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ATTENUATION OF SOLAR RADIATION BY THE PRESENCE OF MOISTURE IN SAN LUIS POTOSÍ, MEXICO.

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A Dios

A mis padres: José Guadalupe y Dulce María

A mis hermanas María Guadalupe y Marina

A Juan José

A mis abuelitos

A mi familia

A mis amigos

El mejor regalo que me dio la vida son ustedes. Gracias por ser las personas que más amo en la vida, gracias por ser cada día mi mayor fortaleza e inspiración, por ser mi apoyo más grande y la luz de mis días, por todo su amor, gracias por siempre confiar en mí, porque cada día soy una persona dichosa y afortunada por tenerlos a mi lado. LOS AMO.

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Advanced Research WRF	**ARW**
Air Force Weather Agency	**AFWA**
Automatic Meteorological Synoptic Stations	**ESIME's**
Automatic Weather Stations	**EMAs**
Center for Analysis and Prediction Storms	**CAPS**
Deutsche Gesellschaft für Internationale Zusammenarbei	**GIZ**
Earth System Research Laboratory	**ESRL**
Economic Commission for Latin America and the Caribbean	**ECLAC**
Electrical Research Institute	**IEE**
Energy Regulatory Commission	**CRE**
Energy Secretariat	**SENER**
Federal Aviation Administration	**FAA**
Grid Analysis and Display System	**GrADS**
Institute for Federalism and Municipal Development	**INAFED**
Instituto Potosino de Investigación Científica y Tecnológica	**IPICyT**
Law of the use of Renewable Energy Transition Financing	**LAERFTE**
MATrix LABoratory	**MATLAB**
Mexican Federal Electricity Commission	**CFE**
National Aeronautics and Space Administration	**NASA**
National Center for Atmospheric Research	**NCAR**
National Center for Environmental Prediction	**NCEP**
National Commission for the Efficient Use of Energy	**CONUEE**

National Oceanic and Atmospheric Administration	**NOAA**
National Solar Energy Association	**ANES**
National Water Commission	**CONAGUA**
National Weather Service	**NWS**
Naval Research Laboratory	**ESRL**
NCAR Command Language	**NCL**
NCEP Final Analysis	**FNL**
Nonhdrostatic Mesoscale Model	**NMM**
Organization of Petroleum Exporting Countries	**OPEC**
Price Waterhouse Coopers	**PwC**
Program to promote PV systems in Mexico	**PROSOLAR**
Root Mean Square Error	**RMSE**
Secretariat of Enviroment and Natural Resources	**SEMARNAT**
Weather Research and Forecasting	**WRF**
WRF Software Framework	**WSF**

Abstract

To model the yearly evolution of relative humidity and solar radiation, the WRF Mesoscale model was applied to simulate the atmospheric dynamics in the state of San Luis Potosí for a period of one year. The principal aim is to locate areas with low and high attenuation of solar radiation by the presence of water vapor.

The knowledge of these physical processes is fundamental for a project for the generation of electricity from solar energy. Calculations were conducted to determine the distribution of daily, monthly and yearly humidity and solar energy means. Applying the methodology of the numerical modeling to calculate the relative humidity and solar radiation, maps on the attenuation were generated. Taking into account the knowledge about the efficiency of solar cells (photovoltaic cells) to generate electricity, recommendations were made of the best places for the installation of solar cell fields.

From all calculations is concluded that it is possible the generation of electricity on a scale for supplying electricity to a large number of consumers taking into account the population and the distribution of towns. The generated information establishes the feasibility of solar cell fields in San Luis Potosí.

Key words: WRF Model, Solar Radiation in San Luis Potosí, Humidity Maps

Resumen

Para modelar la evolución anual de humedad relativa y radiación solar, se aplicó el modelo de mesoescala WRF con el fin de simular la dinámica atmosférica en el estado de San Luis Potosí durante un período de un año. El objetivo principal es localizar las zonas con baja y alta atenuación de la radiación solar por la presencia de humedad.

El conocimiento de estos procesos físicos es fundamental cuando se pretende realizar un proyecto de generación de electricidad a partir de energía solar. Los cálculos se llevaron a cabo para determinar la distribución de la humedad diaria, mensual y anual y mediante energía solar. La aplicación de la metodología de la modelización numérica para calcular la humedad relativa y la radiación solar, mapas en la atenuación se generaron. Teniendo en cuenta los conocimientos acerca de la eficiencia de las células solares (células fotovoltaicas) para generar electricidad, se hicieron recomendaciones de los mejores lugares para la instalación de campos de células solares.

De todos los cálculos se llegó a la conclusión de que es posible la generación de electricidad en una escala para el suministro de electricidad a un gran número de consumidores. La información generada ayuda a establecer la viabilidad de los paneles solares en San Luis Potosí.

Palabras claves: modelo WRF, Radiación Solar en San Luis Potosí, Humedad y Mapas

Zusammenfassung

Das Ziel dieser Forschungsarbeit ist die Anwendung des WRF Mesoscale Model, um die Dynamik der Atmosphäre im Bundesstaat San Luis Potosí, Mexiko für einen Zeitraum von einem Jahr zu simulieren.

Der Endzweck dieses Vorhabens ist es Gebiete mit niedrigen und hohen Verlust von Sonnenstrahlung durch Wasserdampf zu identifizieren. Berechnungen werden durchgeführt, um die Verteilung der täglichen und monatlichen Durchschnittswerte von Luftfeuchtigkeit zu bestimmen. Die angewandte Methodik beinhaltet Berechnungen der Sonnenstrahlung aus den Ergebnissen des Models WRF. Das Hauptziel dieser Forschungsarbeit ist es, Empfehlungen für die besten geografischen Positionen für die Installation von Solarzellen im Bundesstaat San Luis Potosí, unter Berücksichtigung der Effizienz von Photovoltaik Zellen, zu identifizieren. Des Weiteren wird die Möglichkeit von Solarfeldern zur elektrischen Versorgung einer Vielzahl von Verbrauchern untersucht.

Schlüsselwörter: WRF Modell, Sonneneinstrahlung in San Luis Potosí, Luftfeuchtigkeit, Karte

Introduction

The power radiated by the sun on the planet is estimated around 175,000 TW. The energy received from the sun, is used in many ways due to the dynamics of the planet, its atmosphere, the presence of a biosphere, its high temperature (below the crust), the presence of hydrocarbons in soil, photosynthesis, etc. The solar radiation can be used in various ways some of which are: to produce heat directly into a more usable form, to be used by plants for growth by the process of photosynthesis or for inducing electrons movements in silicon cells to produce electricity (Angelis-Dimakis et al., 2011). In this sense this energy source is practically inexhaustible.

In contrast to solar radiation there is oil. The dramatic increase in oil prices and declining reserves of it has forced the industry and governments to search, in a serious manner, alternative energy sources.

Therefore the industry has led to having a demand in 2005 of about 450×10^{18} Joules. This enormous amount of energy is currently generated mainly by fossil fuel reserves (oil, gas, coal). The generation of electricity by fossil fuel reserves led to the greenhouse problem which emits CO_2 into the atmosphere. Theoretically, our planet is in thermal equilibrium with solar radiation which receives shortwave and longwave radiation emitted to space. The CO_2 found in the atmosphere absorbs part of the energy of the long wave emitted by the earth leading to an imbalance and global warming. There is debate among climate scientists. About whether the current warming is anthropogenic or of natural origin (Galicia et al., 1999).

What is certain is that based on measurements of natural climate changes, it had never seen such a rapid change in climatic parameters involved (CO_2, CO, temperature, O_3, etc.).

In this global problem, the energy radiated by the sun on our planet is extremely interesting. Solar energy is renewable, is clean and there are huge amounts of it. It is estimated that the energy radiated by the sun on our planet in one year is 14000 times larger than the total annual energy consumption on our planet by the industry and all human activities (Krauter et al., 2006).

Introduction

To produce energy is an issue that has different boundaries. For fossil energy to be used it is required 100 to 150 million years. In order to use the wood from the trees a source of energy 30 years are required on average to grow a tree. If it is used as burning biomass simply the time required is one year. Use of a hydroelectric power requires some years of construction and accumulation of water. Nuclear power is very dangerous and can cause huge environmental disasters. Wind power is always available but is small and requires large wind farms. Finally, solar power is always available in most of the planet, there are large quantities and today's technology allows a gain of between 6 and 25% of the incident energy. For this reason solar radiation is of great interest (Timilsina et al., 2012).

The use of solar energy requires knowledge of global climate, regional and local. There are weather events that originate on a global scale, others are caused by regional orographic systems and local level, it is important the influence of valleys, mountains and the biosphere. Various factors can affect the incidence of solar radiation on earth's outer covering. Some have detected that dust within the atmosphere initiated by heavy systems of wind can dramatically lessen the radiation present within the surface generated by strong wind systems can substantially reduce the radiation on the surface (Pineda-Martínez, et. al., 2011).

Water vapor is an essential atmospheric element; it is highly variable and can also reduce the incidence of solar radiation. Basically, the water vapor observed in a particular ecosystem has two origins, can be carried by the wind systems from maritime areas where it is generated by solar radiation, or is emitted into the atmosphere by biological and physical phenomenon evapotranspiration of plants. In the phenomenon of evapotranspiration, solar radiation plays a key role (Adame Miranda, 2010; Garatuza-Payan et al., 2001; Gudiño Ayala, 1995). It is therefore necessary to investigate the evolution of an annual cycle of the amount of vapor in the atmosphere and estimate the attenuation caused. In general, the solar radiation is absorbed in the atmosphere in different bands by the presence of elements such as CO_2, O_2, CH_4, NO_2 and H_2O vapor.

Each of these elements has a role in the planetary radiation balance and are investigated individually in many cases by the phenomena to which they are associated. In this paper, the main interest is the role played by water vapor in the attenuation of solar radiation in the state of San Luis Potosí. Since water vapor in the atmosphere is highly variable, it is fundamental to assess the transport generation in the biosphere due to the fact that water vapor varies within location and time in the atmosphere and its interaction with solar radiation. The transport means moving air or wind, or in other words it is necessary to know the atmospheric dynamics. It is therefore necessary to apply an atmospheric circulation model as realistically possible to consider all components that generate weather atmospheric dynamics.

The mesoscale model WRF is a next-generation mesoscale numerical weather. It has been made available to the international scientific community which has enabled to be corrected and that will add a significant amount of options in the study of atmospheric dynamics. This model is the most realistic and contains the existing method of calculating the effect of water vapor including the irradiation on the surface.

Currently, the systems used to generate energy are thermal and photovoltaic systems, it is considered one of the main factors of these systems to be economically feasible is the availability of solar energy in the surface soil so it can be converted into heat or electricity (Suri et al., 2007).

Therefore, knowledge of accurate data about solar radiation is very important for good planning and operation of solar systems. Solar radiation is the amount of energy reaching the surface in a specified time interval, expressed as W/m^2.

The technological problem of converting sunlight into electricity has made important advances. The Photovoltaic cell (PV) is the direct conversion of radiation into electrical energy. PV plays a crucial part in the field of renewable energies, is modular and can occur in blocks and has a long duration. The conversion efficiency of solar radiation into electrical energy is about 25%. But in this technological field there is a huge cost reduction potential for scientific progress

In the particular case of the state of San Luis Potosí is important to estimate the radiation reaching the earth's surface since there are a wide variety of climates and large topographic gradients. La Huasteca is characterized by a humid tropical climate.

Introduction

The Central zone, which houses the city of Río Verde has a dry climate in winter and humid in summer. The Highlands area has an arid climate and relatively humid in the summer. It is interesting in this diversity in the biosphere and the orography to investigate the attenuation of solar radiation by the presence of water vapor and the potential for generating electricity from solar radiation in all areas of the state.

Background

The tables1, 2, and 3 present the major events of the measurement of solar radiation in Mexico.

Table 1: Significant events of solar radiation in Mexico I.

YEARS	EVENT
1911-1917	Dr. Ladislao Gorczynski starts solar radiation measuring standards in Mexico City.(Estrada et al. 2005; Muhlia, 1990)
1923-1928	The SMN, Mexico's National Weather continues performing direct solar radiation measuring, led by Dr. Gorczynski and using an Armstrong electric compensation phirheliometer. Some reports are still kept at the SMN (NWS in English) (Estrada. et al., 2005)
1911-1928	Russian researcher, Ladislao Gorczynski performed measurements with the objective to of knowing solar surface radiation characteristics. He performed them in Tacubaya. He used a thermal battery as a sensor the he designed himself (UNAM, 2011b)
1956	UNESCO promotes through the Institute of Applied Sciences, solar radiation measurements (Diffuse, global, and direct).This was possible thanks to the donation of several countries participating in the International geophysics' year celebration. The results received international approval due to the acquisition of a master phirheliometer and a standard one as well. (UNAM, 2011b)
1957	UNAM's (Mexico National Autonomous University) physics institute, the institute of applied sciences, and the International geophysics institute initiate again with the solar radiation measurement tasks as they install five solarimetric stations in different states, one of them being in UNAM(Estrada, 2005)
1960	In San Luis Potosí, a solarimetric station was installed, which later stop working (Estrada, 2005)
1970´s	The SMN through some weather stations installed heliographs and piranographs, but these were not calibrated, so it was not possible to process the information.
1979	A network of four station was put in service. The data obtained was not trustful due to the quality of the measurement instruments (Estrada, 2005)
Años 80´s	CFE, Mexico's Federal Electricity Commission (Comisión Federal de Electricidad) created a network of 20 solarmetric stations located in hydrologic basins but did not keep neither good calibration nor information processing measures (Estrada, 2005)
1990	CIE, UNAM's Centre of energy investigation (Centro de Investigaciones de Energía) starts evaluating solar energy resources. (Quiñones Aguilar, 2002)
1992	UdeS (Sonora State University) performs solar resource evaluations. and executes an energy driven Project called "Estación Solarimetrica de la UdeS" to cover the needs of solarimetric data that were not constantly and consistently available.. (Villa Martínez et al., 2001)

Source: Own Elaboration.

Table 2: Significant events of solar radiation in Mexico II.

YEARS	EVENT
1996	- Thanks to the Tarpley method, isoline maps and daily average radiation tables were elaborated for each state and month. - In the ITESM, Monterrey's Tech-Mexico City campus (Instituto Tecnológico de Estudios Superiores de Monterrey), the first place for type "A" and "B" ultraviolet measurement location was installed (SMA, 2003)
1997	Starting from the UV radiation measurements obtained from the REDAS, the National Network of Solar Radiation (Red Nacional de Radiación Solar), every hour the solar radiation index, type UV-B is registered and shared. (SMA, 2003)
Since 1997	The solar radiation observatory calculated de UV band type "B" solar radiation and, through three daily measurements it was known the ozone concentration found in the stratosphere.(UNAM, 2011a)
2001	- Proposal by the UNAM geophysics institute to create a national database using an internet server. - Pérez suggests that the use of models is useful since there is a lack of land measurement information along many regions in the country. This lack of information does not allow a thorough evaluation of the results that have been obtained with the models.(Perez et al., 2002)
2003	Through REDRAS, information about Mexico City UV radiation is collected.(SMA, 2003)
2006	- In Mexico, the CFE had 20 piranographs and 6 piranometers, all of them without being calibrated. - The Secretary of Marine, had 10 piranographs and 10 - heliographs without being calibrated. - RAMA, the Environmental Monitoring Automated Network (Red Automatizada de Monitoreo Ambiental) (RAMA) had five referenced piranometers and it focused in UV and active photosynthetic radiation measurements.
2011	- UNAM's Geophysics' Institute proposed projects regarding solar radiation such as: Solar climatology through satellite images and one project to calculate available energy for Mexico City in December of 2011.(UNAM 2011b) - 4 stations belonging to REDRAS were installed to measure global total radiation as well as an equipment to measure active photosynthetic radiation.(SMA, 2003) - Solar Energy Project entitled "Agua Prieta Solar Field 2" by Dr. Rafael López Cabanillas (Urquijo, 2011)

Source: Own Elaboration.

Table 3: Significant events of solar radiation in Mexico III.

YEARS	EVENT
2011	- A project is proposed by the SENER and UNAM to calibrate solar radiation sensors Mexico because no reliable data were available.(El Universal, 2012b)
2012	- Dr. Mauro Valdés and his team calibrated and changed 48 piranometers out of 133 meteorological stations (EMA's) to guarantee the accuracy of solar radiation obtained data. (Velázquez Carranza, 2013) - UNAM's Geophysics Institute studies the solar radiation attenuation processes in the atmosphere and its spatial and temporary quantification.(El Universal, 2012a)
2013	- Today, researcher Mauro Valdés coordinates a project to calibrate earth located SMN stations that measure solar radiation and develops models to measure solar radiation based on atmospheric factors. The objective is to analyze UV radiation, luminosity and ultra-red spectral components. (Velázquez Carranza, 2013; UNAM, 2013) - Mexico does not have a solar radiation database per kilometer square. A project titled "National Solar Resource Inventory" is planned under CONACYT and that will have as objective to identify the most appropriate zones for the installation of solar technology. This projects aims at measuring direct and diffuse radiation, luminosity, UV radiation, aerosol optic depth and solar radiation in inclined planes based on its own models (Olivares Alonso, 2013; Terra, 2012) - As a first phase, a regional map of the country divided in 6 classifications was developed. The map was based in vegetation, radiation, cloudiness, weather, albedo, geology, along with other variables (Velázquez Carranza 2013; Terra, 2013)

Source: Own Elaboration.

As shown in Tables 1, 2, and 3, the progress that has been provided regarding the radiation measurements in Mexico has been slow because it has not yet solar maps of most of the states. It is of utmost importance to conduct evaluations and studies for the solar resource in Mexico. It is noteworthy that this is the first time it is evaluated the solar resource in San Luis Potosí using WRF model.

Objectives

General Objective

To know the distribution and concentration of water vapor in the state of San Luis Potosí in an annual cycle, by using the model WRF and the software's Grads and matlab in order to determine the attenuation of solar radiation by this physical parameter. With the knowledge of the evolution of water vapor in a year and the corresponding attenuation of solar radiation, it is discussed the viability of solar cell fields for the generation of electricity, i.e. applying a methodology of renewable production of electric energy.

Specific Objectives

- Identify areas with high and low attenuation of the solar radiation using the WRF model.
- To determine whether the generation of energy from solar cells is important and economically feasible in areas of the state where attenuation is greater.
- Prepare maps of monthly means distribution of water vapor to know and correctly calculate the period of highest and lowest concentration of vapor.
- Prepare maps of monthly means distribution of solar radiation to estimate the places where the radiation on the Earth's surface is high and low.
- Prepare maps of annual means distribution of water vapor and solar radiation.
- Locate the places with higher and lower solar radiation solar in San Luis Potosí.
- Provide recommendations on the construction of solar cell fields based on the results obtained for the generation of energy in areas most favorable and areas not so favorable.

1 Theoretical Framework

1.1 General Concepts

1.1.1 Solar Radiation Definition

Solar radiation consists of wide spectrum of electromagnetic waves that are emitted by the sun. Electromagnetic waves are divided into different frequencies ranges (visible light, infrared and ultraviolet, radio, gamma, and so on). The sun emits from the photosphere radiation at a temperature of about 6000 K. The total emitted energy by the sun is about 3.8×10^{26} W. This energy is produced in the nucleus of the sun by thermonuclear reactions of hydrogen into helium at estimated temperatures of 1.5×10^{6} K. The reaction is $4\,{}_1^1H \rightarrow {}_2^4He + 2\beta + energía(26.7Mev)$ (Ambient Weather, 2013; Ask, 2013; Gudiño Ayala, 1995).

This energy is produced in the nucleus of the sun by thermonuclear reactions of hydrogen into helium at estimated temperatures of 1.5×10^{6} K. The reaction is $4\,{}_1^1H \rightarrow {}_2^4He + 2\beta + energía(26.7Mev)$.The solar radiation that reaches the earth is measured through the irradiance. Irradiance is the power per unit area that arrives at a surface, the unit of measurement of the irradiance is W/m^2.

Solar radiation can be measured directly using Radiographers (Pyranometers, Heliometers) which is capable of measuring both direct sun and diffuse light or indirectly by using mathematical models or meteorological (AIDA, 2011). Solar radiation is therefore a dynamic phenomenon that change through the time. It is energy that incident on a surface instantly.

1.1.2 Types of Solar Radiation

Solar radiation entails a complexity that goes through distinct levels of transformation upon its passage through the atmosphere. Therefore, it is necessary to discuss the specific concepts pertaining to the different types of radiation (Gudiño Ayala, 1995):

- Direct Radiation: It is the product of radiation that the atmosphere receives directly from the sun. It is radiation in its purest and most direct form.
- Diffused Radiation: It is the product of interferences from things within the atmosphere, such as clouds and the blue sky with the absence of this type of energy, the appearance of the sky would be black.
- Terrestrial Radiation: It is from terrestrial objects. For example reflecting a white wall or floor.
- Global Radiation: It is essentially the sum of both direct and diffused radiation
- Total Radiation: Total radiation entails the total sum of direct, diffused, and terrestrial forms of radiation that are received by way of one surface. Examples can be a wall or a window.

1.1.3 Energy Balance of the Earth

Out of the atmosphere the earth receives a solar power of $15x10^{17}$ kWh yearly. Once the radiation passes through the atmosphere, the planet receives an average amount of $3x10^{17}$ kWh per year, representing 20% of the incoming solar power (Nandwani, 2005) which is still a large amount of solar energy that could supply roughly 4000 times the world consumption in a year.

The loss of radiation is caused when it is crossing the atmosphere because it loses about 53% of the radiation that is reflected and absorbed the substances present in the air, mainly water vapor, oxygen, CO_2, nitrogen, dust clouds and aerosols. A representation of this is shown in Figure 1.

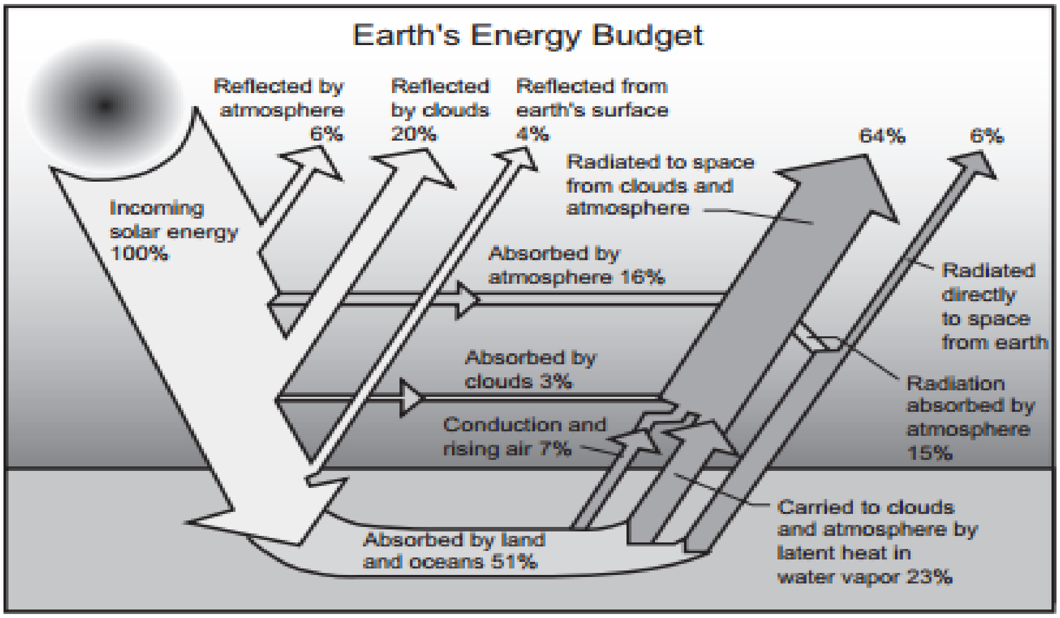

Figure 1: Components of the energy balance of the earth.
Source: Petty, 2006

As indicated by Petty in 2006, the Earth's energy balance occurs through a series of exchanges between land and atmosphere. The Figure 1 shows the scheme of Earth's Energy Budget. About 70% of the energy is absorbed by the earth, approximately 16% of this energy is absorbed by the atmosphere, 3% is absorbed by clouds and the rest is absorbed by the oceans and land. The missing 30% is reflected back into the space. To maintain the equilibrium, the Earth hat to emit to the space a similar quantity of energy, but since the Earth´s temperature is much smaller than the sun the emission occurs in long waves. About 64% of the absorbed energy by the Earth is emitted to space by the atmosphere and clouds. Approximately 6% is emitted by the Earth directly to space. Another form of energy is transferred via water vapor, i.e. latent heat. Other forms of energy transfer are by conduction and radiation absorption. 23% of the radiation reaching the Earth´s surface is affected by water vapor and clouds with water vapor playing a crucial role in attenuation of attenuation. This is the principal reason to investigate the attenuation of solar radiation in a yearly cycle.

1.1.4 Spectral Irradiance

As mentioned Gudiño Ayala (1995), the range of the electromagnetic spectrum is very wide, extending from gamma rays to radio waves. However, solely for purposes of harnessing energy is used the thermal radiation within it includes ultraviolet (UV), visible radiation (VIS) and infrared radiation (IR). The temperature is directly proportional to the intensity of solar radiation and at higher temperatures shorter wavelength of bodies that are within the electromagnetic spectrum subsequently is visible radiation and finally the infrared radiation.

Spectral irradiance is the energy per unit time in the unit area per unit wavelength all the above depending on the wavelength (Gudiño Ayala, 1995). The spectral distribution is shown in Figure 2.

