electrical network involves several problems of technical order and economic order. The network must ensure, at all times and in all places, the coverage of energy demand, guaranteeing an acceptable quality of the power delivered, ensuring high food safety, at the lowest possible cost.

The high prices of fuels have given an important position to the optimal functioning of electric power systems in energy management. The problem that arises is then, the distribution of the total load of the system among the available generation units in order to optimize all resources.

The problem of the Economic Dispatch according to Barrero (2004), is a problem of linear programming and this begins when you have two or more central power supply and must supply a certain amount of demand, therefore, the form of divide the demand between the power stations in search of the optimization of the resources at the moment of connecting to the electrical distribution network.

Methodology

The problem of economic dispatch is proposed to modify and add a random variable containing the probability of Weibull density, which tells us the probable speeds that can be obtained in each of the probable locations in which you want to locate and thus get the powers and under the restrictions of the Economic Dispatch you can find the most efficient location in which it is more convenient to locate the wind farm.

The probability that the wind speed is between certain values according to Martinez (2011) is given by:

$$P(u_a \leq u \leq u_b) = \sum_{i=a}^{b} p(u_i) \qquad (1)$$

Where u_b can be as large as you want, so as to obtain the probability that a wind speed is above the value of u_a. For various reasons it is convenient that the model of the wind speed frequency curve is a continuous mathematical function instead of a table of discrete values. In this case, the probability p (u_i) is transformed into a probability density function of f (u).

The area below the function is unity, this is:

$$\int_0^\infty f\,(u)\,du = 1 \qquad (2)$$

While the cumulative distribution function is given by:

$$F\,(u) = \int_0^u f(x)dx \qquad (3)$$

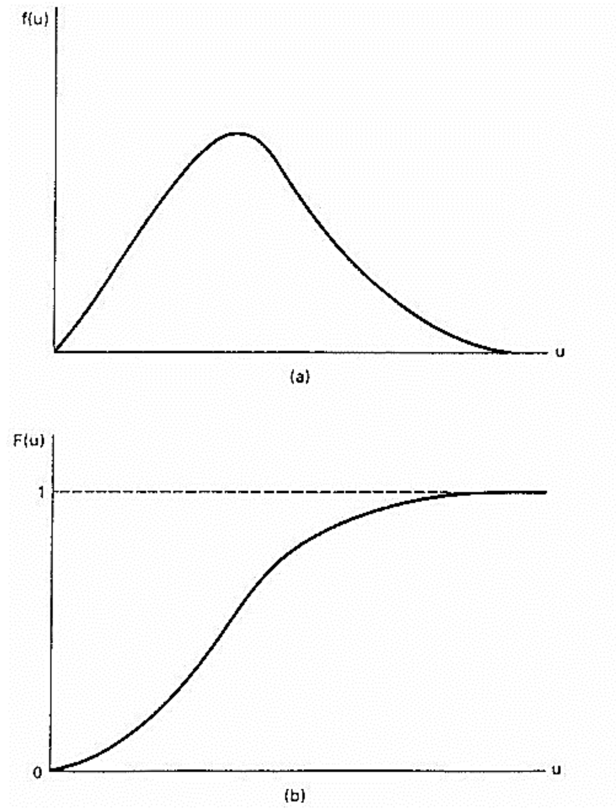
Likewise, the average value is expressed:

$$\bar{u} = \int_0^\infty u\,f\,(u)\,du \qquad (4)$$

And the variance for:

$$\sigma^2 = \int_0^\infty (u - \bar{u})^2\,f\,(u)\,du \qquad (5)$$

The probability functions f (u) and cumulative F (u) are represented graphically in Graphic 2.

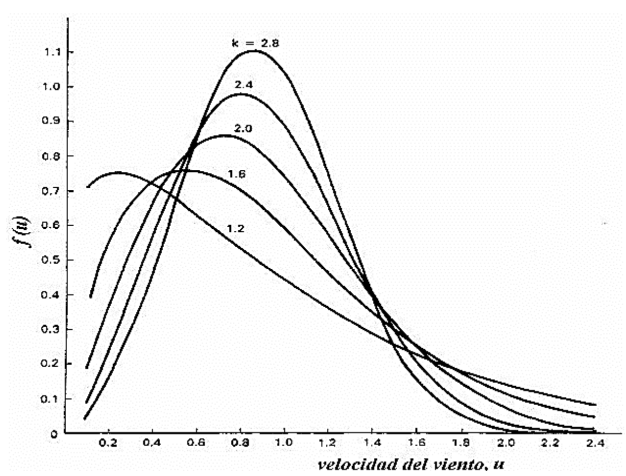


Graphic 2 Weibull distribution functions
Source: Martínez 2011

One of the functions that best fits to describe the distribution of wind speeds is the distribution of weibull which is the one with the highest precision is given by:

$$f(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} exp\left[-\left(\frac{u}{c}\right)^k\right] \qquad (6)$$

This is a distribution of two parameters, where c and k are the scale and shape parameters respectively.