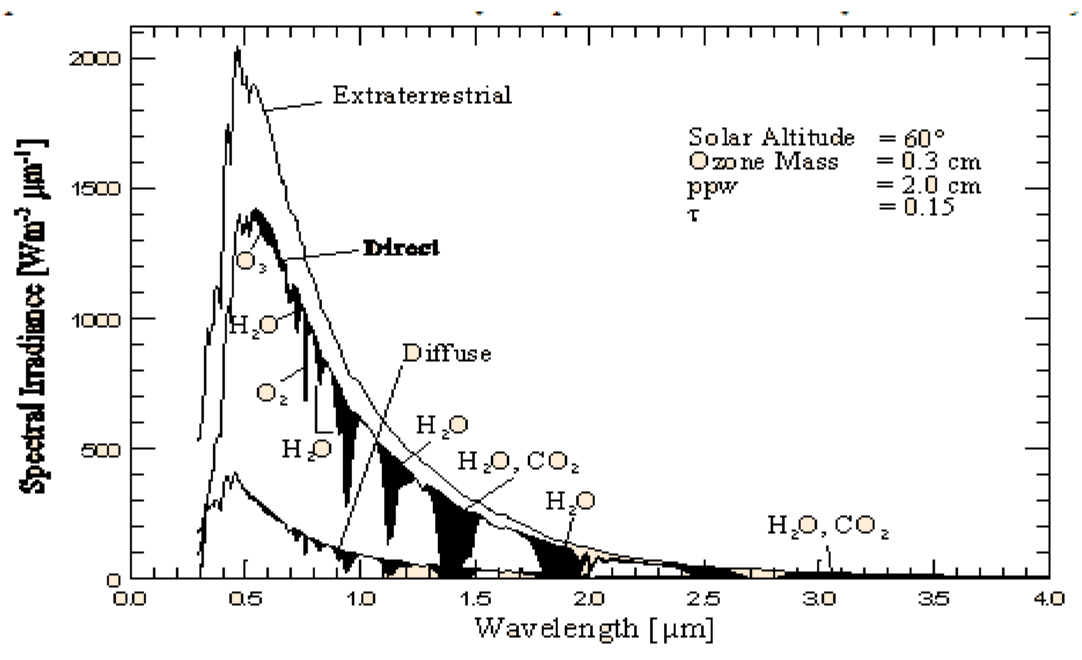

Figure 2: Spectral distribution of direct and diffuse radiation and attenuation due to atmospheric factors.
Source: EUMETCAL, n.d.

The upper curve shows extraterrestrial radiation reaching the top of the atmosphere. Below is the curve of direct radiation attenuation. The graph shows that the water vapor is a major component of attenuation as it traverses across the spectrum beginning at the 690nm (EUMECAL, n.d.)

On cloudy days diffuse radiation is higher than direct radiation instead on clear and cloudless days direct radiation is higher than the diffuse (AIDA, 2011).

1.1.5 Atmospheric Transmittance

An important concept in relation to the solar radiation is the transmittance. The atmospheric transmittance is the percentage of solar radiation passing through the atmosphere at a given wavelength. The atmospheric transmittance is represented as a specific set of regions of the electromagnetic spectrum, each with different wavelengths ranges. The Figure 3 shows the bands and atmospheric transmittance regions (Miguélez, 2002).

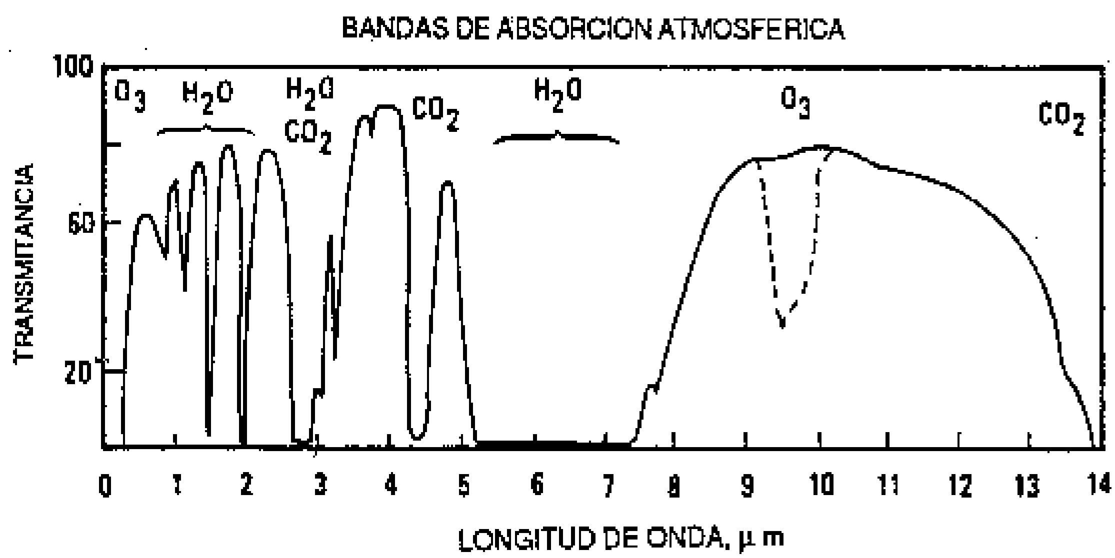

Figure 3: Atmospheric transmittance.
Source: FAO, 2013

1.1.6 Factors That Affect Atmospheric Transmittance

The atmosphere can be seen as a selective filter with different wavelengths. There are physical processes that affect the atmospheric transmittance, and they do not allow a transmittance of 100% (Miguélez, 2003; Castellanos et al., 2009; Hernández, 2011; FAO, 2013):

1.1.6.1 Absorption

Solar Radiation transfers energy to the particles of the atmosphere, increasing the kinetic energy (translational, vibrational and rotational). It has entered the atoms excitation by electromagnetic radiation. These particles can be molecules of dust, gases, and water droplets. Absorption causes the attenuation of solar radiation. Every time a gas absorbs radiation originates internal molecular movement which macroscopically causes an increase in temperature.

1.1.6.2 Dispersion

Occurs when particles of the atmosphere reflect back the solar radiation. The dispersion shows no absorption but it causes an attenuation of solar radiation because radiation is redirected. Hence, a photon meets an obstacle without being absorbed, changing only the direction of travel. This action is known as dispersion. The degree of dispersion is dependent on the transmissivity of a wavelength. The dispersion of large wavelengths is smaller. Very small gas molecules, compared to the wavelength. It causes that solar radiation is dispersed in all directions (back and forth). This phenomenon is known as Rayleigh scattering. The Rayleigh scattering is significant only for short waves (=0.6nm) having little effect on atmospheric transmittance.

1.1.6.3 Albedo

The albedo is the fraction of the total incident radiation that is reflected into space. This fraction is represented in percentage. The albedo is variable depending on several factors (terrain, clouds, slanting rays, moisture, etc.). Approximately 30% of the energy is reflected at a global level. The albedo energy is lost to space and is not involved in the heating of the atmosphere. In places with few clouds the albedo is low. In desert areas, the albedo is high and it reaches values of about 40%. In polar region, the albedo varies depending on the distribution of ice sheets and solar elevation angle. In sites with presence of high humidity, radiation is strongly absorbed and it has an influence on its surface. Usually areas with dark surfaces reflect less than clear surfaces.

1.1.7 Atmospheric Components That Attenuate Solar Radiation

Solar radiation before touching the surface of the earth passes through the Earth's atmosphere in which attenuation occurs affected by both the height position of the sun and atmospheric components. The main atmospheric components that attenuate solar radiation are:

- **The water vapor (H_2O):** It has different absorption bands that are located within the range of 0.7 µm to 8 µm (Pinilla Ruiz, 2007). It is considered the main atmospheric absorber, since it absorbs about 5 times more terrestrial radiation that all gases and it causes in the troposphere a temperature increase (Castellanos et. al., 2009). It is measured by a parameter called condensable water or water thickness. Water thickness is the thickness of the layer of liquid water (at ground level) condensing the water vapor contained in a vertical column of a certain unit area and unit height of the atmosphere and is expressed in cm. Water vapor absorbs infrared radiation or long wave, which is emitted by the Earth and helps to maintain the energy balance of the Earth. Within wavelengths of 5.7 to 7.1µm the absorption of water vapor reaches 100% (Miguelez, 2003).
- **Carbon dioxide (CO_2):** Is a gas with a greenhouse effect. The atmospheric temperature maintenance depends largely on the CO_2. CO_2 is a greenhouse gas (Pinilla Ruiz, 2007) Because it absorbs radiation in the infrared band emitted by the Earth. Most of the CO_2 absorption band turns around 15 µm (Miguelez, 2003) . The weaker peak is located in the 4 µm range.
- **Oxygen and ozone:** Absorbs radiation in the ultraviolet band range (0.1-0.3 µm) and in the microwave region (Pinilla Ruiz, 2007). Ozone absorbs the radiation in

the stratosphere. The solar radiation varies but hardly affects the ultraviolet band of the spectrum which is the most intense energy (Perez et al., 2002). Ozone is primarily responsible for ultraviolet absorption and provides the energy that heats the stratosphere and mesosphere.

- **Aerosols:** Aerosols are dominantly solid particles suspended in the air. The aerosols cause scattering and absorption effects: Increase brightness on dark surfaces and decrease the brightness in light surfaces (Pinilla Ruiz, 2007).Its content is measured in particles per unit volume. They can be terrestrial (pollen, dust, smoke, ash, etc.) or they can have a marine origin as the salt crystals. Aerosols exhibit the phenomenon of Mie scattering, because their sizes exceed the wavelengths of radiation.

1.1.8 Additional Factors That Attenuate Solar Radiation

According to Hofierka (2002) there is a direct relationship between the geometry of the earth and solar radiation reaching the surface. This relationship is obtained using mathematical and astronomical calculations. Another important factor that determines the amount of solar radiation is the terrain. That is, characteristics like the shadow, latitude, altitude, inclination of where they want to know the present solar radiation. An example of this is the elevation above sea level of a site, since it is known that the attenuation of solar radiation varies depending on the altitude by the effect of the thickness of the atmosphere.

Solar energy also depends on the rotation, translation of the earth around the sun, ie other factors that influence their attenuation are the seasons of the year and the position of the place on Earth (AIDA, 2011) .

1.1.9 Relative Humidity Definition

Relative Humidity is the relationship between the amount of water vapor in the air and the amount of vapor that may contain if the air were saturated at the same temperature. It is expressed in percentage (%), and the relative humidity has a direct effect on the interactions that take place in the atmosphere such as solar radiation

1.2 Weather Research and Forecasting (WRF) Model

The use of weather forecasting models to simulate the atmospheric circulation, Earth's climate and the evolution of variables like the relative humidity has increased recently. It is expected that these models be able to calculate the requirements for the provision of solar radiation for up to 72 hours. The problem of various models of numerical weather prediction is that they generally have a low resolution that does not allow giving a detailed mapping of small-scale features (Skamarock et al., 2008).

The Weather Research and Forecasting (WRF) model, like MM5, is a numerical weather prediction (NWP) model to help simulating historical weather events and prediction of events, allowing the analysis of data on a global scale or resolutions smaller than 1 Km (Morales & Sepulveda, 2012). It is used both for research applications and for operational applications. Its main applications are:

- Education (it is accepted as a tool in many universities)
- Research and development in data assimilation.
- Advancement in the weather forecast.
- Operational implementation for prognosis in different scales.
- To perform a global modeling of the atmosphere.
- Research and development of new parameterizations (The code allows easy incorporation of new schemes)
- Ability to model air chemistry
- Regional climate simulations and real-time simulations
- Modeling air quality
- Research with physical parameters
- Predictions and Idealized simulations

The model is used around the world. This model is mainly developed by the Mesoscale and Microscale Meteorology Division of NCAR. However, many researchers, institutions and agencies around the world are performing work together to develop a a mesoscale forecast model of last generation and the development of data assimilation system, data compression, prediction of weather data, implementation of new parameterizations and other improvements to mesoscale and microscale levels. Therefore, it is considered as a “community model”.

According to Skamarock et al. (2008), the main institutions responsible for its development are: National Center for Atmospheric Research (NCAR), National Oceanic and Atmospheric Administration (NOAA), National Center for Environmental Prediction (NCEP), Earth System Research Laboratory (ESRL), Air Force Weather Agency (AFWA), Naval Research Laboratory (ESRL), Air Force Weather Agency (AFWA), Naval Research Laboratory (NRL), Center for Analysis and Prediction Storms (CAPS) and Federal Aviation Administration (FAA).

It is considered a model flexible that can be installed on a wide range of environments. The WRF model is free and can easily be downloaded directly from the website of NCAR.

1.2.1 WRF System Components and Parameterization

As referred López Mendez (2009) and Hernández Ceballos (2011), the model works through four fundamental steps (Figure 4) necessary to achieve a simulation and obtaining output data.

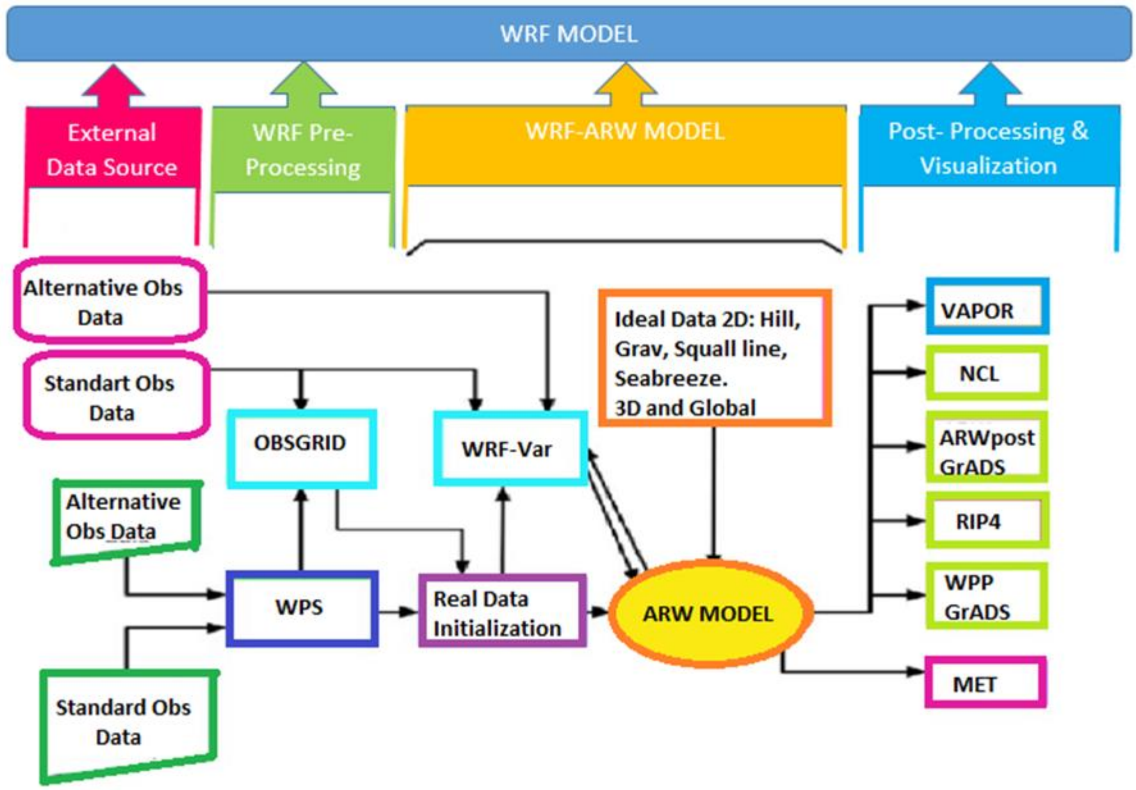

Figure 4: WRF System Fundamental Steps.
Source: Skamarock, 2008.

The first stage is the choice of the input data, the model input data are downloaded directly from the official WRF website. The choice depends on the type of study to be carried out and the region.

The second stage is the WRF Preprocessing System, which works by decoding and interpolating meteorological data which are the inputs that feed the model. The WPS also allows real simulations (the user has the option to define domains to simulate) interpolating terrestrial data to different domains. In other words at this stage is chosen study area, the interpolation of the data, characteristics of the terrain, soil, meteorological input data, and so on.

In order to get an accurate representation of atmospheric processes in this stage, is necessary select the physical parameterizations and dynamics of the region to be simulated, some of the most important parameter settings are shown in Figure 5.

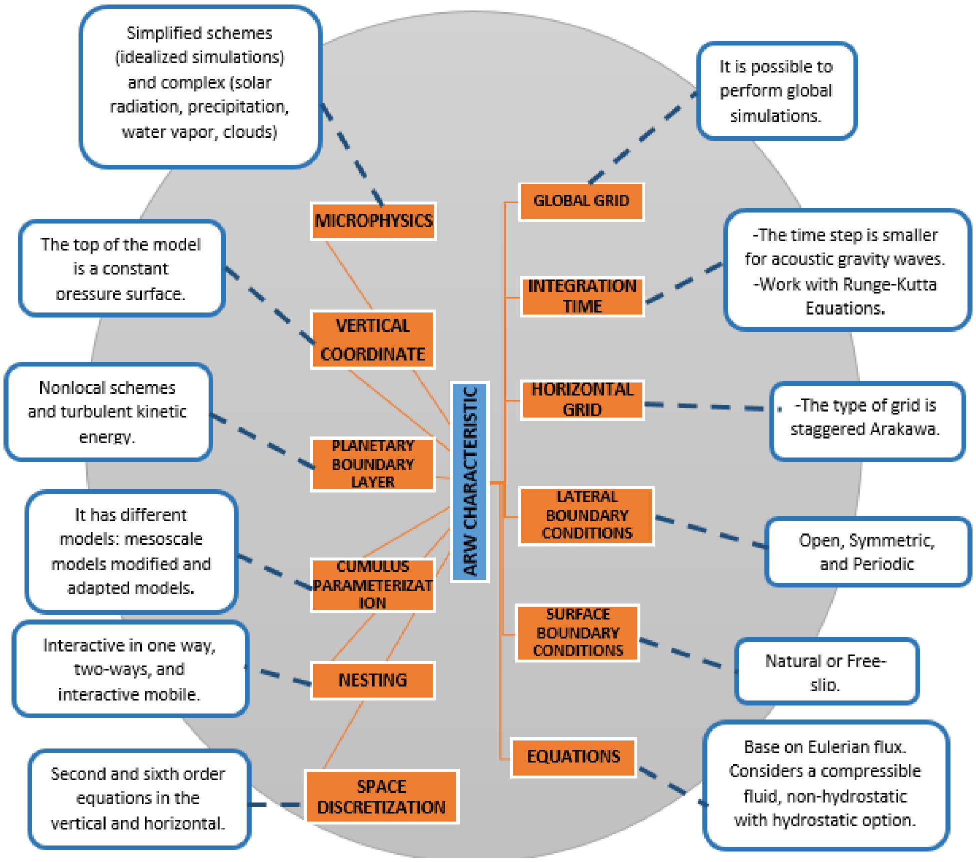

Figure 5: Description of ARW core.
Source: Own Elaboration based on López-Méndez, 2009.

The parameterizations are mathematical representations of various atmospheric processes among major within the ARW Core include (Figure 5). At this stage, meteorological and geographical output files are generated. It is worth mentioning that the number of output data generated depends on the number of domains.

The third stage is the WRF model simulation performed study area. The WRF with the input data as: the settings, the interpolations, and so on, the model executes the work packages that make up its internal structure, and through atmospheric equations, mathematical equations and the information provided as a result the simulation generates the behavior of the atmosphere.

At this stage the model has two dynamic modules each of these modules work independently and have very different characteristics as shown in Figure 6, the first one is the Nonhdrostatic Mesoscale Model (NMM) developed by NCEP. The Second one is the Advanced Research WRF (ARW) developed mainly by NCAR. The component responsible for providing the infrastructure that best fits physics and dynamics to be resolved is the WRF Software Framework (WSF), this packet through that interface with solvers, programs for initialization, WRF-Chem, among others.

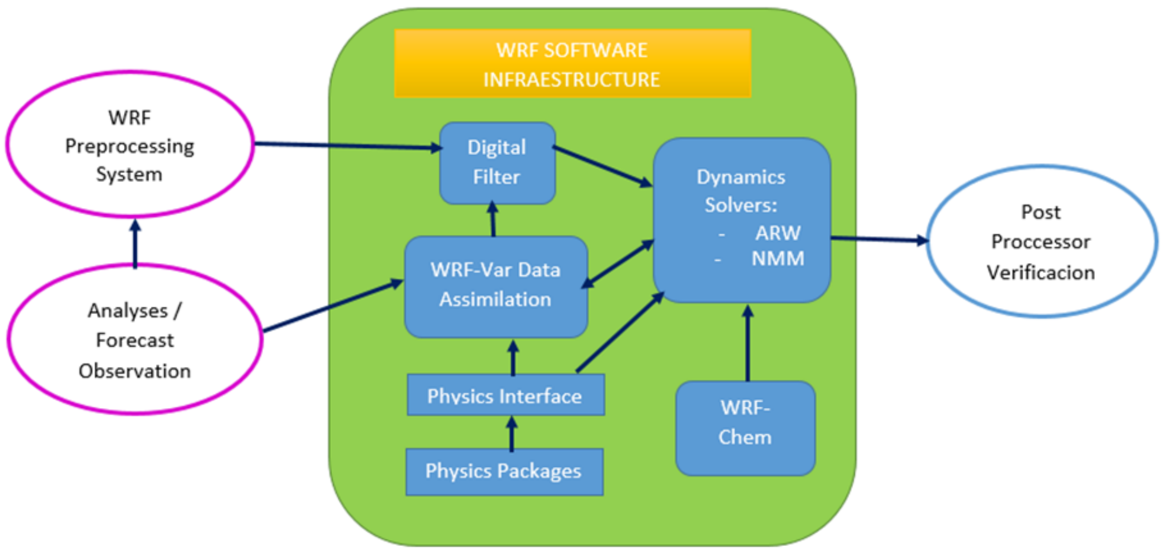

Figure 6: WRF System Components.
Source: Modified on Skamarock et al., 2008

This stage ends with the generation for each of the domains of the full set of simulated meteorological information in each of them this information is encoded in netCDF format. Once the model generates output data is initiated the post-processing stage and prognostic data visualization.

The fourth stage is the visualization and post-processing of the data, is an isolated component of the three previous and model codes, which is optional to use. There are several graphic software that may be used to display numerical simulations, Shamrock (2008) mentioned some software's as MATrix LABoratory (MATLAB), NCAR Command Language (NCL), Visualization and Analysis Platform for Ocean, Atmosphere, and

Solar Researchers (VAPOR), among others. For this thesis, the visualization software used was Grid Analysis and Display System (GrADS).

Another important component (Figure 6) that may or may not be used, is the WRF-Var. This component allows to replace the model initial conditions, performing an update of the initial conditions of the analysis by running interpolated observations that were created with the WPS (radiosonde, radar, etc.). The most significant component is the ARW, the passage from the initiation of the model, either a real or ideal simulation by integrating numerically the primary domain and nested domains.

As seen in Figure 7, it is an example of how parameterizations work. Parameterizations and physical options interact with each other and produce an estimate of the atmospheric circulation very close to the real estimate.

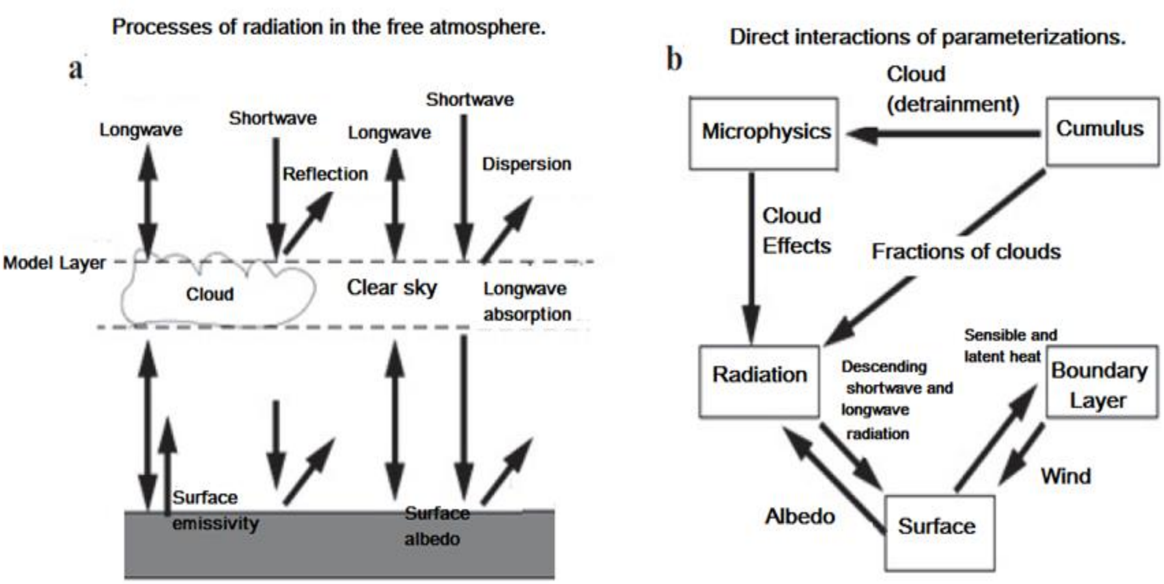

Figure 7: a) Process of radiation in the free atmosphere, b) Interaction of radiation with the parameterizations.
Source: Modified on Dudhia et al., 2005; Zavala Reyes, 2012.

Physical options interact producing an estimate of the atmospheric circulation (Figure 7), which is also very close to the real atmospheric circulation. All these tools that the

WRF has, allow to study meteorological and atmospheric phenomena such as solar radiation, atmospheric contamination, changing land use, moisture, among others.

The WRF model is a system of mesoscale numerical prediction using principles and equations.

1.2.2 Nesting

The WRF has the ability to analyze multiple domains at the same time Nesting is based on having a domain modeling with a fine mesh size, within another model domain having a larger mesh size (Dudhia et. al, 2005)

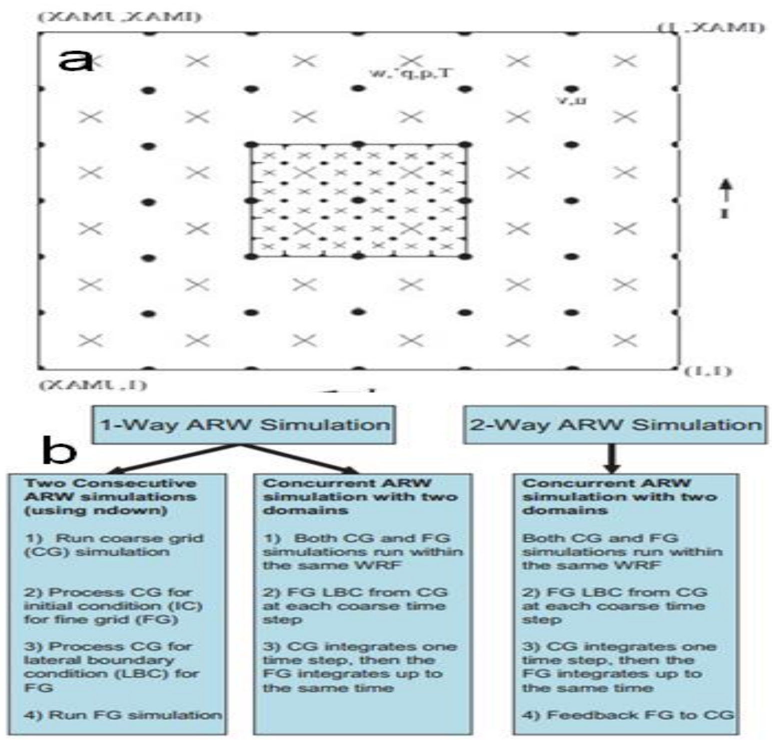

Figure 8: Representation of a): Nested horizontal grid; b): 1-way and 2-way nesting options in the WRF.
Source: Dudhia et al., 2005; Shamrock et al., 2008

There are three ways of performing the nesting between the domains (Figure 8b) (Zavala Reyes, 2012)

- One-way nesting: The interaction takes place in a sense. The WRF model first calculates the larger domain, and the output is interpolated in time and space, to feed the nested domain. The largest domain and nested domain are independent of each other.
- Two-way nesting: The interaction is two-way. Both domains (major and minor) interact, where the bulk domain introduce information to the domain nested by the border with it, while there is a feedback from the smallest to the largest domain.
- Dynamic nesting: It is performed by an algorithm that follows a vortex motion and the movements are defined by the user.

2 Current Situation of Renewable Energy in Mexico

Mexico was placed in the top ten list crude oil producers globally, in the world rankings in 2011 according to the Energy Secretariat (SENER) based on findings of the Statistical Review of World Energy (SENER, 2012d). Mexico went from the seventh global place to have a fall and placed in position number 8 as a producer of oil and in turn to occupy the 12th position in the major list of major oil exporters. It is an oil-rich country with a strong dependence on hydrocarbons and Mexico to be part of the Organization of Petroleum Exporting Countries (OPEC) has not given necessary priority to other alternative energy sources.

At present oil production in Mexico is declining in recent years as it has presented an annual fall of 4% and 5% this threatens the country's energy security. In accordance with a study by the Economic Commission for Latin America and the Caribbean (ECLAC) , where it explains that Mexico after counting in the year 1995 with reserves of 60 billion barrels of oil, came to a substantial decrease in 2010 and has only 15 billion barrels (González, 2013)

Moreover, in 2009, SENER placed in emergency range's Cantarell (the main oilfield in Mexico) because since 2005 it showed losses of 770 thousand barrels per day of production. It is estimated that by 2017, Mexico will only produce 8.4% of national production, this is only 255,000 barrels per day (Serrano Cruz, 2009).

The decrease of oil in Mexico threatens energy security and autonomy of the country due to various factors mentioned by the SENER: Symptoms of important reservoir depletion, high cost of the exploitation of hydrocarbon deposits, the discovery of oil wells is also not of great magnitude in recent years; insufficient renewable energy promotional schemes, making it difficult to attract investment (public and private) to hamper development of renewable energies.

Abuses committed to our natural resources are invested within the redevelopment of the country is a palpable example of this oil in where by the price is higher by oil decline and economic losses which also affect the lives of the population. Oil shortage is an issue because many consider oil to be an ever readily available infinite resource, when in actuality it is only finite resource. Therefore, it should plan and use the energy derived from this resource.

Abuse of natural resources also decreases the ability of the country to meet and exceed the needs present endangers the future of coming generations. Renewable sources will not only help provide some of the energy that oil fails to provide. Another advantage to using renewable energy entails helping to solve many environmental problems derived from hydrocarbons as these threaten the equilibrium and balance of the environment.

The high energy dependence on hydrocarbons in Mexico has been responsible for the later innovation and production of renewable energy within the country. Aware of the risks that such practice entails as well the depletion of oil. The current political party in power had advocated a change in the energy sources assortment through policies based on renewable energy development. It has also started an energy transition, which entails a shift in focus from the energy sector to achieve diverse primary energy sources and reduce environmental impact. Many goals set forth by the Government aim to ensure that 26% of the nation's electricity generation from renewable sources are in effect by 2016. This drive enables the government, in principle, to experience a likely scenario for renewables having a definite reputable acknowledgment within the generation of generation of electricity in Mexico (Ramos Campos, 2011).

2.1 Electrical Current Status and Renewable Energy Potential in Mexico

Among the organizations and institutions that control the energy and electricity sectors are Mexican Federal Electricity Commission (CFE) which is a federal institution in charge of planning the national electricity system. It is considered a monopoly and has a total installed capacity of 52,862 megawatts (MW). The CFE use different types of technology and power as hydro, coal power plants, geothermal plants, wind power plants, thermal and nuclear power and its main responsibilities are: the generation, control, transmission, distribution and commercialization of energy and is the largest electric company in Latin America (CFE, 2012); The SENER is responsible for designing energy policies to ensure energy supplies in an efficient and environmentally friendly (SENER, 2012b), the Secretariat of Environment and Natural Resources (SEMARNAT) which is responsible for promoting and spreading technologies for sustainable use of renewable and non-renewable resources and to manage and regulate the use of these resources (SEMARNAT, 2010); The National Commission for the Efficient Use of Energy (CONUEE) is an organism that promotes energy efficiency and is also a technical body for the use of sustainable energy; The Ministry of Social Development (SEDESOL) and the Energy Regulatory Commission (CRE) also make renewable energy projects.

According to SENER, the Figure 9 illustrates the total energy consumption in Mexico in 2011 which was 90.5% of energy use was based on oil, natural gas, and coal. The energy produced from renewable sources was 6.9%, nuclear power provided was 1.1% and coal 3.1%. This allows Mexico to be the tenth carbon dioxide generator. It is important to note that carbon dioxide is a greenhouse gas and its main source is the electricity industry.

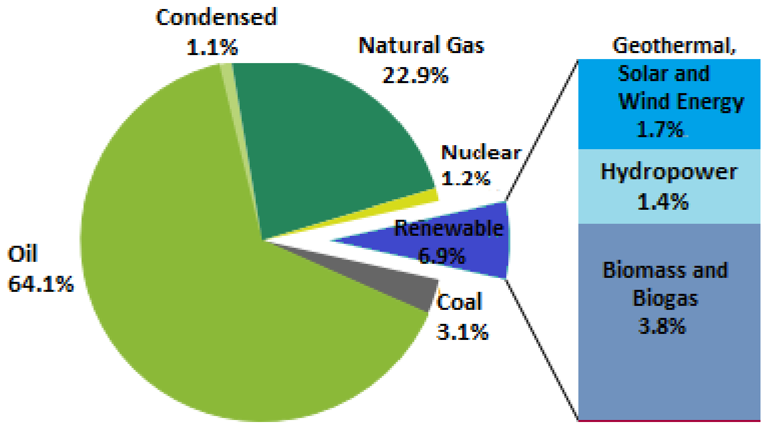

Figure 9: National Energy Balance of Mexico for 2011 is equivalent to 9190.76PJ. Modified from **Source:** SENER, 2012a.

Mexico is a privileged nation with the large amount of resources and potential for developing renewable energies. As mentioned before García Fariña (2001) the principals characteristics of the country are the Following:

- Substantial amounts of organic waste within the countryside and urban areas along with big portions of agricultural wastes
- Solar radiation in high amounts
- Resources of water for the installment of small hydro plants
- Water and steam used for the development of geothermal fields
- Locations with rough and constantly approaching winds
- Possible location used for the generation of electrical force by tides in the Gulf of California

2.2 Renewable Energy in Mexico

The types of energies that are legally which are considered to be renewable energy in Mexico are solar, hydropower (less than 30MW generations), biomass, wind, small, mini and mycro-hydroelectric stations, tidal energy, and geothermal. It is important to note that only maremotermical types of energies are beneficiaries of economic incentives. The main potential of renewable energies is listed below.

2.2.1 Small, Mini and Micro-Hydroelectric Power Stations.

Within this category are included those stations not exceeding a nominal power of 30 MW which are defined according to their ability. Micro hydro is considered if its rated power is less than 1MW; Mini Hydro power if this between 1 and 5 MW, and small plant if the plant is between 5-30 MW.

Mexico has extensive hydrological resources, this type of energy currently has a total capacity of 286.6 MW concentrated in 14 states in Mexico. There are hydroelectrics over 100 years old in the state of Mexico and Puebla. This type of energy does not cause pollution of air and water, it is flexible in operation, low maintenance, and its infrastructure lasts for several years and requires no fuel.

The CFE does not consider the hydroelectric potential of small hydro because it takes into account potential above the 40GWh/year.

Valdez Group (2006) conducted a study which states that the generation potential is about 9.79 TWh/year. This potential is the sum of 583 projects sites or take into account the analysis. There are still too few evaluations to find the national potential of this type of energy.

2.2.2 Geothermal Energy

According to the SENER (2010) the CFE had 38 geothermal power plants that are in operation in 2011. Most of them are located near the northern city of Mexicali, within the state of Baja California and generate 645 MW, which represents 72% of the current installed geothermal capacity in Mexico. The other 28% consist of Michoacán state (191.6 MW), Puebla state (4MW) and Tres Virgenes that is located in Baja California Sur state (10MW). The thermal reserves are divided into three types (Figure 10) as shown below:

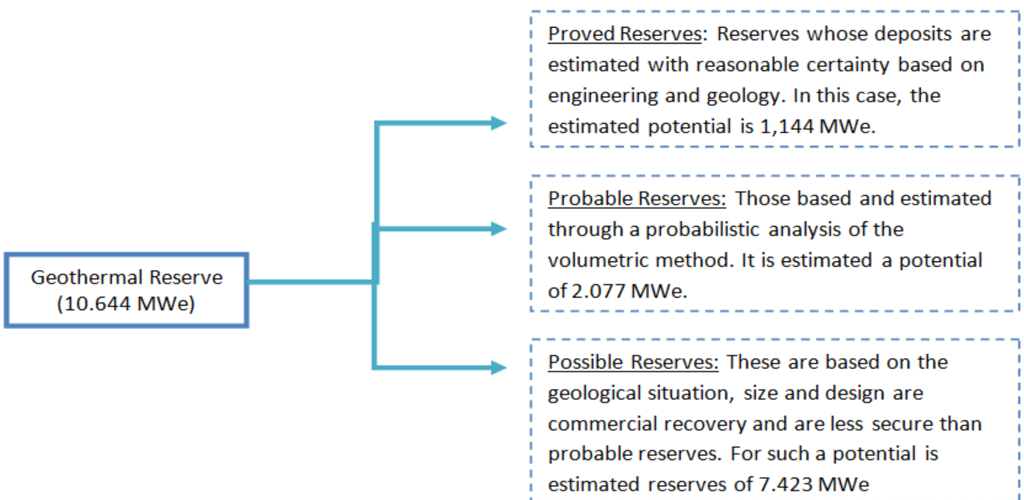

Figure 10: Areas with Geothermal Potential.
Source: Own elaboration, based on SENER,2012c.

The CFE has identified geothermal projects (Figure 11), which are currently under study with a capacity of 434.1 MW.

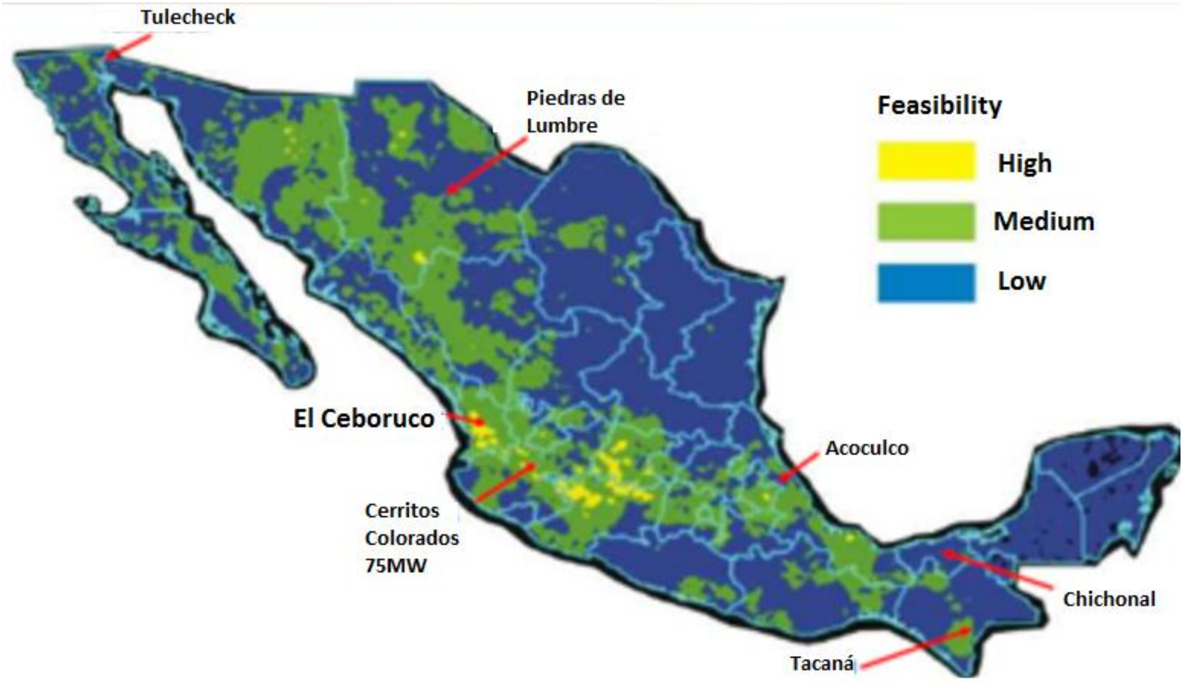

Figure 11: Areas with high potential geothermal.
Source: Modified from REDEREQ, n.d.

As Solano (2008) mentioned, Mexico occupies the third place worldwide in geothermal power generation, with the installed capacity is able to supply electricity for a city of one million people. A renewable energy source of 1000 megawatts may prevent an annual emission to the atmosphere of 800 tons of air pollutants and 3.5 million tons of CO_2.

According to a study conducted by Price Waterhouse Coopers (PwC) geothermal potential was estimated at 10,000 MW nationwide using existing information and technologies. A projection of 2,200 MW generated by geothermal plants is expected by 2020 (SENER, 2012b). This potential could have an impact of 95.4 billion Mexican pesos, 117.3 billion Mexican pesos of investment and could reduce 13% of the daily imports of natural gas, capturing 14% of CO_2 emissions and generate 36.700 direct and indirect jobs.

The database of the Electrical Research Institute (IIE), 2332 includes geothermal manifestations in 29 states. The four most exploited geothermal fields are Sulphurs with188 MWE, Cerro Prieto with 720 MWE, Los Flue with 40 MWe and Three Virgins with 10 MWe (Adame Miranda, 2010).

2.2.3 Ocean Energy

Currently, Mexico lacks pilot project or commercial development of electricity generation plants in operation by tidal energy, only ocean power prototypes are in existence. despite the country's reputation of possessing a big tidal potential in California's Gulf where it could be possible install 26 GW and have a production of 23,000 GW per year which would represent the complete production of all current hydropower plants of the country (SENER, 2010).

2.2.4 Wind Energy

Arenas (2006) conducted the numerical modeling of the wind circulation in the region of Tehuantepec Isthmus for one year. He estimated the zones with high wind speeds and calculated the potential of the region for the generation of electrical energy.

Wind Resource Atlas of Oaxaca estimated that 7.3% of the state with wind resource potential greater than 400 W/m2 (Saldaña Flores & Miranda Miranda, 2005) It was evaluated only a small portion of the country there are several preliminary wind maps some of them of: San Luis Potosí, Oaxaca, Guanajuato and other states. The disadvantage is the results of the maps being not approved or it measurements are not calibrated to the earth. The Electric Power Research Institute is working on a wind map with a resolution of 5x5 Km (Adame Miranda, 2010). The Figure 12 shows a preliminary wind map:

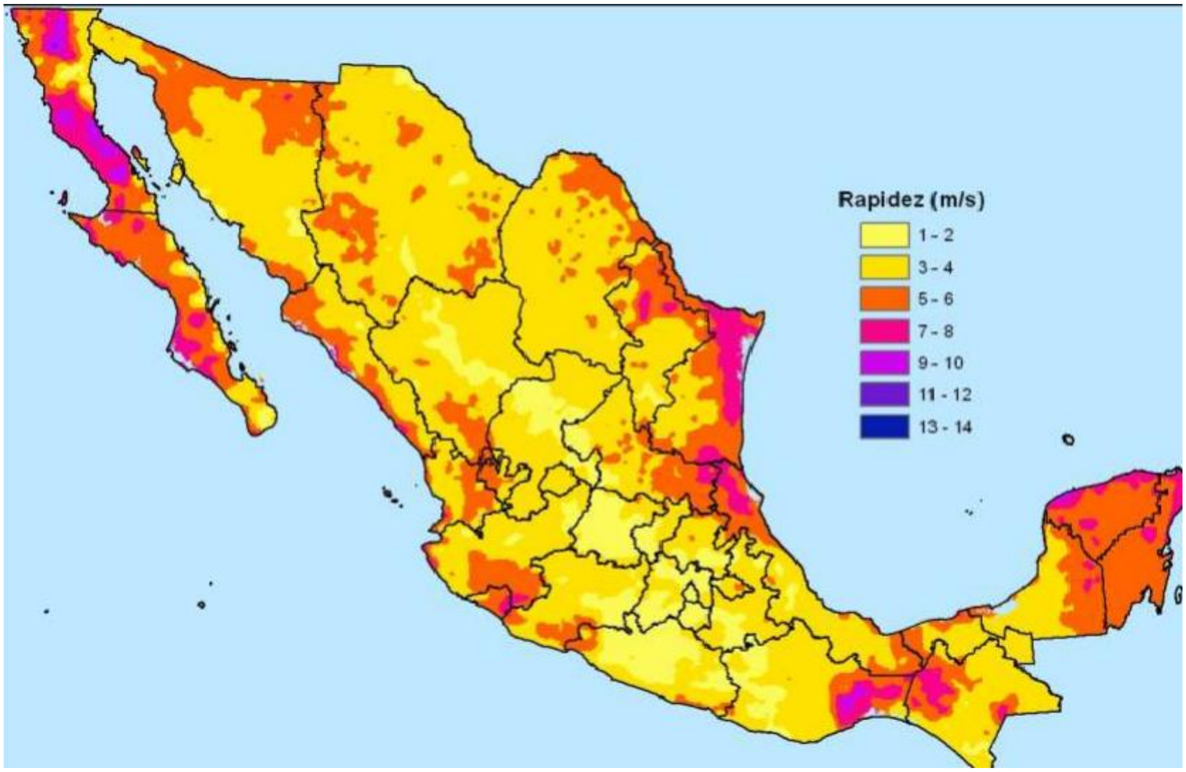

Figure 12: Wind Distribution in Mexico to 50 meters high.
Source: Adame Miranda, 2010.

The total capacity of power generation through wind energy in 2011 was 86.8 MW plants from La Venta (Oaxaca) with 84.7MW, Guerrero Negro (Baja California Sur) with (0-6MW) and COP16 generator (1.5MW). That same year he was granted 27 permits for wind power generation for various modalities (small production, independent producer, exporting, auto supply). Most projects are located in the state of Oaxaca. It aims to exploit the Isthmus of Tehuantepec region because it has the greatest potential. Greater potential is estimated at 40,000 MW.

2.2.5 Solar Energy

Mexico is a very diverse country that has a great potential of renewable resources due to its geographic location and its various ecosystems has very good and very high solar irradiance in most of the country (IEE, 2011). As seen in the Figure 13, the state of San Luis Potosí is located in zone II, which is a convenient location with average of 4.7 to 5.8 kWh/m^2.

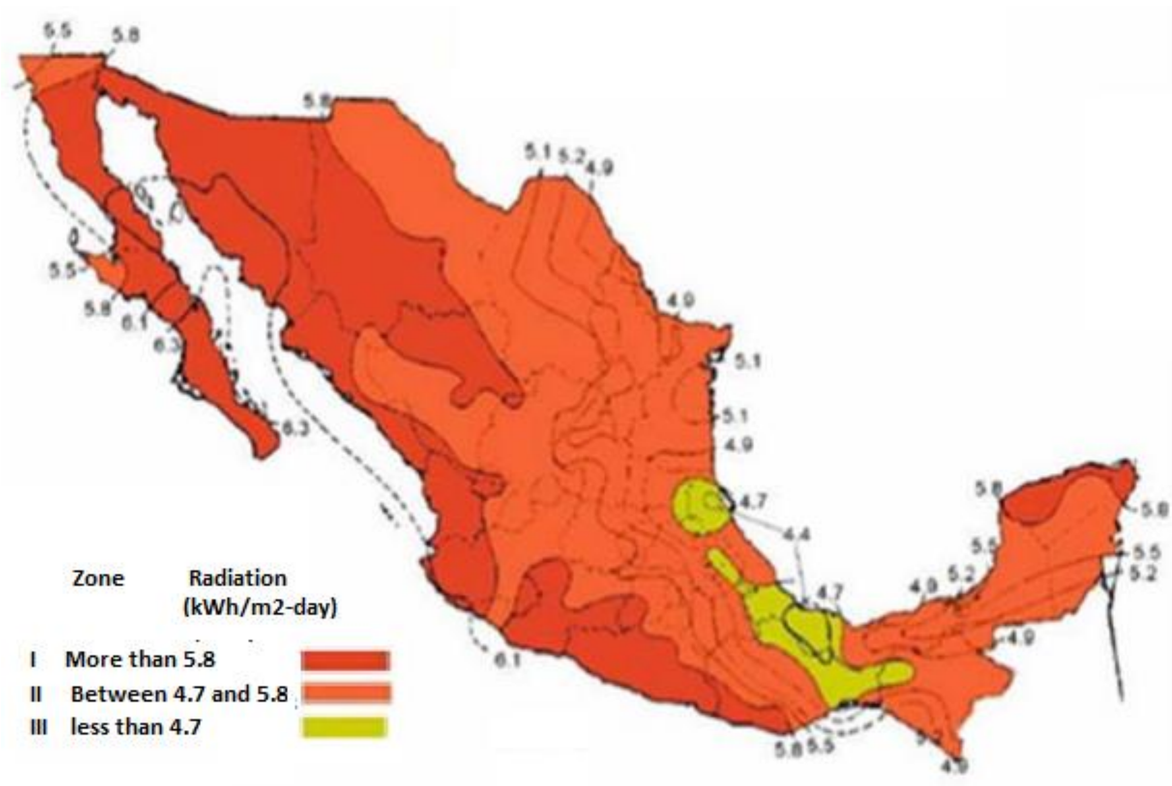

Figure 13: Average daily solar radiation in Mexico.
Source: IEE, 2011.

Each year, the National Solar Energy Association (ANES) does an energy balance of the energy capacity installed in Mexico that makes use of solar energy. Installed. The table 4, shows the installed power in 2010:

Table 4: National Mexican Solar Balance 2010.

National Energy Balance 2010		
Renewable Energy Type	**Characteristic**	**Final Use**
Solar Radiation	**SOLAR HEATING** **Total installed area in 2010:** 272,580m^2 **Total accumulated installed area in Mexico in 2010:** 1,665,502 m^2 **Average solar radiation:** 20,880 kJ/m^2 per day. **Useful heat generation: 20.880 kJ/m^2**	Water heating for swimming pools, hotels, sports clubs, residential homes, hospitals, agriculture and industries.
	PHOTOVOLTAIC MODULES **Total installed capacity in 2010**: 3.502 MW **Accumulated total capacity in 2010**: 28.62 MW **Average hours of insolation**: 5.8 hours/day. **Capacity factor and average sunshine hours**: 20.7%	Rural electrification, residential, water pumping, commercial, industrial. Isolated systems and connected to the electricity grid.