Graphic 3 Weibull distributions with parameter c = 1
Source: Martínez 2011

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The integral over the entire domain of the f (u) is the unit, so that, for various values of k (form) the peak indicates the most frequent velocity as shown in Graphic 3. The determination of the k and c values they depend on the values of u registered in the case. Since f (u) is the Weibull distribution, the probability that the wind speed u is greater than or equal to u_a is:

$$P(u \geq u_a) = \int_{u_a}^{\infty} f(u)du = exp\left[-\frac{u_a}{c}\right]^k \quad (7)$$

Thus, the probability that the wind speed is within a range of 1 m / s in width, centered in u_a is:

$$P(u - 0.5 \leq u \leq u_a + 0.5) \cong f(u_a) \quad (8)$$

By implementing the probability of the Weibull density at the probable points of location of the wind farm, the approach of the economic dispatch is based on the following conditions.

Each line in the electrical network transmits the power from the supplying node to the receiving node. The amount of power sent is proportional to the difference of the angles of these. The power transmitted from node i to node j through line i - j is therefore:

$$B_{ij}(\delta_i - \delta_j) \quad (9)$$

Where B_{ij} is the susceptance called the constant of proportionality, of the line i-j; and δ_i and δ_j the angles of the nodes i and j, respectively.

For physical reasons, the amount of power transmitted through a power line has a limit. This limit is justified by thermal or stability considerations. Therefore, a line must work so that this transport limit is not exceeded in any case. The latter is formulated as:

$$P_{ijmax} \leq B_{ij}(\delta_i - \delta_j) \leq P_{ijmax} \quad (10)$$

Where P_{ij}^{max} is the maximum transport capacity of the line $i - j$.

It must be stressed that the transmitted power is proportional to the difference of angles and not to a given angle. Consequently, the value of an arbitrary angle can be set to 0 and considered as the origin:

$$\delta_k = 0 \quad (11)$$

Where k is an arbitrary node. A consequence of arbitrarily selecting the origin is that the angles are unrestricted variables in sign.

The power produced by a generator is a bounded positive quantity lower and higher. The lower bound is due to stability conditions (analogous to how a car can not move at speeds below a certain limit). The upper bound obeys to thermal considerations (as well as the speed of a vehicle can not surpass a certain superior level). The above restrictions can be expressed as:

$$P_i^{min} \leq p_i \leq P_i^{max} \quad (12)$$

Where pi is the power produced by the generator i $P^{min}i$ and Pi^{max} are, the maximum and minimum admissible output power for the generator i.

In each node, the power that arrives must coincide with the power that comes out of it (corresponding to the law of conservation of energy), which can be expressed as:

$$\boldsymbol{\Sigma}_{j \in \Omega i} B_{ij}(\delta_i - \delta_j) + p_i = D_i, \quad \forall i \quad (13)$$

Where Ω_i is the set of nodes connected through the lines to the node i and D_i the demand in the node i.

As indicated above, the power transmitted through each line is bounded, so

$$-P_{ijmax} \leq B_{ij}(\delta_i - \delta_j) \leq P_{ijmax}, \quad \forall j \in \Omega i, \forall i \quad (14)$$

Results

The implementation of economic dispatch in the region is shown in figure 3 where the main elements of this problem are:

- Parameters

VA_i = Random power variable i i= 1 Matamoros, 2 Soto la Marina, 3 Altamira.
P_i = Losses of electrical energy at point i. i= 1 Matamoros, 2 Soto la Marina, 3 Altamira.
B_{ij} = susceptance of the i - j line
P_{ij}^{max} = The maximum transport capacity of the line $i - j$

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- Variables

δi= Phase angle in the location i i = 1 Matamoros, 2 Soto la Marina, 3 Altamira.
L_i= Binary 1 = If the location i is the most efficient to locate the wind farm.
0 = The location is not feasible.
for i = 1 Matamoros, 2 Soto la Marina, 3 Altamira.