Source: Own elaboration modified on ANES, 2013.

2.3 Incentives

The Federal legislature of the Union in Mexico in 2008 adopted the Law of the use of Renewable Energy and Energy Transition Financing (LAERFTE), which provides several articles whose objective is to develop national strategies for the sustainable development of the renewable energy establishing programs and projects that involve society and the government to achieve the exploitation, production, processing and consumption of these energies. The table 3 shows some incentives for the production of renewable energies as established by the SENER (SENER, 2010) established incentives listed below in table 5:

Table 5: Incentives for Renewable Energy in Mexico.

Incentives	Explanation
The Fund For Energy Transition And Sustainable Use Of Energy	It is a government fund that has three billion pesos, with the objective is to promote national energy sector through projects, programs and actions aimed at the further development of renewable energy.
Integrated Energy Services for Rural Communities	The goal is to supply renewable energy to 50,000 rural Mexicans homes that are insulated from the mains.
Support mechanism for renewable energy projects	Support mechanisms allowing financing through National Financial renewable energy projects.
Clean Development Mechanisms (CDM)	It is based on Article 12 of the Kyoto Protocol, a developed country can invest capital in a developing country in order to reduce Carbon Emissions. In exchange, the developing country gives to the developed country an emission reduction certificate.
Accelerated depreciation of fixed asset depreciation	Allowed 100% investments in machinery and equipment for power generation from renewable sources.
Energy Sector Fund Energy Sustainability	Promotes research and applied technological innovation, technological development, renewable energy adoption, energy efficiency and clean technology.
Tariff 0	No pay import tax or export items such as: anti-pollution equipment and items for investigation or technological developments (machinery, tools, animals, plants)

Source: Own elaboration based on SENER, 2010.

Despite existing renewable energy incentives in the Mexican legal framework, two incentives are not yet establish which would help Mexican investors. (Ramos Campos, 2011) The first is the incentive of property, it must have a property right under Mexican law because there are several problems related to the ejido communal properties assets and responsible for producing renewable energy. This incentive is critical to investors in renewable energy.

The second incentive has already been adopted by developed countries including Germany. It is the incentive for preferential treatment in which the government has an obligation to supply a set percentage in the renewable energy law to interconnect contacts that are within renewable energy projects. This would create a renewable energy market where the government would create actions to promote them.

2.4 Barriers

There is a numerous list of barriers to the development of renewable energy projects in different countries. Some are technical barriers, market barriers, political, regulatory, institutional, social and environmental. Each of these barriers consists of a different magnitude, importance, and legal framework of the countries involved.

Therefore, each of these barriers should be eliminated by implementing strategies according to their particular circumstances, in order to subsequently achieve adequate large-scale utilization of renewable energy, in countries where these energies are beginning to be important.

In Mexico, it is recognized that energy policy must take into account the diversification for the generation of electricity, driving the development of renewable energy to achieve sustainable development (SENER, 2010), despite enabling impediments and barriers to its implementations. The main barriers are explained below:

2.4.1 Institutional Barriers

No credits for capacity are currently granted for intermittent power production facilities, and CFE is under no obligation to purchase any renewable energy production. However, in the case of self-supply with intermittent sources, CFE is mandated to serve as an energy storage as explained earlier. Otherwise, the regulatory framework is very limited. Such that CFE cannot unilaterally grant exceptions or provide incentives for renewables, unless the legal framework is modified or alternative attractive market-based solutions are identified.

The bureaucratic process to establish companies is excessive, the energy sector institutions are rigid against the development of new sources that are dominated by those who benefit from the "status quo" and this seriously complicates the entry of new players who have the necessary technology along with the resources needed to increase the supply of renewable energy. It is important to know that the paperwork for new projects is long and complex and response times are very long (Huacruz, 2007).

In addition, most energy policies are centered on fossil fuels and renewable types of energy were not considered in the original interpretation of the constitution to be a national heritage. Another factor to consider is that the CFE, monopolistic in character, does not compete with other companies and therefore has no incentive to improve.

2.4.2 Social Barriers

Illustration 1: Protest in Oaxaca State against the installation of wind farms
Source: Desinformemonos Journal, 2013.

Renewable energy presents social barriers that can be mainly divided into two categories: generic barriers, the visible presence of the machinery and the second site-specific barriers that tend to vary from one place to another in response to local sensibilities, natural and cultural the most fundamental is the infrastructure that causes disruption to transform the natural landscape (SENER, 2010).

The 21st article of the LAERFTE, promotes the social development of the community in accordance with the best international practices for sustainable social rural development, and the participation of local and regional communities to achieve social development (Camara de Diputados, 2012). This law has not been respected by major international producers, as their projects are far from fulfilling social criteria. While harnessing the energy potential of a good geographical position, allowing states to benefit from it in its energy projects, transnational corporations take advantage of the weak Mexican property laws. An example of this can be seen in Oaxaca, particularly in The Ismo located in the area of La Ventosa. Within this region, indigenous communities are being unjustly deprived of their land for wind projects favoring foreign capital. Within this region, there are currently a number of indigenous protests aimed at up keeping social rights. Protesters contend that farmers have been tricked, manipulated and convinced to rent their land to multinationals, without receiving a long-term benefit. In addition, 11 wind projects in this area are occupying 8000 hectares of land without informing people. Such projects affect more than 5000 families and violate international law and indigenous people rights. (Moreno, 2012). The illustration 11 shows a protest by residents of a community in Oaxaca who fight against the installation of wind turbines.

Another social barrier to the implementation of clean energy is the social perception of many, contending that oil is inexhaustible and that there are better alternative energy sources such as nuclear. For the most part, the population is not informed of the environmental benefits of renewable energy and lack the current cultural context and traditions of utilizing the source. For example, there are very sunny areas with solar panel suppliers, where there is no solar heater present. No coverage value over time (Embajada de los Estados Unidos, 2009).

2.4.3 Human Resources and Technical Barrriers

Within this area, the country has very little capacity of national human resources as there are currently few trained human resources available for project development work, engineering, design and operation of components. There currently is an incipient local renewable energy industry with very weak links between enterprise and institutions of study and innovation projects. However, some universities have already adopted several projects and programs. Most are based on theoretical and empirical knowledge to be modified in practical applications and national training programs.

There are very few national technological advances advancements to the weak links mentioned above, there are very few examples of successful national commercial projects. One of the reasons is the lack of utilization of national infrastructure. For example, in 1999 there were 200 companies with enough Mexican infrastructure to produce component wind turbines, and only one of them was successful in installing and producing energy (Huacruz, 2003). Unfortunately, Mexico is technological dependent, making it a country that imports foreign technology. For this reason, a further cooperation between industry and research is necessary in order to develop projects as well as increase the interest of universities to foster and initiate new educational programs in the areas of renewable energy.

2.4.4 Environmental Problems

Renewables also cause environmental problems which must be identified for proper environmental assessment. Solar energy generates direct contamination but not containing substances for heat transfer that can cause pollution if they reach the environment. The panels can produce optical and aesthetic discomfort and intensive use of the surface can therefore generate related environmental problems (soils for agricultural production, protection of species and biotopes). The shade and albedo modification can have impacts on microclimate, flora and fauna. Other environmental impacts occur during the manufacture of the materials to produce as steel, copper and aluminum major environmental problems generated by dust emissions and flouride compounds.

The creation of wind farms brings about landscape and scenery alteration, allowing sound pollution as a result of the electromagnetic and mechanical sound generated by the wind turbines. Such practice further affects avian wildlife due to the wind towers burdening the migratory patterns, producing a risk of accidents resulting from the release of rotor blade. For example, the state of Quintanna Roo experiences an environmental issue resulting from the use of renewable energy (Aparicio, 2012).

2.4.5 Barriers to the Implementation Solar Energy in Mexico

There are specific barriers to solar system deployments in Mexico. The SENER and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in its program to promote PV systems in Mexico (PROSOLAR) identified the most significant barriers which are shown in table 6:

Table 6: Obstacles to the implementation of Solar Energy Systems in Mexico.

Obstacle	Description
Financial	- There is very little economic funding that allows to have a competitive and financing PV market. - The investment cost to start is very high - High transaction costs due to the bureaucracy of institutions and administrative procedures for the purchase, sale or interconnection. - High transaction costs arising from the lack of competitiveness in the market.
Legal, Regulatory, Policy	- No recognized environmental benefits - Lack of standards to ensure performance, durability and installation of the systems. - Lack of transparency in regulation.
Technique	- Low level of performance and efficiency of the systems. - Little flexibility in design and colors. - They overlook the needs of buyers.
Lack of Capacity	- The products and services are in a mature stage. - No user is encouraged to invest in these systems.
Lack of Information	- There is very little information about the potential market. - Manufacturers provide very little information to potential customers. - There is uncertainty about the technical performance of the systems. - Reduced information about the depletion of nonrenewable resources and its economic effects on the country.

Source: GIZ & SENER, 2012.

The following section presents a description of the state of San Luis Potosí, in order to know more in detail the study area to be evaluated.

3 Study Area

The state of San Luis Potosí is located in central Mexico, between the Sierra Madre Oriental, the mountains of Zacatecas, and the Gulf Coastal Plain. It represents 3% of the area of the country. Because of its land area, the state is in the fifteenth place nationally (INEGI, 2011).

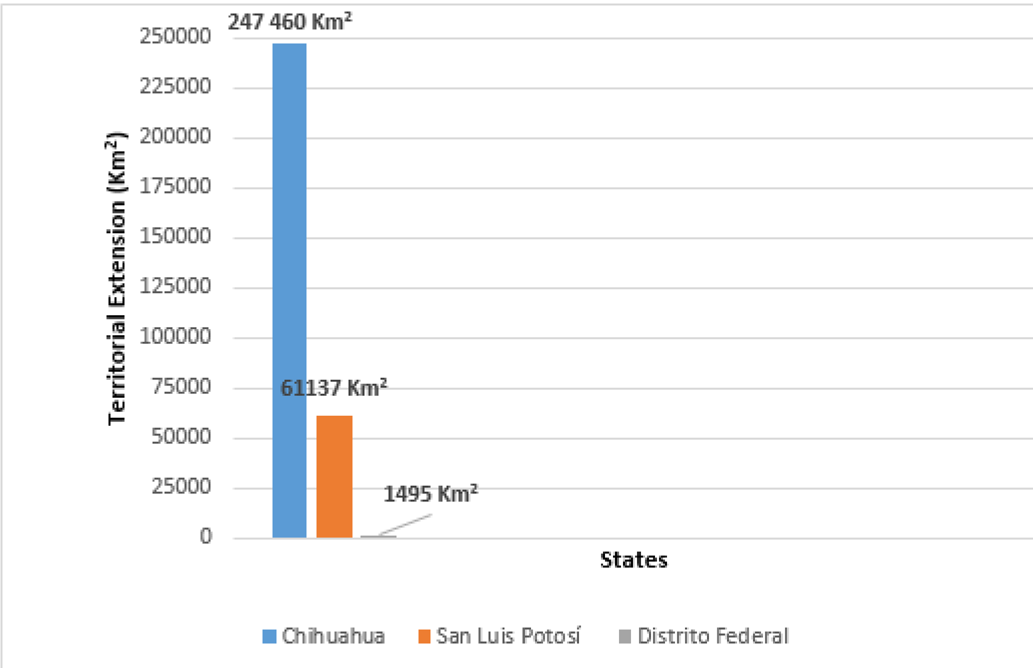

Figure 14: Comparison of territorial extension between San Luis Potosí, the largest state of Mexico (Chihuahua State), and the smallest state (Federal District).
Source: INEGI, 2010

The northern area of the state is traversed by the Tropic of Cancer. The area is very irregular and extends over two-thirds of the plateau. San Luis Potosí bounded on the north by Coahuila, south by Querétaro, east by Veracruz, Guanajuato and Hidalgo, west by Zacatecas. To the northwest of the state are located the states of Nuevo Leon and Tamaulipas ("States of Mexico," 2010). San Luis Potosí's uniqueness can be attributed to the fact that it is the only state in the country that borders nine other states.

San Luis Potosí's variety of vegetation is mainly due to differences of altitude presented. The state can identify three main areas: the Huasteca which is located east of the state, the highlands in the west, and the Central zone. San Luis Potosí, geographically is located between 21 ° 15 'minutes and 24 ° 37' north latitude and between 0 ° 32 'east and 3 ° 20' west of the meridian of Mexico (De la Torre-Moreno, 2006).

3.1 Geographic Areas of San Luis Potosí

San Luis Potosí present four distinct geographical areas which divide the state into four main areas: Highland, Central zone, Middle zone and Huasteca. This classification is mostly related to the height above the sea levels Figure 15 shows, the division of the zones.

Figure 15: Principal areas of San Luis Potosí
Source: COAPU, 2011.

However, it is important to consider that all of these regions are characterized by several chain mountains, by diverse types of vegetation and by a complex topography. It is relevant to be aware that this division is necessary to comprehend the behavior of physical and meteorological parameters. The topography influences largely the temperature values and the intensity of solar radiation. The neighborhood of the Huasteca to the Gulf of Mexico explains why this region is characterized by high values of relative humidity.

3.2 Climate

The state of San Luis Potosí has a total area of 63241 Km^2 (Durán García et al., 2002) and is characterized by a variety of weather patterns due to the altitude, latitude, and topography. These three patterns generate a gradient of moisture in the atmosphere that runs through the area of the Central Bureau and the Huasteca zone. The latter is more humid due to the influence of winds from the Gulf of Mexico (Juaréz Rueda, 1992).

As mentioned by De la Torre-Moreno (1992), in the Gulf of Mexico, there are large moist air masses reaching the state and causing a large increase in water vapor, mainly in the Huasteca, also causing heavy rainfall and warm temperatures. Because of the increase in altitude towards the west, the air masses are losing temperature and humidity, precipitation in lower areas and the rain shadow effect, resulting in little rain in the Central Plateau. San Luis Potosí has three climate types according to their zone. The western part has a dry climate, the Huasteca area's climate is that of a tropical rainforest, while the eastern Highland have a temperate climate.

The territory has 73.84% climates where evaporation exceeds precipitation, (more than half of western state) except for the highlands of the Sierra de Catorce, La Trinidad and Camaron, and the cord of the Mesa Larga. Of these highlands mentioned, the largest holding is 47.43% with the dry, semi-dry remain with 23.72% and 2.69% with very dry. Wetter climates than the previous ones mentioned are the semi-warm. These cover 15.99% of the state surface and extend from north to south. These start from the vicinity of Salto del Agua and Las Moras, extending to Tamasopo and Xilitla. Warm temperature mainly comprises 8.46% of the lands of the Northern Gulf Coastal Plain, which are tempered with 1.70% in the upper portion of the Sierras de Catorce, La Trinidad and Camaron. Importantly to note that semi-cold occurs only in the higher partion of the Sierra de Catorce, representing 0.01%.

As a result of the combination between the temperature´s magnitude and the amount of precipitation, there originates a predominance of semi-dry climates the state. The variation of temperature and precipitation is influenced by factors such as latitude, altitude, relief and distribution land and sea. Figure 16 shows a representation of the climate in the state.

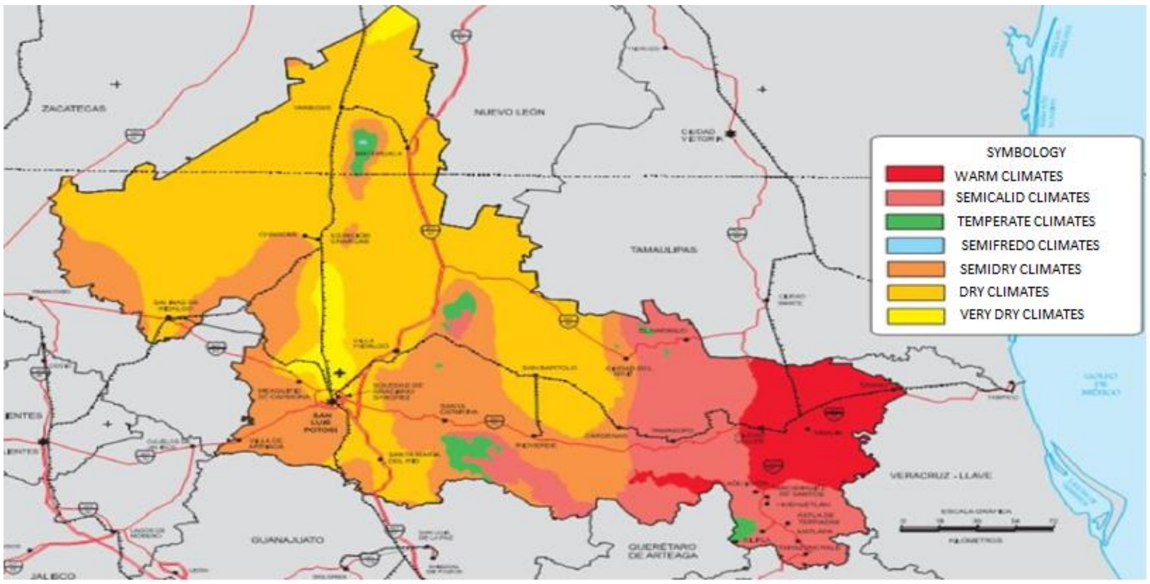

Figure 16: San Luis Potosí Climate.
Source: De la Torre-Moreno, 2006.

It features two thermal zones in San Luis Potosí, which are delimited by their latitude. The first is the warm tropical area that extends from parallel 10 north to the Tropic of Cancer, which covers 3/4 of the state. The warm region is the second area which is inside of the Tropic of Cancer. It extends to the Arctic Circle and includes the remaining portion of the entity.

The altitude influences the temperature. Therefore, if the temperature increases, the altitude decreases and vice versa. The North Gulf Coastal Plain, which has a lower altitude of 200m, reported the highest annual average temperatures in San Luis Potosí from 24°C to 26°C.

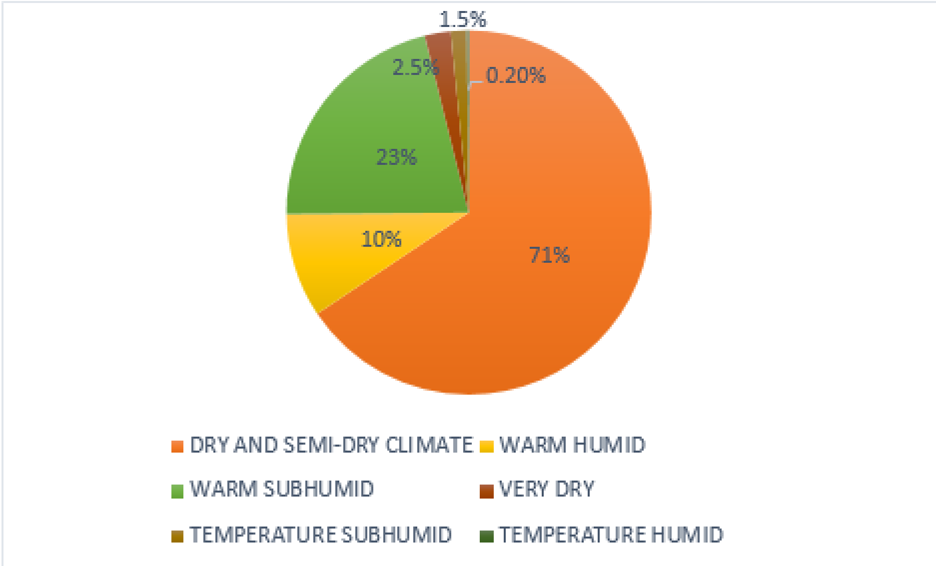

Figure 17: Distribution of the principal climates in San Luis Potosí.
Source: INEGI, 2011.

Figure 17 shows that the predominant climate San Luis Potosí is the dry and semi-dry climate.

Moreover, the Institute for Federalism and Municipal Development (INAFED) made a state climate classification taking into account the topography and showing the percentage area occupied by these climates, the table 7 shows the classification:

Table 7: Classification of the climates of the state according to topography.

Subtype	State Area percentage
Warm Sub-Humid With Summer Rains	8.89%
Semiwarm Wet With Rain All Year	0.35%
Semiwarm Humid With Abundant Rainfall In Summer.	9.35%

Semiwarm Sub-Humid with Summer Rains.	5.82%
Temperate Humid With Abundant Rainfall in Summer	0.16%
Temperate Sub-Humid with Summer Rains	1.48%
Semifreddo Subhumid with Summer Rains	0.02%
Warm Semidry	0.09%
Medium-Dry Semiwarm	9.92%
Medium-Dry Tempered	12.36%
Dry Semiwarm	20.17%
Dry Temperate	28.81%
Very Dry Semiwarm	1.42%
Very Dry Temperate	1.16%

Source: Modified on INAFED, 2010.

3.3 Orography

The orography is diverse, presenting different altitudes, plains, and mountains. It is part of three main provinces. The Northern Gulf Coastal Plain, the Bureau of the Central and the Sierra Madre Oriental.

The northwest of San Luis Potosí has formed a group of mountains and continental sedimentary rocks. The Sierra Madre Oriental crosses the state from northeast to southeast.

The Sierra Gorda runs throughout the state from north to south, and it is located in this area where one can find the most important elevations, such as the San Miguelito mountain range, also known as “El Venado”. Within the Sierra Gorda, the highest mountains of the state include the following. The Sierra de Catorce and Cedral, which because of their configuration and shape give rise to different valleys and plains.

The major elevations of the orography of San Luis Potosí are shown in Table 8. As seen in the table, the highest elevations present in the state are located in Cerro Grande, with an elevation of 3180 meters above sea level (m.a.s.l), Sierra de Catorce with an elevation of 3110 m.a.s.l, and Sierra Coronado that has an elevation of 2810 m.a.s.l. The minimum altitudes are located in the Moctezuma and Tampaón rivers, at 50 meters above sea level (INEGI, 2011).

Table 8: Name of the main elevation of San Luis Potosí.

Name	Elevation (msnm)
Cerro Grande	3180
Sierra de Catorce	3110
Sierra Coronado	2810
Sierra Los Picachos del Tunalillo	2770
Sierra San Miguelito	2630
Cerro el Fraile	2620

Source: INEGI, 2011.

These also present plains and mountains in the form of stage. The lowest being the Huasteca. Secondly, a line consists of mountainous Sierra de Rosal, Moctezuma, Tapona, Ahualulco, and San Miguelito. It is located a plain in the desert of El Salado, which was made plain between the mountains of San Miguelito and Alvarez.

In the south-central region of the state, there is a system between the Sierra de Alvarez, which includes the municipalities of Zaragoza, San Nicolas, Cerritos, San Pedro, and Armadillo de los Infantes. Also, in this region of the state, the Ahualulco system situated between the municipal and several delegations is located.

3.4 Hidrography

Two areas are clearly distinguished in terms of the hydrography of the state of San Luis Potosí (Flores, 2012):

- The first is called the northwest and it is characterized by air currents are not significant. It is part of two regions, the hydrologic region of "El Salado" and "Lerma Santiago". Presents intermittent streams because the climate of the area is dry, semidry and also due to the scarcity of rain. Generally, water channels disappear due to seepage and evaporation.
- The second is the southeastern region that has a large fluvial network mostly in the east of the state. The region is part of the hydrological 26, Panuco. Presents coastal plains and the area is characterized by abundant rains help riverbeds as the Moctezuma River. Its most important water currents are part of the Panuco River basin. An example is the Green River passing through 6 municipalities and finally joining the Santa Maria River.

The Santa Maria River runs from the west to the east of the state, and is one of the biggest rivers located south of the state. The river flow increases with the Gallinas river. On your way to the east receives the waters of the Valleys river (Río Valles) changing its name to Tamuín where finally flow into the waters of the Rio Moctezuma in the limits of Veracruz (INAFED, 2010).

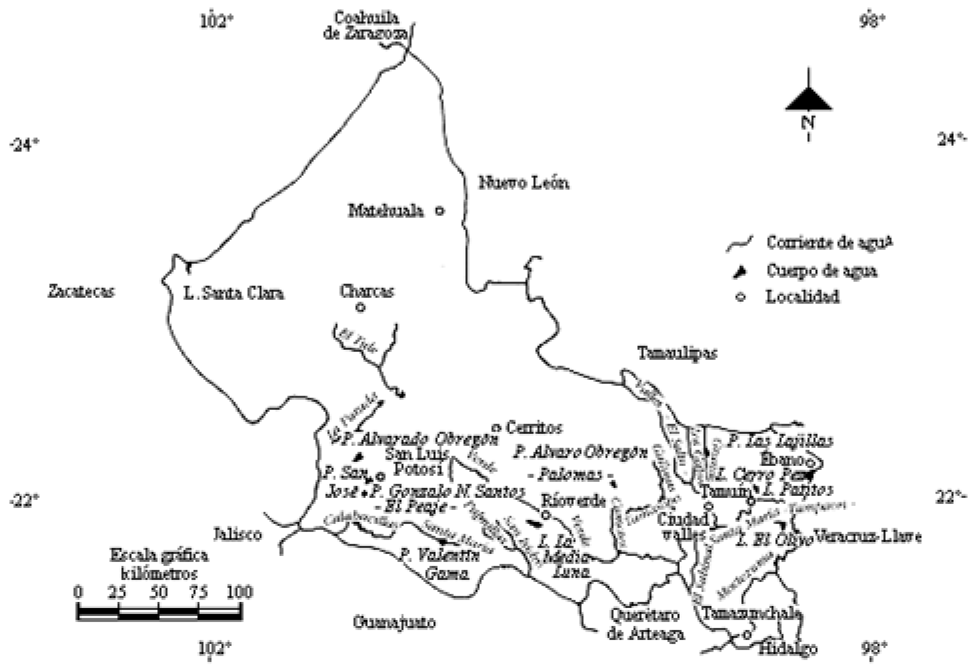

Figure 18: Currents and bodies of water in San Luis Potosí
Source: Breve historia de San Luis Potosí, 2009.

As for hydrography, the Highland is characterized by springs, underground water, closed and endorheic basins, and temporary streams. The Highland has no rivers, it only has streams flowing into lakes or temporary waters (INAFED, 2010).

The dam of San Jose in the Highland region is considered one of the few deep water bodies like Alvaro Obregon Dam. Both rivers are artificial. In rainy seasons, the San José Dam is fed by streams that form and are known as Santiago currents.

Evaporation causes the greatest loss of water in the Highland because the evaporation is very high. Southeast of Matehuala are located major streams of Highland among them are Blanco Chico and Gavia (breve historia de San Luis Potosí, 2009). In the semi-desert areas of the Highland are formed basements absorbing runoff from the mountains, when the water is filtered at shallow depths as in the desert areas groundwater aquifers are lost by evaporation. The San Luis Valley has problems standing water because the water is not filtered.

The middle region like the Highland has closed basins and springs. The most important hydrological systems in the middle zone are the Green River or the river Alaquines. La Huasteca has permanent streams, springs, ponds, and Panuco River basin. This area contains the most important hydraulic resources of the state.

Because of the terrain, the Media zone and Huasteca have many surface water reservoirs. In some regions, you can find watershed now turned into swamps or closed basins converted into shallow lakes (Breve historia de San Luis Potosí, 2009). In the coastal plain is possible to find large and very deep lakes surrounded by wetlands as the Tiger, gaps or the Fish.

There are also springs as San Tiburcio or Sabinito. Water Births as Ojo de Agua or Crescent near Rio Verde in the east of the Sierra Madre (INEGI, 2011).

La Huasteca and the middle region have a close link between them because the most important waterways in the Huasteca region originate in the middle zone. The Green River passing through the middle region passing through Ciudad Fernandez and Green River populations, and reaches the town of San Nicolas Tolentino where it forms the dam of the Swallows (AIDA, 2011). Another important river is the Moctezuma River which originates in the Basin of Mexico and enters the southeast of the state by the Taman Valley and crosses the south-west state of reaching the limits of the state of Veracruz.

Once known the study area, is important to understand the methodology of the thesis, which consisted of a series of stage all in order to obtain a characterization of solar radiation in the state of San Luis Potosí.

4 Methodology

To investigate the attenuation of the solar radiation by the presence of humidity in the atmosphere, it is necessary the application of a numerical model to simulate the evolution in a yearly cycle of the relative humidity which is a measure of the moisture contain and of the incoming radiation on the Earth surface. The explanation for the development of this principal aim is as follows. The methodology was divided into several stages, with the objective of having in each of these stages a specific goal. A general representation the stages covering the methodology is presented below in:

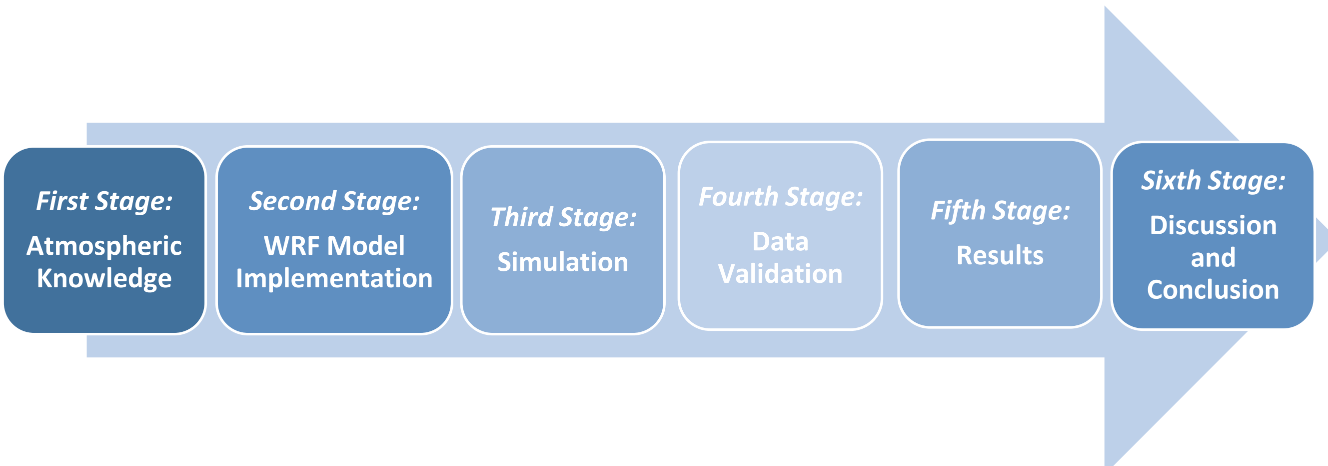

Figure 19 Methodology Scheme.
Source: Own Elaboration.

4.1 First Stage

To study with a numerical model the variability of moisture in the atmosphere was necessary, as a first step, the study of the major concepts of physics and atmospheric dynamics:

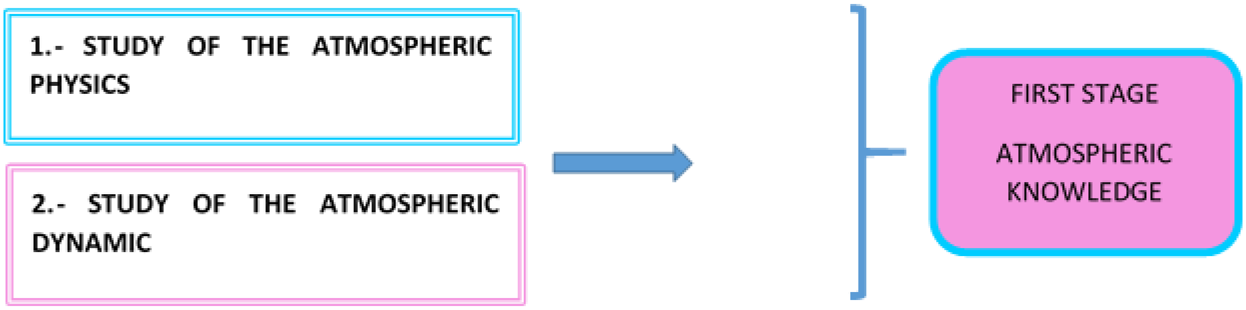

Figure: 20: Basic components for the study of atmospheric processes.
Source: Own illustration.

The main concepts studied during this stage were:

1. Study of the atmospheric physics: The principal physical themes and the equations that describe the dynamics were conceptually learned, this knowledge is useful for this case study. Some of these equations are: ideal gas equation, equations to measure and to calculate the quantity of moisture in the atmosphere, equation for the water vapor pressure and first and second lows of thermodynamics, etc. It was also necessary to study the dynamic processes in the atmosphere without considering mathematical details, since it is not the focus of this work. Several aspects of the solar radiation were also learned.
2. The study of the most important aspects of the dynamics or atmospheric circulation that transports water vapor. It is important to know the forces generate the movement or wind. The knowledge of wind is of fundamental importance because wind carries the main substances that affect solar radiation, like dust, aerosol, and vapor water, which is to be studied in the case study.

This first stage was important because it covers the investigations of the main concepts of physics and dynamics of the atmosphere for the realization of the case study and for a better interpretation of the results.

4.2 Second Stage

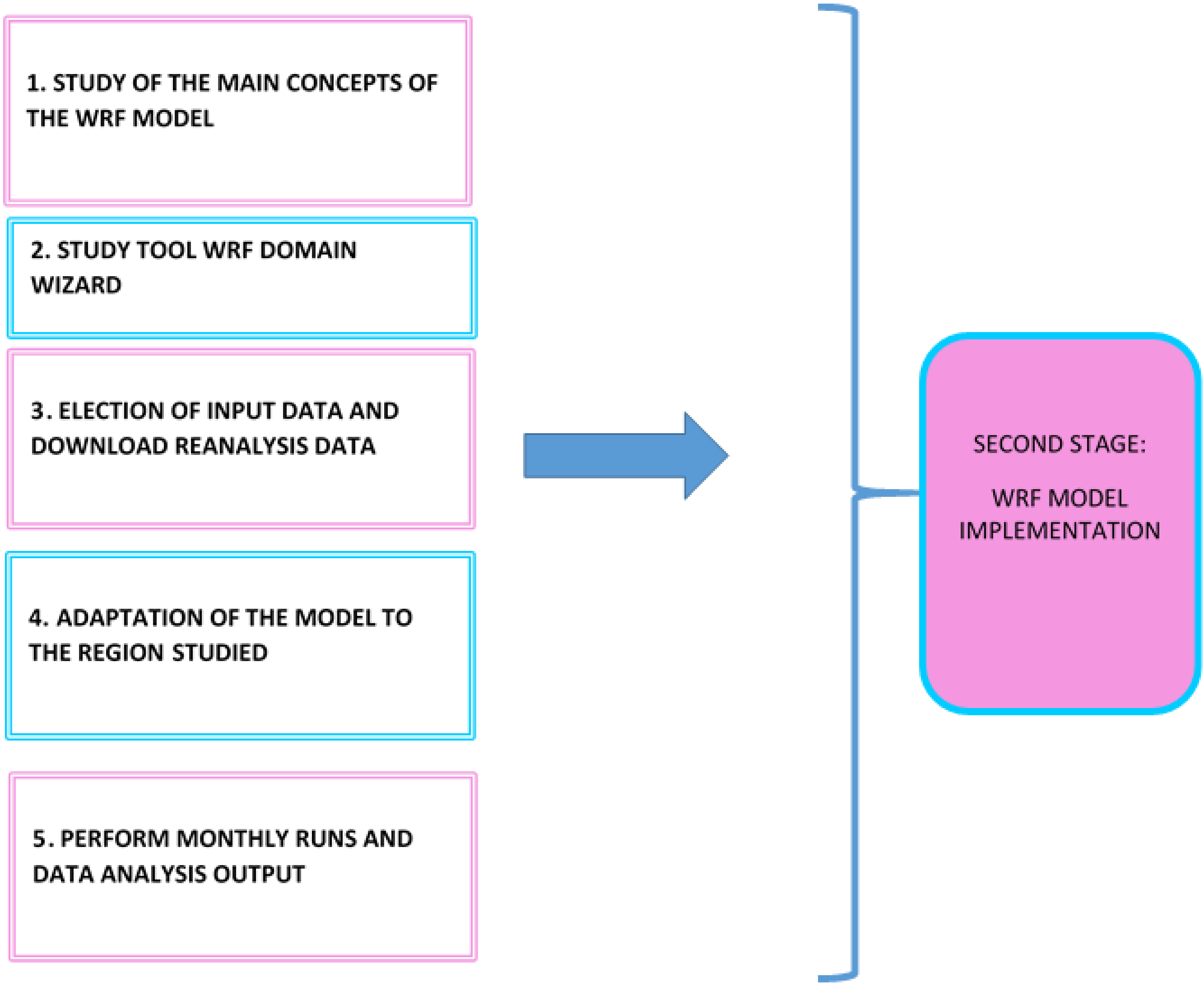

Figure 21: Knowledge and implementation of the WRF model.
Source: Own illustration.

Study of the main concepts of the WRF model and Study tool WRF domain wizard

During this 2 stages, the training was at the Instituto Potosino de Investigación Cientifica y Tecnológica (IPICyT) which is located in San Luis Potosí, Mexico. The main objectives were: to learn the use of the WRF model, the explanation of the operation of the main modules of the WRF model, and tools for visualization and interpretation of the results.

Note that in this particular stage, theoretical and practical classes were carried out in order to choose the best parameters for the case study, for the realization of the maps and also for validation and interpretation of results.

Election of input data and download of reanalysis data

The input data for the model WRF are meteorological data of re-analysis. This data set includes Mexico and the state of San Luis Potosí. The data allowed the atmospheric simulation of the year 2011, after correct parameters and correct coordinates were assigned. To set the boundary conditions, the meteorological data of the pre-processing system were assigned. These data are from the National Center for Environmental Prediction (NCEP), and are called NCEP Final Analysis (FNL). The input data set has a temporal resolution of 6 hours and a spatial resolution of 1.0 X 1.0 (degrees). This data can be downloaded to a temporary time from the year 1999 to date (National Centers for Environmental Prediction, National Weather Service, NOAA, U.S. Department of Commerce 2000). When analyzing the data, the WRF can also make predictions of future events.

The case study analysis can be carried out on the surface and also at different pressure levels ranging from 10 mb to 1000 mb. The study makes a complex analysis of many variables, including solar radiation, relative humidity, vertical wind motion, precipitation rate, air temperature, evaporation, wind components u (east) and v (north). The data can be downloaded in two different formats, which can be either grib1 or grib 2. For this thesis, the data downloaded was grib 2. (National Centers for Environmental Prediction, National Weather Service, NOAA, U. S. Department of Commerce, 2000).

Adaptation of the model and parameters for the studied region

The WRF Domain Wizard is a graphical interface for the pre-processing system of the WRF (WPS). It allows defining nested domains, it chooses the region to study and projection, it runs WPS programs (geogrid, ungrib and metgrib) in a more simple way, it visualizes NetCDF output files, it types the information in the files "namelist", it calculates Coriolis parameters, it scales factors, altitude, latitude and longitude, it interpolates the input data, it interpolates terrestrial data variables and time invariants like terrain height and land data, it Interpolates time invariant simulation grid (eg , the height of the terrain and soil type) and it interpolates the meteorological fields in domains of other simulation model. (Duda, 2012; Dudhia, 2013)

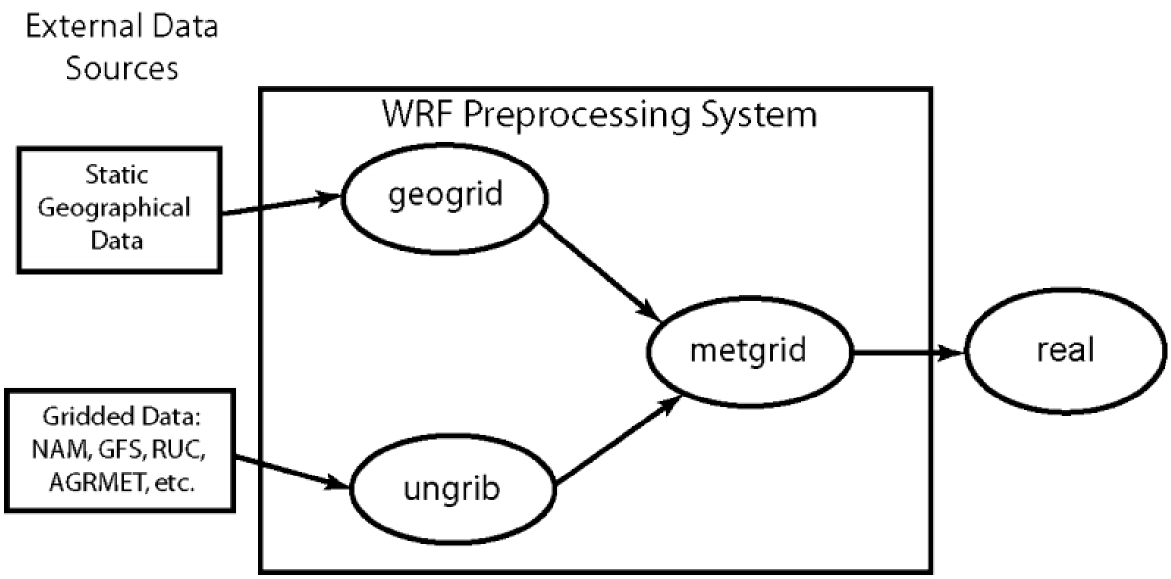

Figure 22: WRF Program Flowchart.
Source: Duda, 2012.

For any modeling project, it is necessary as a first step to select the study area. To define the area, the geogrid module is used (Figure 22). Geogrid performs data interpolation of topography, soil type, albedo, land-water mask, and vegetation among others. Also, specifications are performed in this model from the center position, resolution, position of the grid points, number of points, and distance between points in the whole domain. Geogrid module is used whenever the domain of the study area is modified.

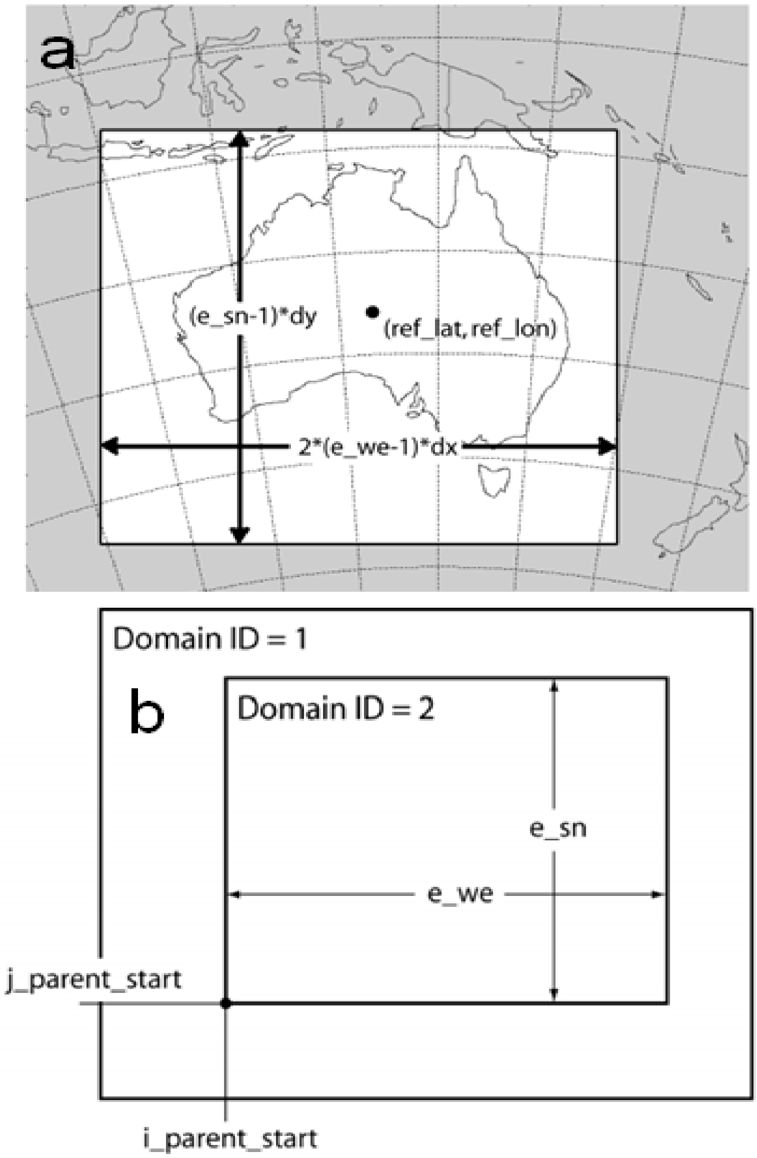

Figure 23: a) Definition of the Domains. To define the domains, the most important coordinate set is the central coordinate (b) Defining Nested Domains.
Source: Duda, 2012.

Figure 23 shows: The grid space between domain 1 and domain 2 is determined by domain 1. The formula for calculating the nest is dimension (n *parent_grid_ratio + 1).

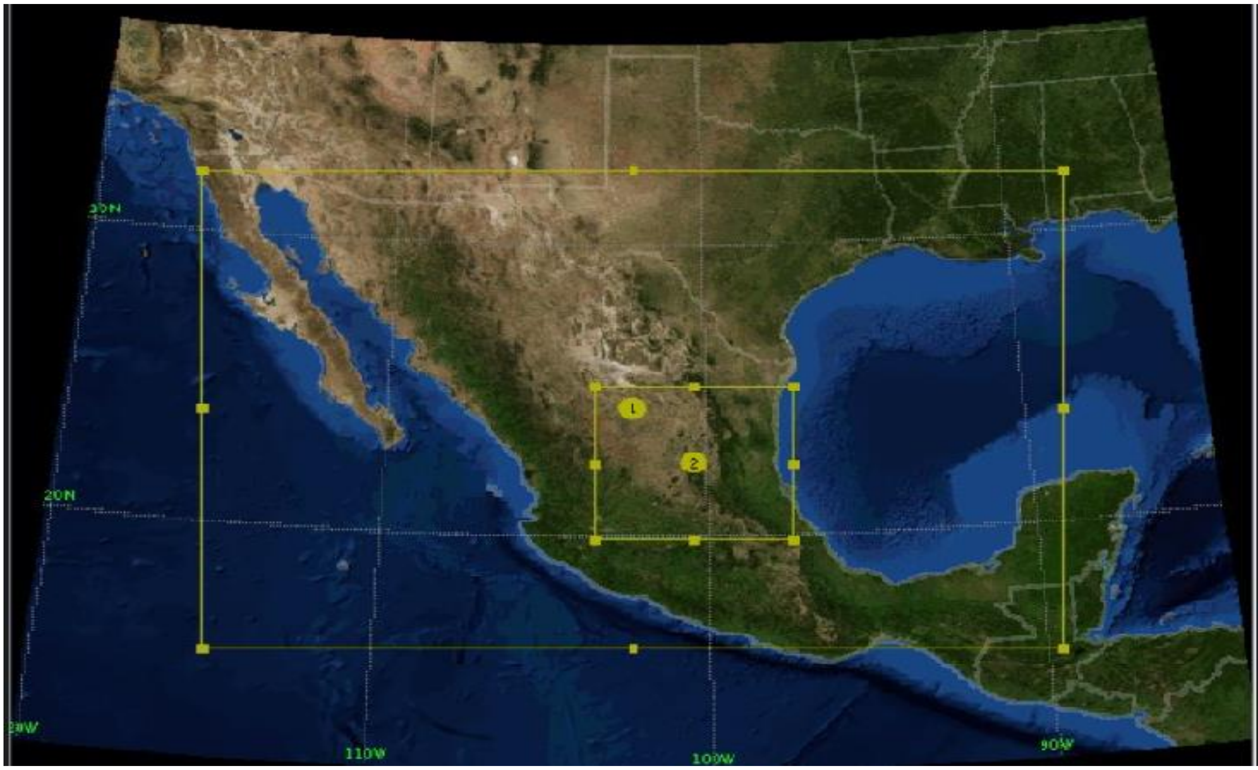

Figure 24: Domains selected for the numerical simulations of the state of San Luis Potosí using WRF Domain Wizard tool.
Source: Own elaboration.

For the case study, the numerical modeling period is an annual cycle divided into monthly periods. 2 domains were selected (Figure 24). The type of domain configuration that was chosen is telescopine nest and a Lambert Conformal projection. The first domain has a mesh size of 27 km, the central coordinate is located at latitude 24.451 ° N and longitude 102 315 ° W, covering much of the country. The second domain shows a mesh size of 9 km, the central coordinate of this domain is latitude 22.584 ° N, longitude 100 407 ° W and governs the state of San Luis Potosí. Table 9 shows the main characteristics of the selected domains.

Table 9: Main characteristics of domain 1 and 2.

Nest	Domain 1	Domain 2
PID	1	1
Ratio	1	3
Left	1	46
Right	100	69
Top	67	37
Bot	1	16
NX	100	69
NY	67	63
Res	10	10
Pts	6700	4347
dx.deg	0.1812	0.06041
dy.deg	0.1802	0.0601
CenLat	24.451	22.584
CenLong	-102.315	-100.407

Source: Own elaboration.

The grid point distance (resolution) of the first domain is 28.2 km, and has a geographic data resolution of 10 m. The Horizontal dimension (X axis) of the grid points is 100 grid points, and the Vertical dimension (axis Y) is 67 grid points. For the second domain, the nest Horizontal dimension is 69 points, while the Vertical nest mesh dimension is 63 grid points (Table 9).

After selecting the domain of the study area, another important aspect is to select physical schemes, dynamic and time of the case study. The parameterization or local configuration of the model was carried out taking into account the selected study area and were chosen the WRF schemes that best adapted to it. It was necessary to make several preliminary tests to achieve the best simulation of the region. Table 10 shows the main schemes that were adapted for the state of San Luis Potosí.

Table 10: Principal schemes and parameterization selected for the local configuration of San Luis Potosí.

	Scheme	Variable Name in WRF	Values assigned to the Variable	Explanation
TIME-CONTROL DOMAIN				
Temporal Resolution	Δt (seg)	time_step	150	Time-step for integration.
Spatial Resolution	Δx, Δy (Km)	dx, dy	28200, 9400	Total Spatial resolution of the domains
Vertical Resolution	ETA Levels	e_vert	28 levels	Vertical Resolution Levels.
Input Data	Nested	Input_from_file	True, True	
Domains	Domain Maximun Number	Max_dom	2	Specifying the Number domains.
PHYSICAL PARAMETRIZATION				
Microphysics	WSM 3-class simple ice scheme	mp_physics	3, 3	Predicts three categories of hydrometers: vapor, cloud water/ice, and rain/snow. This scheme is computationally efficient for the inclusion of ice processes.
Long Wave Radiation Option	RRTM Scheme	re_lw_physics	1, 1	It uses pre-set tables to accurately represent longwave processes due to water vapor, ozone, CO_2, and trace gases (if present), as well as accounting for cloud optical depth.
Short Wave Radiation Option	Dudhia Scheme	re_sw_physics	1, 1	It has a simple downward integration of solar flux, accounting for clear-air scattering, water vapor absorption, and cloud albedo and absorption. It uses look-up tables for clouds.