- Objective Function:

$$Min\, z = P_1\ VA_1L_1 + P_2\ VA_2L_2 + P_3\ VA_3L_3 \quad (15)$$

- Subject to conditions:

Law of conservation of energy

$$\delta_4 = 0 \quad (16)$$

$$1.64\, X10^{-5}(\delta_4 - \delta_1) + VA_1L_1 = 0 \quad (17)$$

$$0.02164\ (\delta_4 - \delta_2) + VA_2L_2 = 0 \quad (18)$$

$$0.0374(\delta_4 - \delta_3) + VA_3L_3 = 0 \quad (19)$$

Power transmitted through each line

$$-0.23 \leq 1.64X10^{-5}(\delta_4 - \delta_1) \leq 0.23 \quad (20)$$

$$-0.4 \leq 0.02164\ (\delta_4 - \delta_2) \leq 0.4 \quad (21)$$

$$-0.4 \leq 0.0374(\delta_4 - \delta_3)\ \leq 0.4 \quad (22)$$

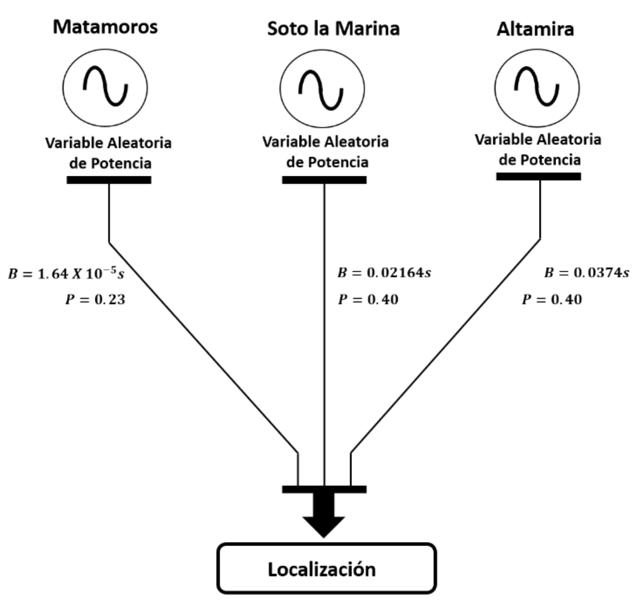
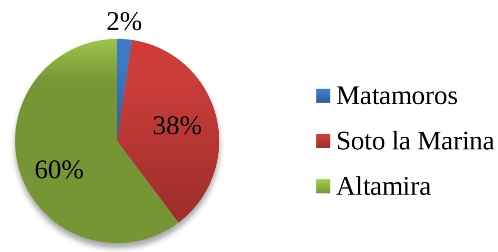


Figure 3 Approach of the proposed problem of the Economic Dispatch
Source: Own authorship

Conclusion

For purposes of this work, the modifications that were made to the economic dispatch show an optimal solution, and the use in the region is viable.

When running the problem of linear programming 385 times because the sample size was determined at a confidence level of 95%, with random power variables with Weibull distribution, of which 9 times was in Matamoros, 144 in Soto the Navy and 232 in Altamira as shown in Graphic 4.



Graphic 4 Frequency graph of location results
Source: Own authorship

From this same graph it is observed that 60% of the runs of the proposed Economic Dispatch method, Matamoros has a better Weibull probability density curve, but it has a great restriction because the transmission line to which it connects has lower transmission capacity, compared to Soto la Marina and Altamira, which prevents the wind farm from being located in that place. This can be seen in the equations (20), (21) and (22) that indicate the maximum power transmitted through each line.

This method developed in a problem which can be adapted to any situation not only focused on wind energy, but any type of clean energy that you want to minimize.

This minimization can be considered in transmission losses, generation and / or installation costs, as well as CO_2 emissions, among others. Additionally, this study allows to be a useful tool in the efficient location of electric generators.

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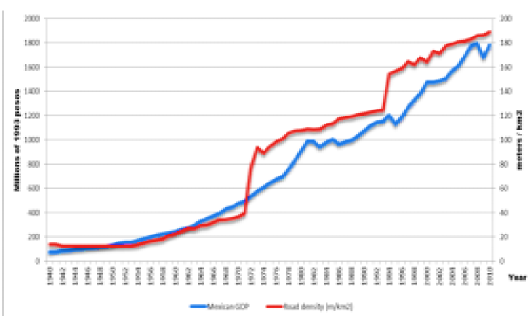

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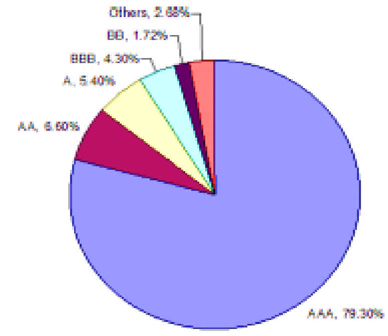

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C	Borrower may be in bankruptcy but is still paying its obligations
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