	Scheme	Variable Name in WRF	Values assigned to the Variable	Explanation
PHYSICAL PARAMETRIZATION				
PBL	YSU scheme	bl_pbl_physics	1,1	Represent fluxes due to non-local gradients. It is including the analysis of the interaction between the boundary layer and precipitation physics.
Surface Physics	Noah land-surface model	Sf surface physics	2, 2	This is a 4-layer soil temperature and moisture model with canopy moisture and snow cover prediction. It includes root zone, evapotranspiration, soil drainage, and runoff, taking into account vegetation categories, monthly vegetation fraction, and soil texture. The scheme provides sensible and latent heat fluxes to the boundary-layer scheme.
Cloud Effect	With cloud effect	ecloud	1	Cloud effect to the optical deph in radiation.

	Scheme	Variable Name in WRF	Values assigned to the Variable	Explanation
PHYSICAL PARAMETRIZATION				
Surface Levels	Noah Landsurface model	num_soil_layers	4	Number of soil layers in the land surface model This is a 4-layer soil temperature and moisture model with canopy moisture and snow cover prediction. The layer thickness are 10, 30, 60 and 100cm (adding to 2 meters) from the top down. It includes root zone, evapotranspiration, soil drainage, and runoff, taking into account vegetation categories, monthly vegetation fraction, and soil texture.
Cumulus	Kain-Fritsch (new Eta) scheme	cu_physics	1,1	Utilizes a simple cloud model with moist updrafts and downdrafts, including the effects of detrainment, entrainment, and relatively simple microphysics.

	Scheme	Variable Name In WRF	Values Assigned To The Variable	Explanation
PHYSICAL PARAMETRIZATION				
Heat and Moisture Fluxes From The Surface	with fluxes from the surface	isfflx	1	With fluxes from the surface.
Snow Cover Effect	Without snow cover effects	ifsnow	0	Without cover effect.
Input Source	WPS/geogrid but with dominant categories recomputed	Surface_input_source	1	Where landuse and soil category data come from.
Land Categories	24 - for USGS (default); 20 for MODIS	num_land_cat	24	Number of land categories in input data.
Surface Layer Options	MM5 Monin-Obukhov scheme	sf_sfclay_physics	1	Surface-layer option (old bl_sfclay_physics option). Surface exchange coefficients for heat, moisture, and momentum. A convective velocity following is used to enhance surface fluxes of heat and moisture.

	Scheme	Variable Name In WRF	Values Assigned To The Variable	Explanation
DYNAMIC PARAMETRIZATION				
Turbulences and Mixing	Evaluates 2nd order	diff_opt	1	Turbulences and Mixing Options.
Eddy coefficient option	Horizontal Smagorinsky first order closure	km_opt	4	Eddy coefficient option: horizontal first order closure that is recommended for real-data cases.
Advection options for moisture	Original	moist_adv_opt	1	Advection options for Scalar Variables.

Source: Own elaboration based on parameterizations used in the case study.

It can be seen in the table 10, for the long-wave solar radiation variable was selected the RMTN scheme, this scheme takes into account in its analysis water vapor and other atmospheric factors such as CO_2, ozone and other gases. Furthermore, as mentioned by Fernandez et al (2011), due to the spectral band used by the model and its method of correlation (correlation-k) it includes RRTM scheme and thermal infrared radiation absorbed and emitted by the surface and gases.

For short-wave solar radiation, the scheme of Dudhia was best adapted because this scheme calculates ionizing radiation and photochemistry, absorption, reflection and scattering by factors such as: water vapor, cloud cover and albedo.

After selecting the domain, the next step is to jump-start the ungrib module. Ungrib module helps to transform grib format data to write the data in the format that reads the WRF, so that the data can be interpolated to the model grid, generating output files, with the format YYYY-MM-DD (year-month-day) that will be read by the module metgrib.

Metgrib module is the last module to prepare the data and begin the meteorological analysis in the real.exe module. Metgrib horizontally interpolated output atmospheric data, taking global forecasts and perform the interpolation of the model grid.

Finally, the last module (real.exe) takes care of the vertical interpolation of the input data as well as takes into account the boundary conditions and assigned meteorological data (temperature, radiation, humidity). One example is the vertical interpolation of soil data. This is the last step of the model, and this is where the initialization is performed. This module performs the numerical simulation and takes into account the time that is necessary to investigate and simulate (1 day, 1 year, 1 month, some period of time or specific date, and so forth).

Monthly runs

Once adjusted, the model realized a pilot analysis in order to estimate the duration of the modeling of one week, taking note of the results in order to calculate the duration to simulate one year.

The analysis was performed on two different computers. One of them, a model hp dv6000 laptop with an AMD turion dual core where the numerical analysis to simulate one week needed an approximately period of 1 day. The other, a desktop computer with 7-core processor, which is used 5 core and needed a time of approximately 1 day to perform the numerical analysis of a month.

In estimating the time needed for the simulation of one year, monthly runs were made to complete the numerical simulation of one year. The main problems were presented at this stage, with compilation problems making it necessary to repeat the runs of some months. At the end of the WRF model numerical analysis, and once the twelve output files were generated (one for each month), it was necessary to use the tool to transform WRF to GrADS output file type ('ieee data files' or NetCDF files). Once transformed, the output format is used to make monthly maps.

4.3 Third Stage

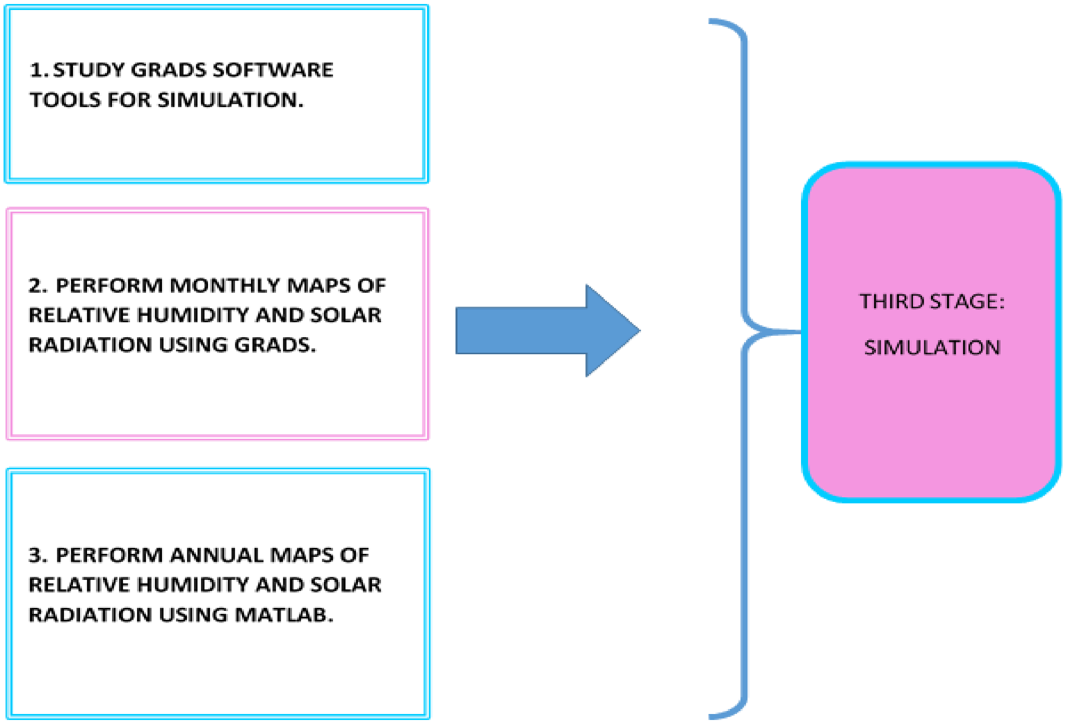

Figure 25: Realization process of the third stage.
Source: Own elaboration.

Grads software tools

The main features of the software GrADS are (COLA, 2013) :The Grid Analysis and Display System (GrADS) is a free software that helps to manipulate, visualize and access data related to the earth sciences. Grads can read the following formats: binary, GRIB, NetCDF, SDS. For the information contained in the input files, the GrADS uses a data description file (ASCII file) that uses the .ctl extension. (CIMA, 2008). The software can read data from weather stations as well as handling gridded data. GrADS has a 5-dimensional data environment (longitude, latitude, vertical, weather and grid dimension used in the dataset). The Grid types, which can be displayed are: variable resolution, non-linearly space, gaussian and regulate. A data set can be temporary or spatial and can be overlaid graphically. The program allows operations using expressions that are included and also it defines new expressions because its interface is programmable. The data set can be displayed with different types of diagrams as shaded contours, smoothed contours, streamlines, windvectors, grid boxes, and station model plots and scatter plots. It is used worldwide to generate maps of different meteorological variables. The software is financed by different institutions. The original development of the software was funded by the Research Program of Advanced Information Systems of the National Aeronautics and Space Administration (NASA).

This stage was developed in the field phase and it was performed in the IPICyT institution.

Monthly maps of relative humidity and solar radiation

After studying the basic concepts and using the GrADS software, the daily-monthly averages of solar radiation and relative humidity maps were prepared resulting in 12 maps of monthly averages of solar radiation, 12 maps of monthly mean relative humidity.

Annual maps of relative humidity and solar radiation

In order to draw the annual maps, it was necessary to extract data from monthly average values of solar radiation and humidity, which are the data sets that were extracted using the output of grads software. Once extracted the monthly averages, we proceeded to perform the annual average, generating two files. The two files were opened with the matlab software, allowing the plots of the annual averaged relative humidity and solar radiation.

4.4 Fourth Stage

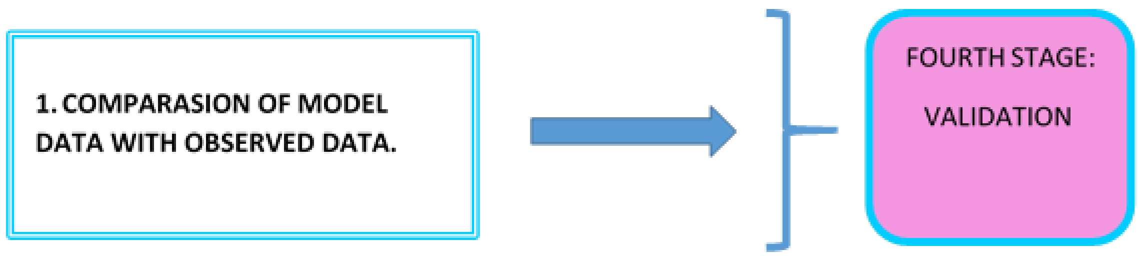

Figure 26: Realization of the fourth stage.
Source: Own elaboration.

To evaluate the accuracy of the output of the mathematical model and the reproduction of the physical parameters analyzed, an evaluation needs to be performed taking into account the observed data and the data produced by the model.

In order to carry out the comparison and evaluation, National Weather Service (NWS) dependence through the National Water Commission (CONAGUA) is necessary for providing meteorological data, time and national weather (CONAGUA, 2010).

By way of sensors, the EMAs (meteorological stations) transmit information of meteorological variables, automatically generating output files with an average of every 10 minutes of various meteorological variables, including solar radiation, temperature and relative humidity in each of the weather stations (SMN, 2013b).

The National Weather Service has a national network of 187 Automatic Weather Stations, (EMAs) and 84 Automatic Meteorological synoptic stations (ESIME's). For this thesis, it was necessary to use the EMAs database to evaluate some months of the year 2011. The meteorological stations selected were three of the four located in San Luis Potosí. Table 11 shows the location and name of the selected stations (SMN, 2013a).

Table 11 Geodata of the weather stations used for comparing the WRF model output data.

State	Station Name	Latitude	Longitude	Altitude
San Luis Potosí	Matehuala	23º38'51"	100º39'27"	1627
San Luis Potosí	Ciudad Valles	21º58'47"	99º01'51"	58
San Luis Potosí	Ciudad Fernández	21º56'102"	100º01'18"	1009

Source: SMN, 2013a.

To make the validation, a quantitative and qualitative analysis was made taking into account the output of the meteorological station and WRF model.

4.5 Fifth Stage

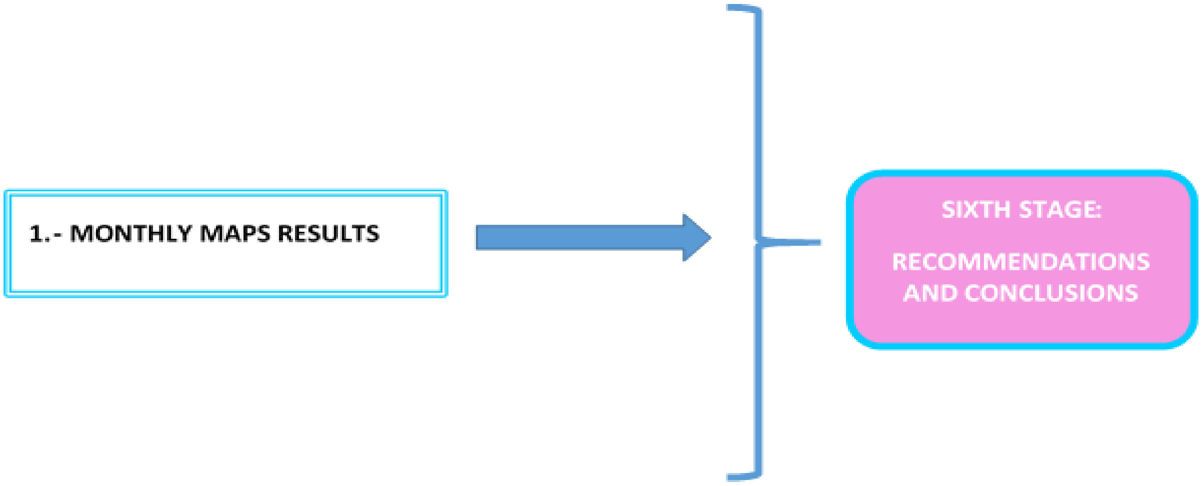

Figure 27: Realization of the fifth stage.
Source: Own Elaboration

During this monthly maps of solar radiation and relative humidity will be explained and also explain how moisture affects solar radiation.

4.6 Sixth Stage

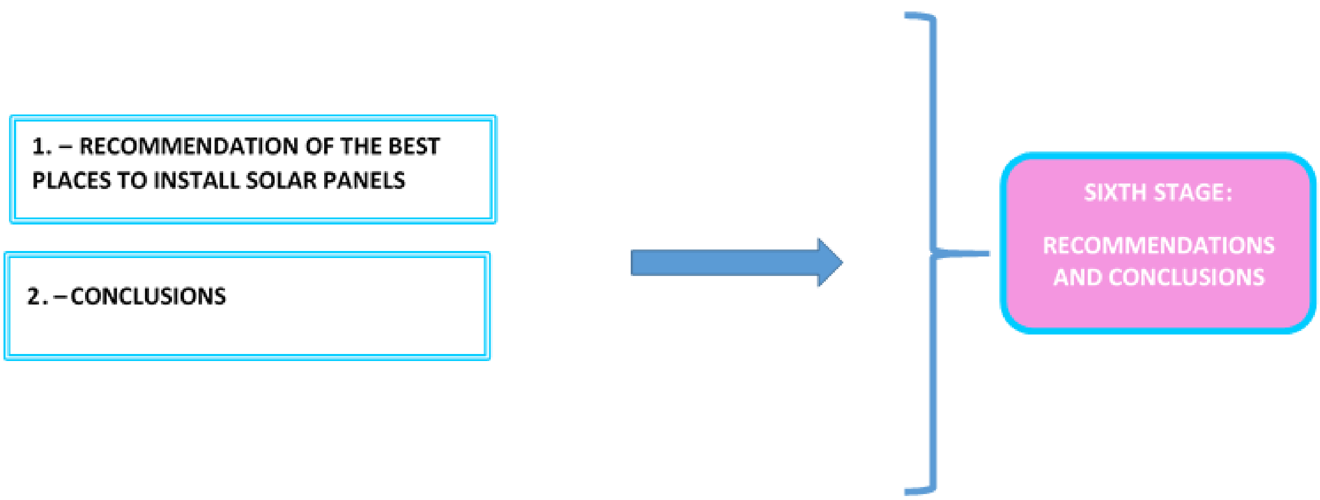

Figure 28: Realization of the sixth stage.
Source: Own elaboration.

Based on the results, recommendations will be made about the most feasible municipalities for the installation of solar panels, and finally the conclusions of the most important points of the thesis are mentioned.

5 Validation of the Calculations

Nowadays, the use of numerical models to predict weather events is one of the main tools that support the scientists for analysis and predictions of meteorological events (Aragón-Rodríguez et al., 2012). The validation of a model is the process that helps to evaluate and measure the degree of accuracy of the data presented by a model compared to the real world. In other words, the validation determines the degree of accuracy to which the model makes a representation of reality through comparisons of measured and observed data (Mayes, 2009; Paez, 2009). It is very important to have models with a high level of accuracy to allow field replacement, experimentation or analysis in areas where it is very difficult to access information.

According to Krause et al. (2005), the main reasons for validating a model are: to know in a quantitative way how the model reproduces either historical events or future events. The validation allows making improvements in the modeling and it adjusts the values of parameters. Knowing input variation data, it is possible to achieve accurate and precise simulations and compare the current model simulations with previous simulations.

The validation also permits changes in the programming and design of the model so that the model increases its accuracy, being stable and acceptable. A validation shows the limitations and advantages of the model and it indicates how to modify parameters to better adapt the model to the area of study.

Murphy (1993) conducted an analysis to determine aspects of a functional prognosis. His assumptions are based on three main features: consistency, reliability and value. Consistency refers to the judgment that makes the forecaster based on his knowledge and judgment which can be good or bad. That is, the correspondence between the judgment of the observer and the prognosis, that the judgment of the modeler is bad does not necessarily mean that the model is wrong. The quality is the correspondence that has the forecast with what actually happened, which is so close to the actual values. The value corresponds to what extent the model helped making a decision that generated some benefits (economic, social and environmental). Figure 29 illustrates the process required to accomplish a model validation.

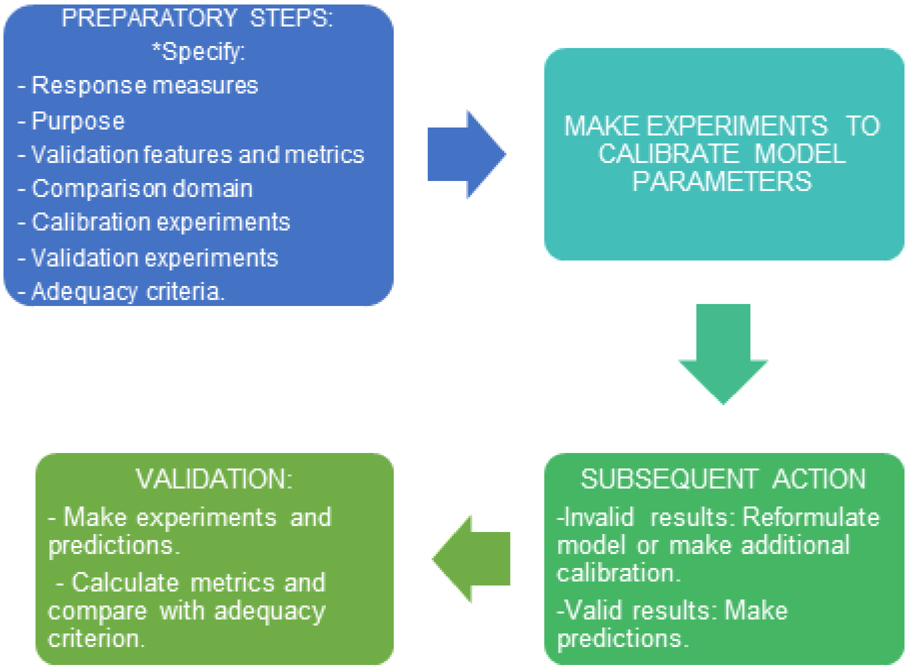

Figure 29: Process for validating a model.
Source: Urbina et al. 2005.

The diagram consists of four main stages. The first is the preparation of the input data. The second step is calibration which is a simultaneous process to the validation. In the calibration process boundaries, physical and chemical parameters, input data and mathematical equations of the model are specified (Paez, 2009). In order to perform the validation, stage experiments and predictions are made and the outputs are compared with the actual data.

After performing the validation of the model, the level of reliability of the numerical experiments are known. If the degree of reliability is high, this can positively influence the development and initiating of specific projects (Mayes, 2009).

5.1 WRF Model Validation

To evaluate the WRF meteorological model, we used two types of analysis:

- Qualitative analysis: the evaluation of the model using a visual verification represents a quick empirical test. It is not recommended to use this analysis for validating a model without the simultaneous application of a quantitative analysis. The reason are various disadvantages such as the great susceptibility to errors of interpretation by the observer. It is not considered as a quantitative measure of verification (Laing, 2011). For the case study, qualitative analysis was performed using graphs comparing the modeled data (data from WRF model output) with the observed data (output data from weather stations provided by the Modulation Transfer Function (MTF).
- Quantitative analysis: The statistical estimation helps to make a comparison of modeled and observed data. It is useful to describe the accuracy of a model. The data must be quantified to determine the variation that exists when compared with reality. This is why it is very important to perform a quantitative analysis of the data. (Mayes, 2009).

The present research work is based on the analysis and validation of the results, it does not assign to analyze all the advantages and disadvantages of the model but it gives a general idea of the performance.

5.2 Qualitative and Quantitative Validation

Qualitative Validation

As mentioned in chapter 4, the qualitative validation was carried out considering three weather stations (Matehuala, Ciudad Valles and Ciudad Fernandez) and three meteorological variables (temperature, relative humidity and solar radiation) for three months of the year (February, July and August). It was not possible to make other comparisons for other locations due to lack of information from the Automatic Weather Stations (EMA's).

The following methodology was the cell-point validation by comparing observations at specific points with the corresponding cell in the applied lattice, i.e. the analysis was carried out only at points where data in weather stations could be generated. This allows comparing observed and calculated values, although this process is only in time and punctual.

The comparison of observed and modeled data used from the WRF model output which was assigned to the software GrADS real coordinates where weather stations are located. GrADS interpolates the data output of the model taking into account the coordinates of the location of the meteorological stations to fit the specific point of the observed data.

We proceeded to take the GrADS output values and the EMA’s values to plot the data. We considered for the plotting of the monthly time series four daily values (0:00, 6:00, 12:00 and 18:00).

Summer

Temperature

In Figure 30, observed and calculated temperature data at three different places of the modeled domain (Ciudad Valles, Ciudad Fernández and Matehuala) are displayed. In general, considering the complex topography of this region of Mexico, the model reproduced reasonably well the temperature evolution in the summer time. In Ciudad Valles (Figure 30a), a place located in the low regions of San Luis Potosí, near the Gulf of Mexico, the model tend to yield lower values in comparison with those observed in the meteorological station. Ciudad Fernández is located at the foot of the mountain chain Sierra de Alvarez where mountain-valley wind and temperature effects may play an important role. These effects are probably not well represented in the model which explains the temperature differences (Figure 30b). It would be necessary to consider a higher resolution for these regions with large topographic gradients. In Matehuala, a place located about 2000 m above the sea level, the temperature modulation and minima values are very well reproduced. There are some differences in the temperature maxima in some periods of the month August, 2011.

Although the model adequately represents the tendency (the ups and downs of temperature) at all stations, it can be seen that the model underestimates the temperature at the three stations for the entire modeled period of time. High temperature events like that observed from 12 to 16 August are difficult to be modeled correctly with the applied resolution in this research work. However the general agreement in the whole modeled year is acceptable. The differences among observed and modeled data are of the same order as those found in the literature for similar applied resolutions.

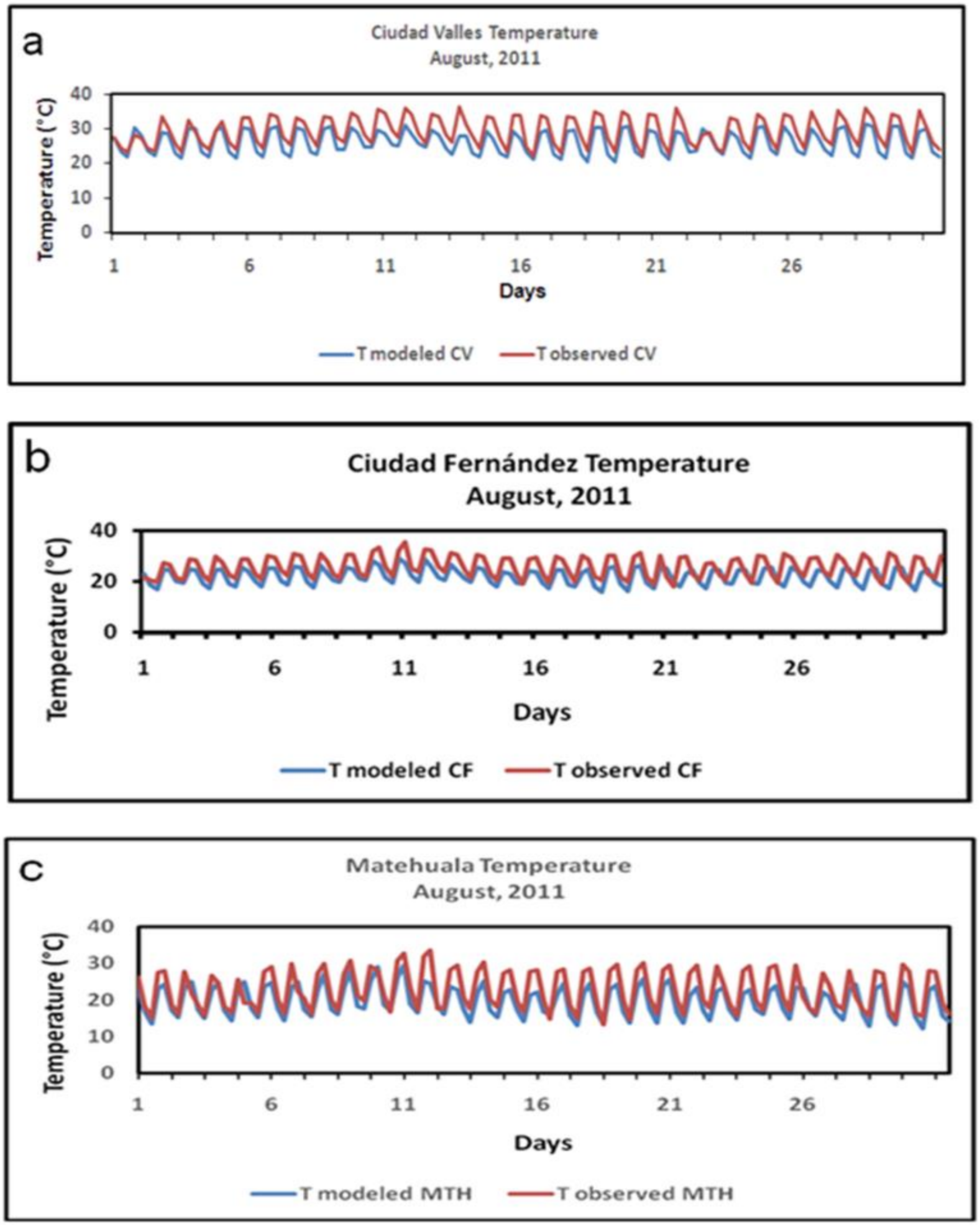

Figure 30: Observed and calculated temperature time series at Ciudad Valles (a), Ciudad Fernández (b) and Matehuala (c) for August, 2013. These temperature values are representative of the three principal regions of San Luis Potosí above sea level; about 100m (Ciudad Valles), about 1000 (Ciudad Fernández) and about 2000m (Matehuala)
Source: Own elaboration.

Relative Humidity

The evolution of the relative humidity in Ciudad Valles, Ciudad Fernández and in Matehuala reveals that this parameter experiments a larger diurnal variation in Matehuala where it varied among 20% and near 100% in August 2011. The smallest range of variation occurred in Ciudad Valles where the relative humidity changed among 50% to 100 %. The largest differences between simulated and calculated values were found in Ciudad Fernández, the model tended to underestimate the low values. This time series shows that in August, the relative humidity reaches almost a value of 100 % in summer. The model prediction was very accurate from 19 to August 22. Since the relative humidity depends strongly on the temperature, the time series indicate that in Matehuala the largest daily temperature changes occur. The knowledge of the evolution of the humidity in the atmosphere is of fundamental importance to estimate the solar radiation on earth surface. As Figure 31 shows.

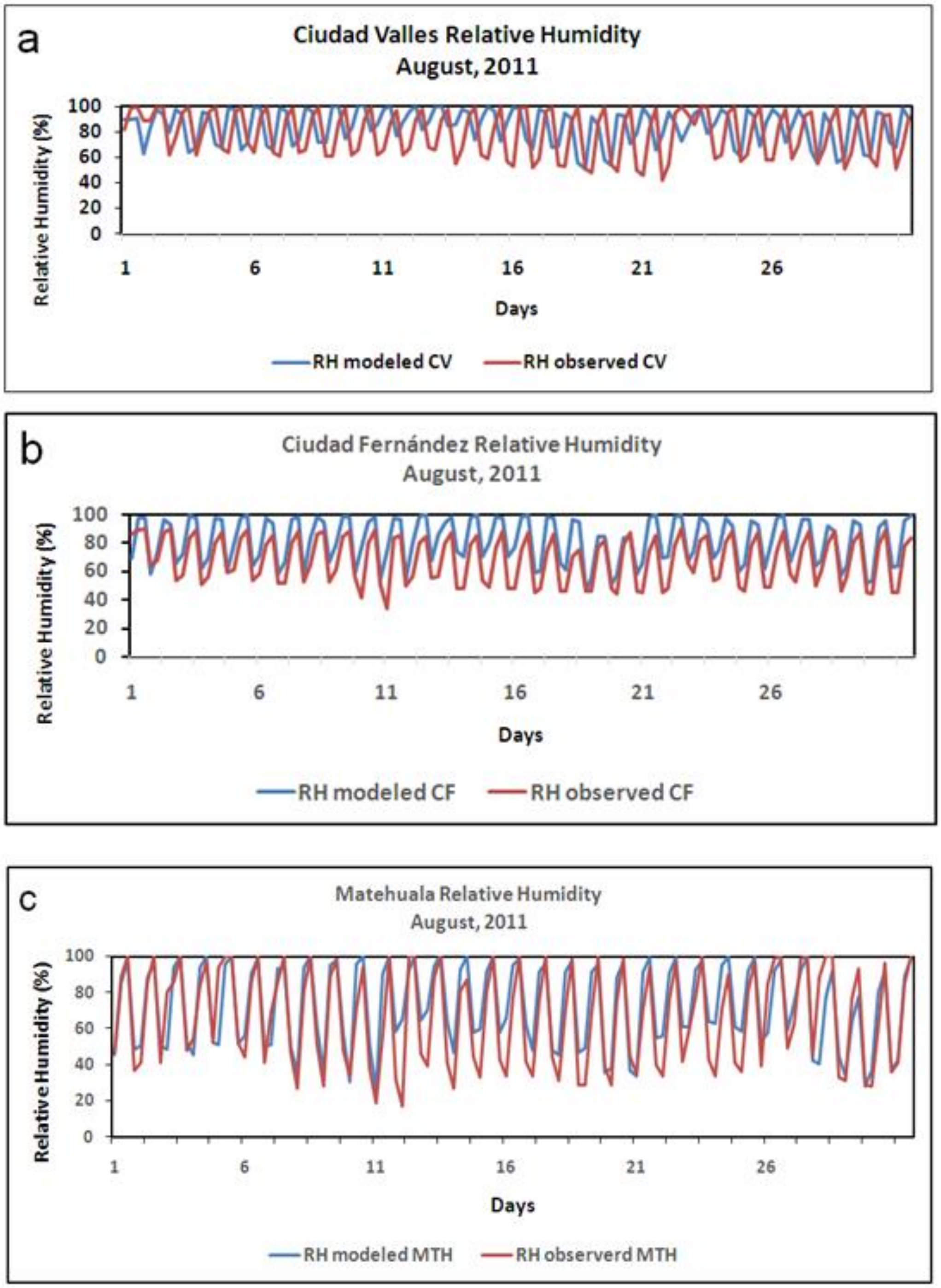

Figure 31: Comparison of observed and calculated relative humidity at stations located in Ciudad Valles, Ciudad Fernández and Matehuala (August, 2011).
Source: Own elaboration, 2013.

Solar Radiation

The solar radiation at the earth surface is affected by the presence of water or water vapor in the atmosphere. The solar short wave radiation is strongly absorbed in different frequency ranges of the solar emission spectrum. In Figure 32, observed and modeled solar radiation (W/m^2) values at for different times of a day (00:00, 6:00, 12:00 and 18:00) are shown for August, 2011. These time series reveal that in Ciudad Valles (Figure 32a) is a large variability in the levels of solar radiation in summer. Clearly, the model overestimated the values of solar radiation in some periods. In Ciudad Fernandez (Figure 32b) and in Matehuala (Figure 32c), the model reproduced very well the solar radiation values, except for specific periods (e.g. 22 to 24 of August).

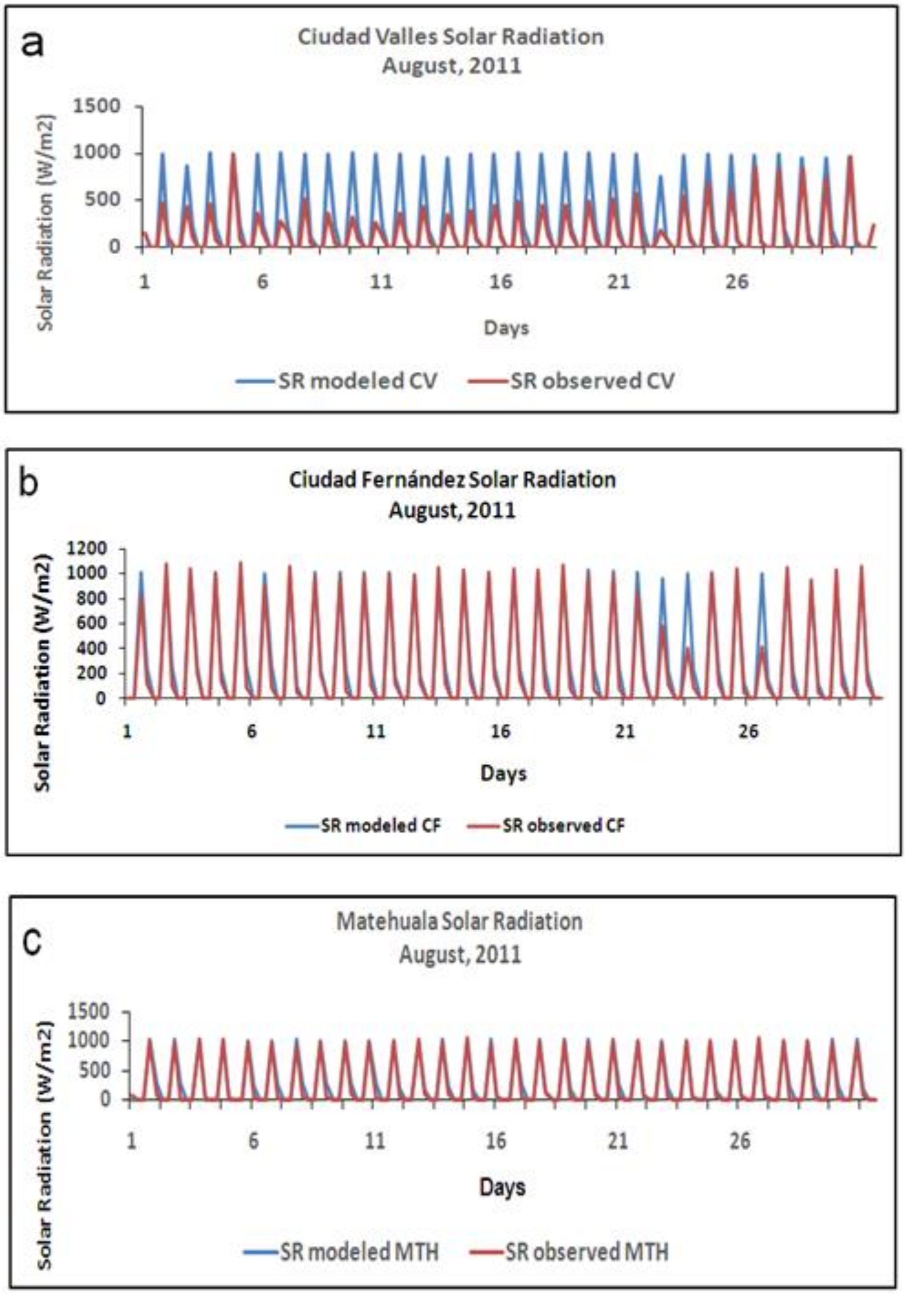

Figure 32: Observed and calculated time series of solar radiation at Ciudad Valles, Ciudad Fernández and Matehuala in August, 2011. The time series are based on four different daily values at the times 00:00, 6:00, 12:00 and 18:00 (August, 2011).
Source: Own elaboration, 2013.

Winter

The results of the numerical modeling in winter situations are documented with data obtained for Ciudad Valles. The numerical experiments showed that it was more difficult to reproduce the observed data in the low regions of the considered domain, i.e. in zones where Ciudad Valles is located. To the west of Ciudad Valles is the chain mountain, called Sierra Madre Oriental. To the east, north and south extend the coastal plains. Ciudad Valles is about 130 km from the coast of Gulf of Mexico. In winter, this region experiences tens of cold fronts with large temperature and relative humidity changes. The Sierra Madre Oriental and the valley cause locally also variable winds in direction and intensity modifying the temperature values. All these variations are found in the temperature time series (Figure 33a) for the February, 2011. The events occurred between 2 and 6 February and between 10 and 12 February reflect the effects of the entering of cold fronts. The temperature dropped from about 28 °C to approximately 4 °C on 2 February. These strong changes are also reflected in the relative humidity where the normal daily oscillations do not occur in this period of time. This event was probably associated with clouds formation in higher layer because the solar radiation diminished radically. Figure 33 shows that the temperature, the relative humidity and the solar radiation on the earth surface are closely related. The development of temperature, relative humidity and solar radiation is very accurate simulated by the model. Similar results were found for other places like Ciudad Fernández and Matehuala. The WRF model reproduced complex temporal variations of not only temperature and relative humidity but also of solar radiation. The results showed that the model is capable of reproducing atmospheric parameters such as temperature, relative humidity and solar radiation in a region with a very complex topography and in three different zones with different climate and vegetation. One of the differences is the altitude of the locations, as Ciudad Valles is situated about 150 m, Ciudad Fernández about 1000 m and Matehuala about 2000 m above the sea level.

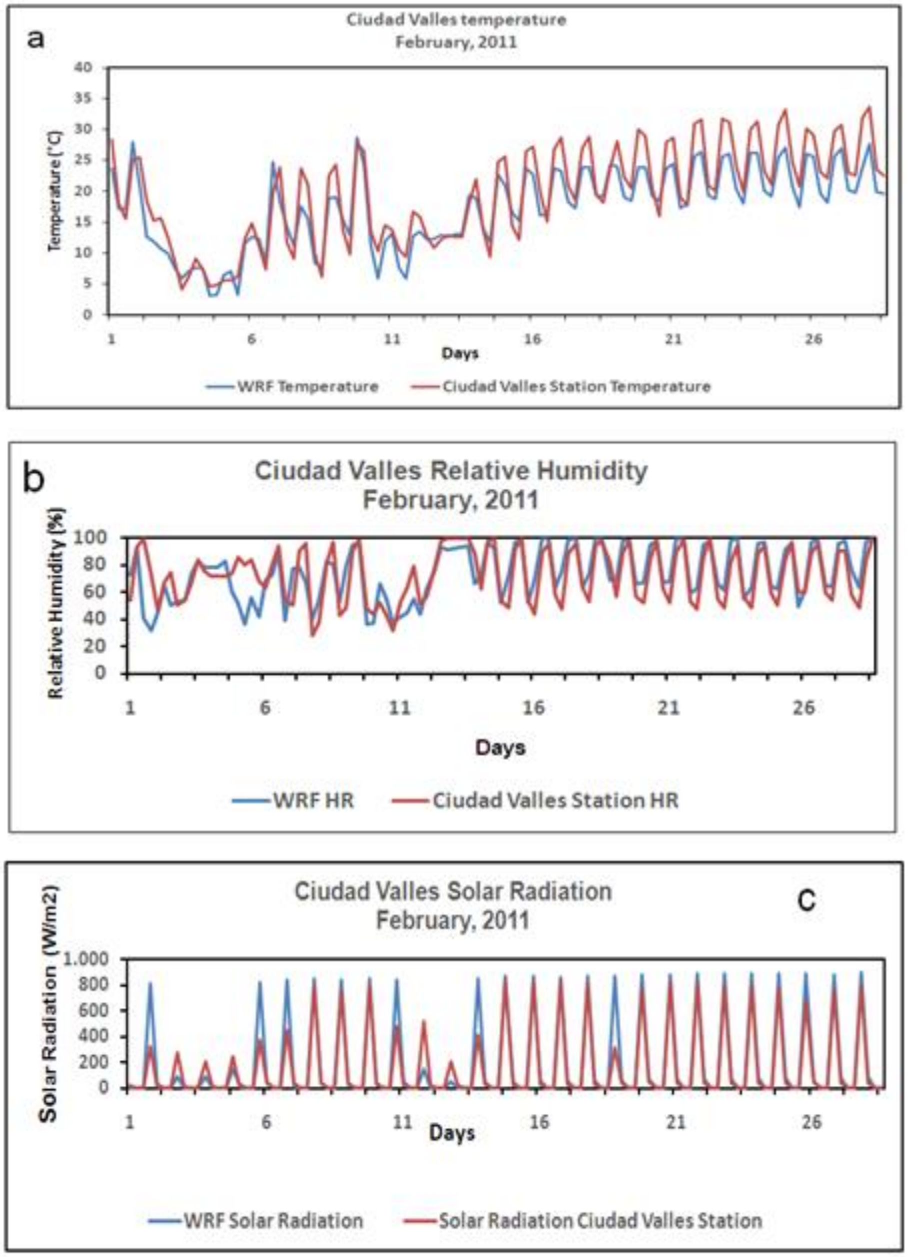

Figure 33: Observed and calculated temperature, relative humidity and solar radiation time series at Ciudad Valles (a) Temperature (b) Relative Humidity (c) Solar Radiation (August, 2011).
Source: Own elaboration, 2013.

Quantitative Validation

A statistical estimation of the quality of the results was carried out. Several statistical parameters were applied in order to identify the difference among measured and modeled data. The results of these statistical estimations are described in tables 12 and table 13 for the months February and August, 2011. One of the most common method to estimate errors is the Root Mean Square Error (RMSE) (Willmont, 1992). The root mean square shows the average degree of the match data, i.e. how different are modeled and observed values. It is a measure of the root mean square deviation among observed data (O_i) minus the modeled data (M_i) and divided by the total number of data. The RMSE is calculated applying the following formula (López-Méndez, 2009).

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{N} \frac{(O_i - M_i)^2}{N}}$$

Nash and Sutchliffe (1977) proposed a formula, which is the ratio of the squared difference of observed and modeled data divided by the difference among observed data and its mean value. This formula allows to evaluate the efficiency of the model. Perfect efficiency implies that the result is equal to 1, i.e. it is consistent with a perfect match of observed and modeled data. If NS = 0 indicates that the values of the model and the mean of observed values are similar (Sarría & Ferrando- Palazón, José Antonio, 2008). If the efficiency is less than zero, NS < 0, implies that the observed mean is a better forecaster than the model.

$$NS = 1 - \frac{\sum_{i=1}^{N} (O_i - M_i)^2}{\sum_{i=1}^{N} (O_i - \overline{O})^2}$$

The formula Mean Absolute Error (MAE) shows how close are observed and modeled data. Therefore it is considered as a "measure of closeness" (López-Méndez, 2009), or in other word, it is a quantity applied to measure how close predictions are to real events.

$$\mathrm{MAE} = \sum_{i=1}^{N} \frac{|O_i - M_i|}{N}$$

The following formula allows calculating to what extent the existence of extreme values affect the model errors. It is the quotient of RMSE and MAE.

$$\frac{\mathrm{RMSE}}{\mathrm{MAE}} = \frac{\sqrt{\sum_{i=1}^{N} \frac{(O_i - M_i)^2}{N}}}{\sum_{i=1}^{N} \frac{|O_i - M_i|}{N}}$$

Willmont formula (W) is sensitive to extreme values and the adjustment sample having the model values usually range from 0 to 1. In the case the value is 1 indicates that the setting is ideal (Sarría, 2008).

$$W = 1 - \frac{\sum_{i=1}^{N} (O_i - M_i)^2}{\sum_{i=1}^{N} \left(|O_i - \bar{O}| + |M_i - \bar{O}|\right)^2}$$

The BIAS is another statistic formula that is used to determine the reliability of the model, i.e. the capability and the tendency of the model to predict a variable. A positive result (positive reliability) shows that the model underestimates the values. On the contrary a negative result (negative reliability) shows that the model overestimates the values. It measures the correlation between the calculated mean forecast and the mean of observed data. (Sarría, 2008; López-Méndez 2009):

$$\mathrm{BIAS} = \sum_{i=1}^{N} \frac{(O_i - M_i)}{N}$$

The results of these statistical results indicate that for the temperature the RMSE was about 3.5 °C for Ciudad Valles and Matehuala and about 5 °C for Ciudad Fernández. The latter is located in a complex topographic gradient, which explains the order of magnitude of the differences. In general, the order of magnitude of the errors coincides with those obtained in other calculation which were found in the literature (Pineda Martínez, Luis Felipe & Carbajal, 2009; Pineda-Martínez et al., 2011).

The Nash and Sutchliffe index for temperature, relative humidity and solar radiation is quite variable, from very well to bad, which is an indication of complex atmospheric circulation in the different seasons of the year. The estimations of the BIAS parameter reveal that temperature and solar radiation are, in general, underestimated by the model whereas the relative humidity is overestimated. These differences can be also explained by the fact that the standard vegetation distribution contained by default in the model was applied. However, it is necessary to carry out local improvements of the vegetation distribution because land use changes occur in the whole domain.

Other factors which can affect the results of the WRF-model are the location and the elevation of the weather stations. These factors may lead to overestimations or underestimations of the results. It is important to know at what height above the ground the sensors are located as the model approximates the topographic changes. It is known from thermodynamic calculations that the temperature varies with high about 7 °C/km. Differences of about 100 m in the approximation of the topography may lead to errors of about 1 °C (Aragón-Rodríguez et al., 2012).

Table 12: Results of the statistical analysis of calculated (WRF model) and observed data for February, 2011.

February 2011							
Temperature	**Meteorological Station**	**RMSE (°C)**	**NS (°C)**	**W (°C)**	**MAE (°C)**	**BIAS (°C)**	**RDCM/MAE (°C)**
	Ciudad Valles	3.318	0.8247	0.9471	2.8538	1.9934	1.1626
Solar Radiation	**Meteorological Station**	**RMSE (W/m^2)**	**NS (W/m^2)**	**W (W/m^2)**	**MAE (W/m^2)**	**BIAS (W/m^2)**	**RDCM/MAE (W/m^2)**
	Ciudad Valles	121.181	0.8133	0.9607	50.809	-32.089	2.384

Relative Humidity	Meteorological Station	RMSE (%)	NS (%)	W (%)	MAE (%)	BIAS (%)	RDCM/MAE (%)
	Ciudad Valles	14.6841	0.468	0.8533	10.7911	-1.206	1.36

Source: Own elaboration, 2013.

Table 13: Results of the statistical analysis of calculated (WRF model) and observed data for August, 2011.

August 2011							
Temperature	**Meteorological Station**	**RMSE (°C)**	**NS (°C)**	**W (°C)**	**MAE (°C)**	**BIAS (°C)**	**RMSE/MAE (°C)**
	Ciudad Valles	3.612	0.3034	0.8188	3.2266	3.1262	1.1194
	Matehuala	3.7969	0.521	0.8587	3.3115	2.9685	1.1466
	Ciudad Fernández	5.185	0.9969	0.6495	4.2077	3.8484	1.2322
Solar Radiation	**Meteorological Station**	**RMSE(W/m^2)**	**NS (W/m^2)**	**W (W/m^2)**	**MAE (W/m^2)**	**BIAS (W/m^2)**	**RMSE/MAE (W/m^2)**
	Ciudad Valles	249.9	-0.1136	0.8465	134.3094	-127.6549	1.8606
	Matehuala	84.236	0.95916	0.9899	44.3745	-39.992	1.8983
	Ciudad Fernández	105.45	0.9984	0.9829	50.86	-36.4257	2.0733
Relative Humidity	**Meteorological Station**	**RMSE (%)**	**NS (%)**	**W (%)**	**MAE (%)**	**BIAS (%)**	**RMSE/MAE (%)**
	Ciudad Valles	24.85	0.8166	0.3917	20.3564	-5.1454	1.2207
	Matehuala	15.208	0.6861	0.9064	11.3214	-6.1336	1.3433
	Ciudad Fernández	15.6	0.1394	0.8087	15.8024	-13.2985	0.9871

Source: Own elaboration, 2013.

An incorrect definition of the domain of the study area may also result in variation of the output data. Validations should be performed for specific areas and the results should be analyzed carefully, particularly in extrapolation processes) (Paez, 2009). Another more complicated factor is the thermal turbulence, since a bad estimate could cause that the model does not adequately reproduce the parameter. As mentioned by Aragón et al., (2012), the temperature is related to two main factors: the topographic difference introduced by approximations in the model and by the station location (steep slopes generate major errors) (Aragón-Rodriguez, 2012; Zavala Reyes, 2012; García, 2003). A good fit of these two parameters is necessary in order to reduce a minimum of errors. Finally, it has to be considered that the calculated yearly evolution of temperature, relative humidity and the attenuation of solar radiation by the presence of humidity in the atmosphere are acceptably modeled.

6 Results: Attenuation of Solar Radiation by Water Vapor

The principal aim of this research work is to know the potential of generation electrical energy by solar radiation. Since solar radiation is strongly absorbed by the presence of water (in vapor, liquid and solid phases) in the atmosphere, and the humidity undergoes large daily, seasonal and yearly changes, it is necessary to calculate the evolution of the relative humidity at least for a year to have a first idea on the average yearly radiation on the earth surface of the state of San Luis Potosí. Since the Tropic of Cancer cross through this region in the northern side (Highland zone), the study area is then located in subsidence area, i.e. in areas where the air tends to flow from the high zones of the troposphere to the ground. In these areas precipitation is small, and only the neighborhood to the Gulf of Mexico increases the relative humidity.

The circulation and the evolution of all physical and atmospheric parameters were modeled for the year 2011. The quantity of generated information is huge. For this reason, it was considered to plot the results in monthly averaged charts of the considered domain, i.e. the state of San Luis Potosí. For this aim, 26 maps, 12 monthly-averaged maps based 4 daily radiation data (00:00, 06:00, 12:00, 18:00), 12 monthly-averaged maps, based on 4 daily relative humidity data (00:00, 06:00, 12:00, 18:00). From these monthly averaged maps, an annual-averaged map for the solar radiation and one annual-averaged map for the relative humidity was calculated. Finally, two databases of monthly-averaged solar radiation and relative humidity data were generated.

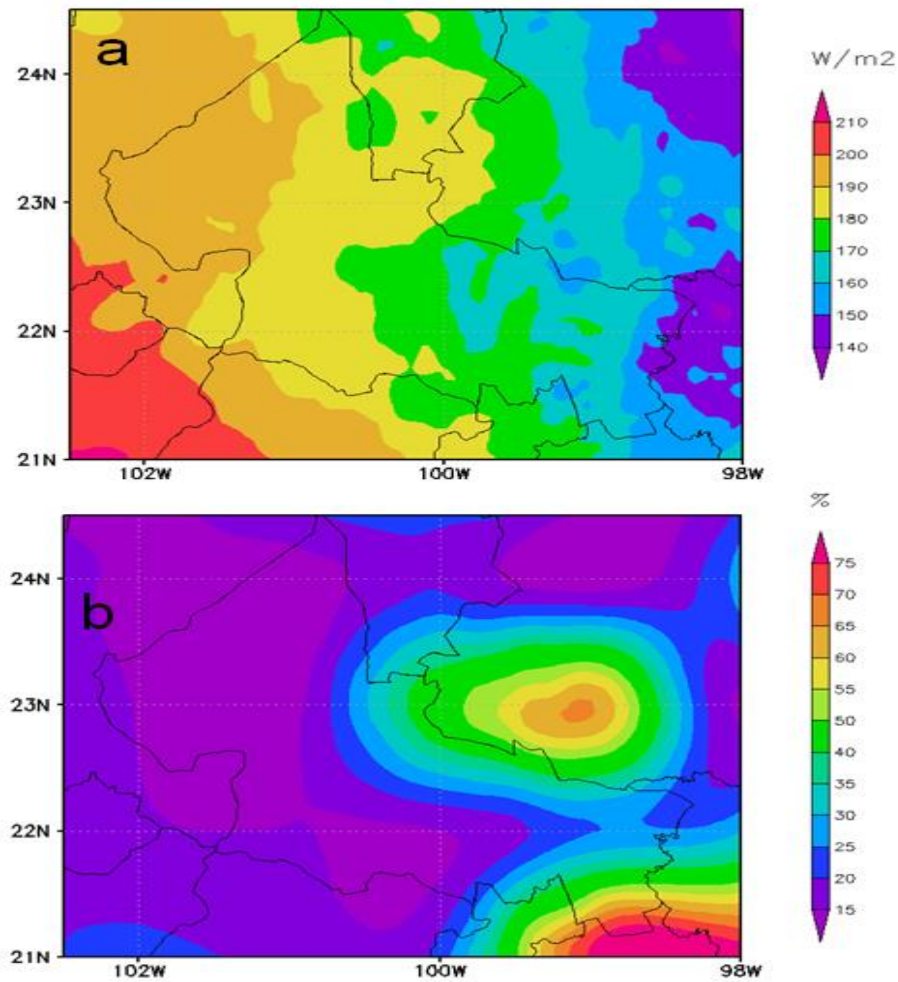

Figure 34: Distribution of monthly means of solar radiation (a) and relative humidity (b) for January, 2011.
Source: Own elaboration based on results of the analysis with the mathematical model WRF, 2013.

In Figure 34, maps of monthly means of the distribution of solar radiation and relative humidity are shown for January, 2011. It is observed that higher values of solar radiation occurs during this period in the western side of the state. The Highland area reaches maxima values of about 200 W/m^2 and minimum average of 170-180 W/m^2 (Figure 34a). Areas with less solar radiation during the month of January are located in the eastern side of the domain with values varying between 140 and 160 W/m^2. In the central part, the solar radiation achieves values of 180-210 W/m^2. Conversely, the distribution of relative humidity reaches maxima values on the eastern side and minima values on the western side. In the Huasteca region, the numerical calculations indicate that the relative humidity varied mostly between 70 % and 90 %, and even about 90-100 % in the southeastern side (Figure 34b). Observe that relative humidity values are very low in the Highland area (15-20 %). The calculations showed that solar radiation and relative humidity are inversely proportional, i.e. the presence of water in the atmosphere affects strongly the solar radiation values on the earth surface.

In February 2011 (Figure 35a), maximum values of solar radiation are depicted in the southern part of the Highlands. In this area, a value of about 240 W/m^2 was calculated. In the middle zone of the state, the solar radiation varied between 220 and 230 W/m^2 and from here decreased eastward until a value of 160 W/m^2 in the Huasteca region. Although the irradiation of short waves from the sun varies normally in the north-south direction, with high values in the equatorial region and very low values in the polar zones, topographic and humidity factors determine the existence of a gradient of solar radiation in the west-east direction in the study area. This west-east gradient is also observed in the distribution of the relative humidity (Figure 35b). Although the patterns may vary along the year, it is important to mention that this relative humidity gradient is completely established in February which indicate that in this month topographic factor dominates. The relative humidity in the Highlands and in the central part is very low (~ 20-30 %). From the central part to the Huasteca there is a strong gradient with changes from 30 % to 90%.

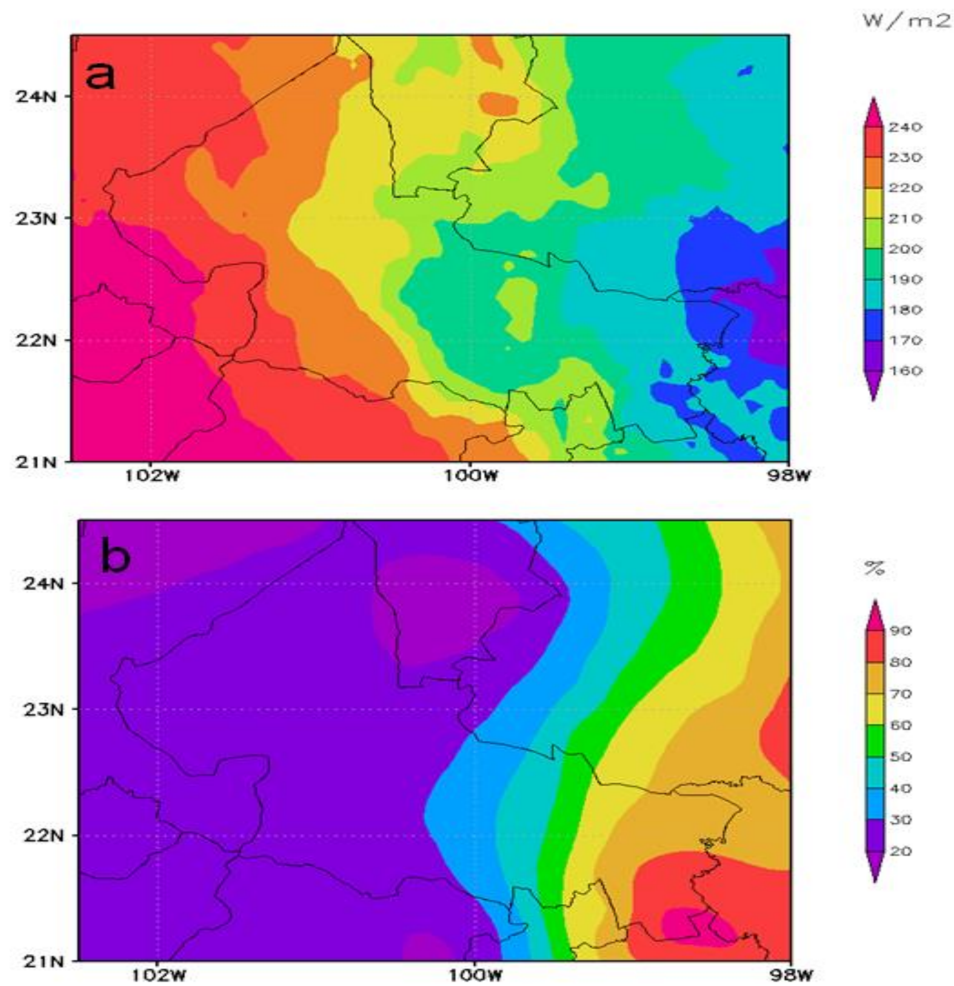

Figure 35: Distribution of monthly means of solar radiation (a) and relative humidity (b) for February 2011.
Source: Own Elaboration based on results of the analysis with the mathematical model WRF.

Although in March (Figure 36a) the general pattern of solar radiation in the study area remained quite similar to that of February, there was an overall increment of about 30-35 W/m^2. Again the maximum value (~285 W/m^2) is found in the Highland and the minimum (~ 240 W/m^2) in the Huasteca area. It is interesting to mention that in the distribution of solar radiation March, topographic factors like chain mountains and valleys manifest clearly in the more complicated pattern of this month. The study area is immerse in the general circulation of the atmosphere where the dynamics is controlled by high and low pressure areas, by instabilities that cause the propagation of cold fronts, flow of warm and moisture air from marine regions, local forcing mechanisms, and other not mentioned forces. This mesoscale circulation intensifies and weakens in the study area causing changes in the distribution of the relative humidity like that observed from February (Figure 35b) to March (Figure 36b) where the gradient changed from a west-east to a north-south direction.

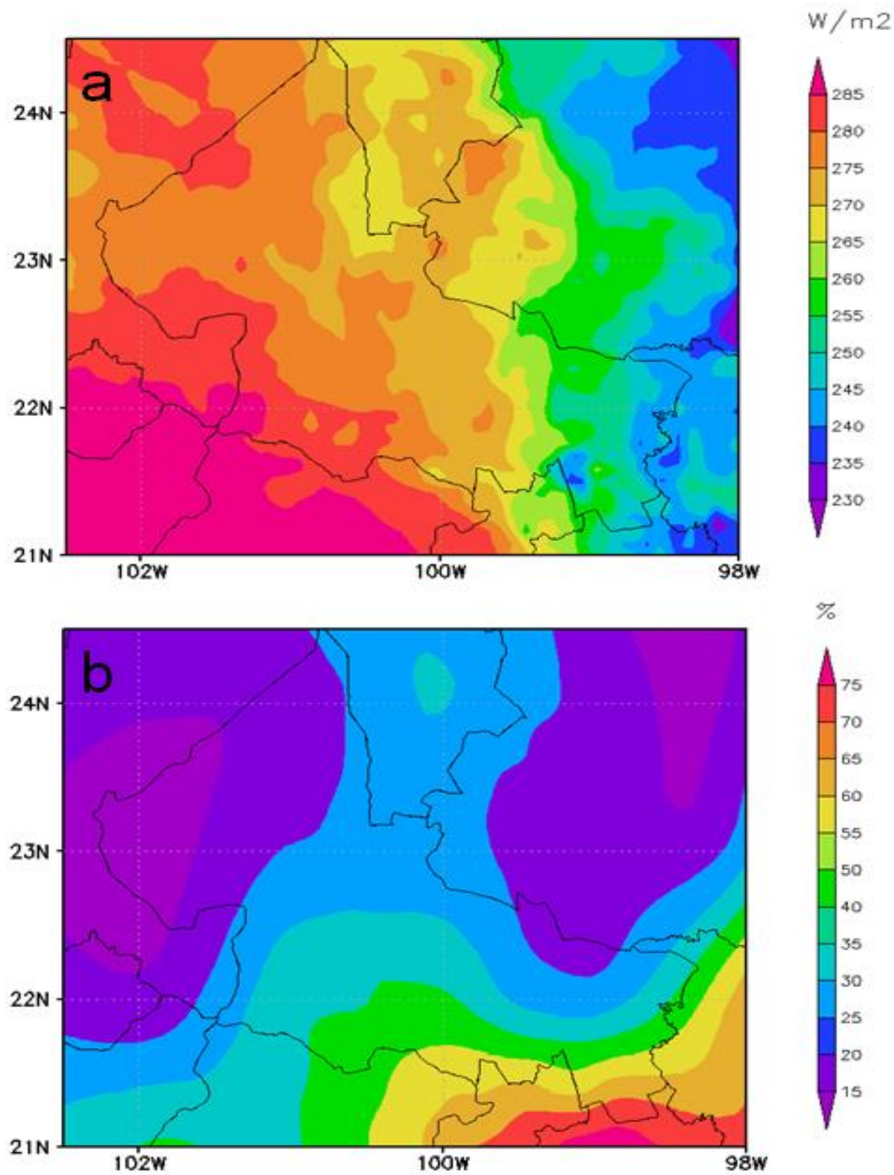

Figure 36: Distribution of monthly means of solar radiation (a) and relative humidity (b) for March 2011.
Source: Own elaboration based on results of the analysis with the mathematical model WRF, 2013.

The monthly mean of solar radiation for April 2011, for the entire domain reveals values ranging between 280 and 320 W/m^2. It indicates that the calculated values for this month for the Huasteca region are larger than those calculated for the Highlands in January and February. The correlation between solar radiation and relative humidity is clearly observed in Figures 37a and 37b, where a gradient oriented in the west-east direction is observed. We conclude that the solar radiation in this month was controlled by the distribution of the relative humidity, i.e. by the humidity contain in the atmosphere. In the Highlands, the values of the relative humidity are still very low. In the central part of the state we distinguish a strong gradient which implies a heterogeneous relative humidity.

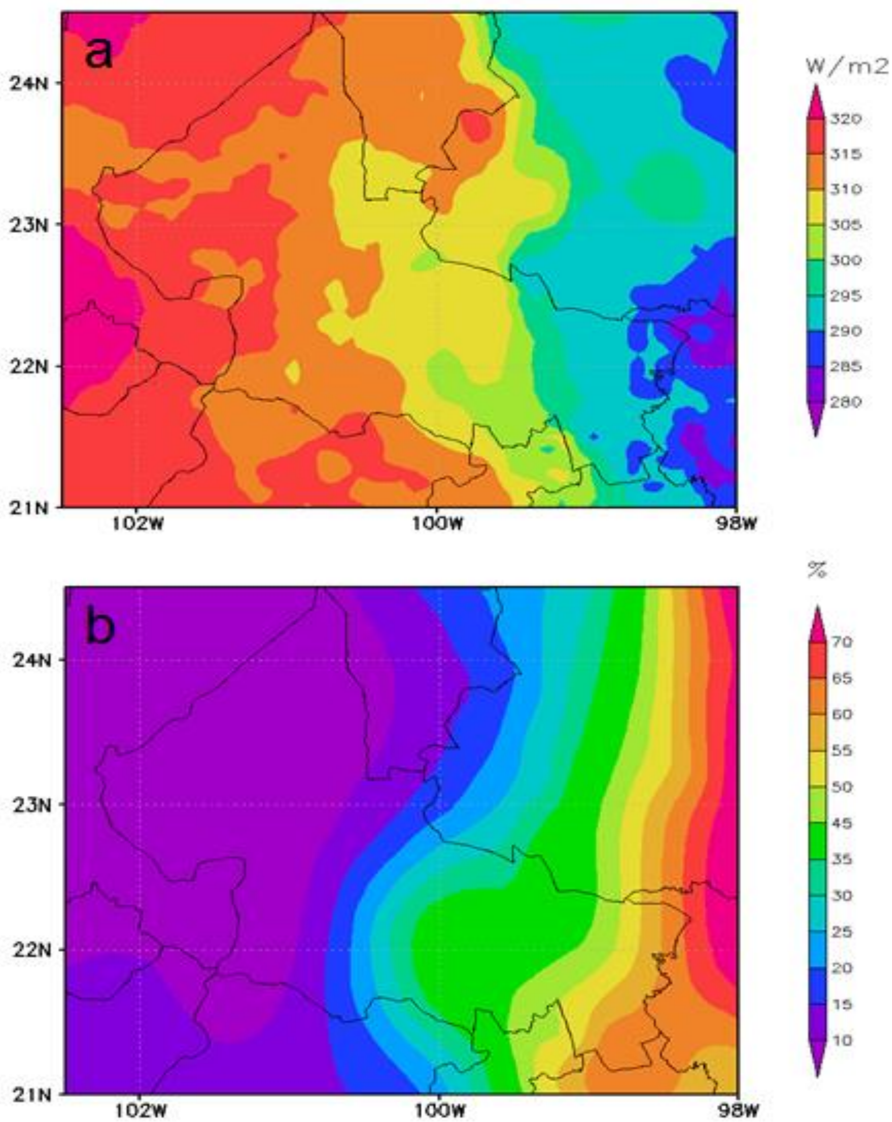

Figure 37: Distribution of monthly means of solar radiation (a) and relative humidity (b) for April 2011.
Source: Own elaboration based on results of the analysis with the mathematical model WRF, 2013.

The difference in solar radiation values between the Huasteca and the Highlands was of about 70 W/m^2 in January and February. In May this difference decreased to about 55 W/m^2 (Figure 34a and Figure 37a). This difference reduction is also observed in the corresponding relative humidity patterns. Although there is still a west-east gradient in the values of solar radiation, we distinguish a complex behavior with intermittent areas and undulating lines which is an indication of topographic effects. In fact, chain mountain influences appear in Figure 38a. This influence occurs in the following way: first, temperature decreases with height. Second, a quantity of water vapor in the atmosphere is saturated more easily at lower temperatures. Saturated water vapor condenses forming liquid water. For this reason, there is more vegetation in the high zones of a chain mountain. If there is more water trapped in the high zones then there is more transpiration by the vegetation. If there is more humidity in the atmosphere, then there is more attenuation of solar radiation. The net effect of all these processes is reflected in Figure 38a. and in Figure 38b, the strong gradient area is now displaced to the east, but there is also a gradient in the central part of the state of San Luis Potosí.

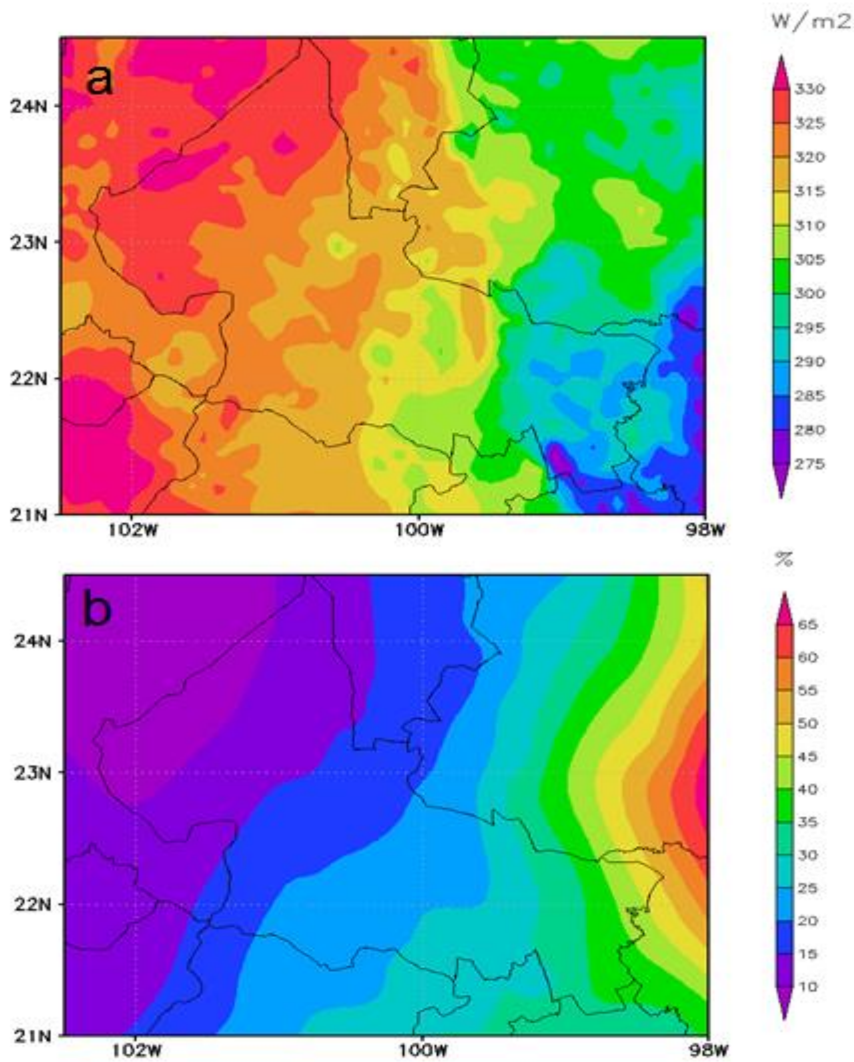

Figure 38: Distribution of monthly means of solar radiation (a) and relative humidity (b) for May, 2011.
Source: Own Elaboration based on results of the analysis with the mathematical model WRF, 2013.

The area with a solar radiation of the order of 330 W/m^2 embraces large region of the Highland (Figure 39a). The radiation in most of the area of the Huasteca zone is about 270-280 W/m^2. However, a minimum of nearly 220 W/m^2 is observed in the southeastern region of the domain. It is interesting to mention that the model was able to reproduce this minimum of solar radiation in the area of Xilitla a region characterized by exuberant vegetation, high humidity values and large precipitation. The area in Xilitla is very humid, which explains the minimum value in solar radiation, as it is observed in

Figure 39a. The gradient of relative humidity is located in the Highland region, it is an indication on how higher concentration values of relative humidity displaced westward (Figure 39b).

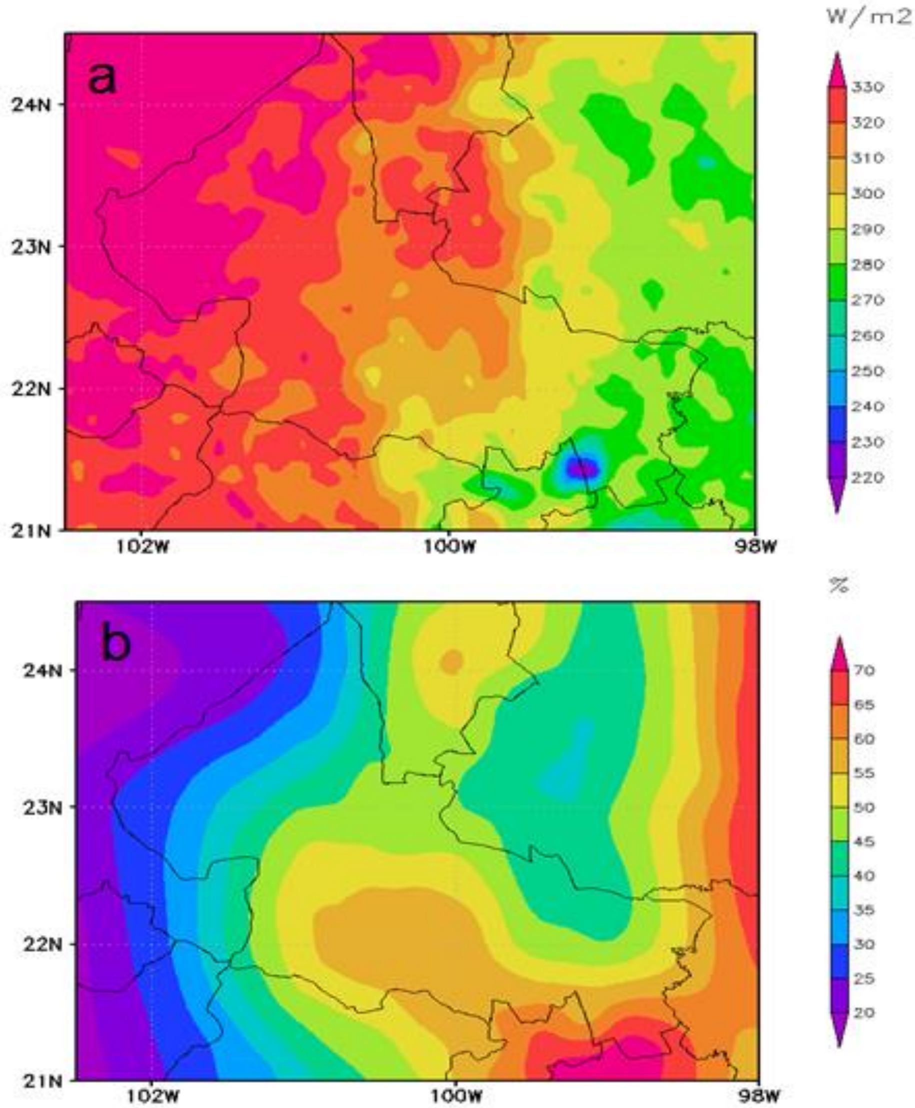

Figure 39: Distribution of monthly means of solar radiation (a) and relative humidity (b) for June, 2011.
Source: Own Elaboration based on results of the analysis with the mathematical model WRF, 2013.

The values of solar insolation (or radiation) in July are slightly smaller than in June (Figure 40a). There is a reduction in the highest value from 330 W/m^2 to 320 W/m^2 in the Highland. A minimum of the solar radiation in the area of Xilitla is also observed clearly in July. The explanation for a slightly solar radiation decrease in July is that the relative humidity increased notably in this month (Figure 40b). The minimum value of the relative humidity, normally found in the Highland region, increased from 20% in June to 45 % in July, which explains the decrease of the solar radiation.

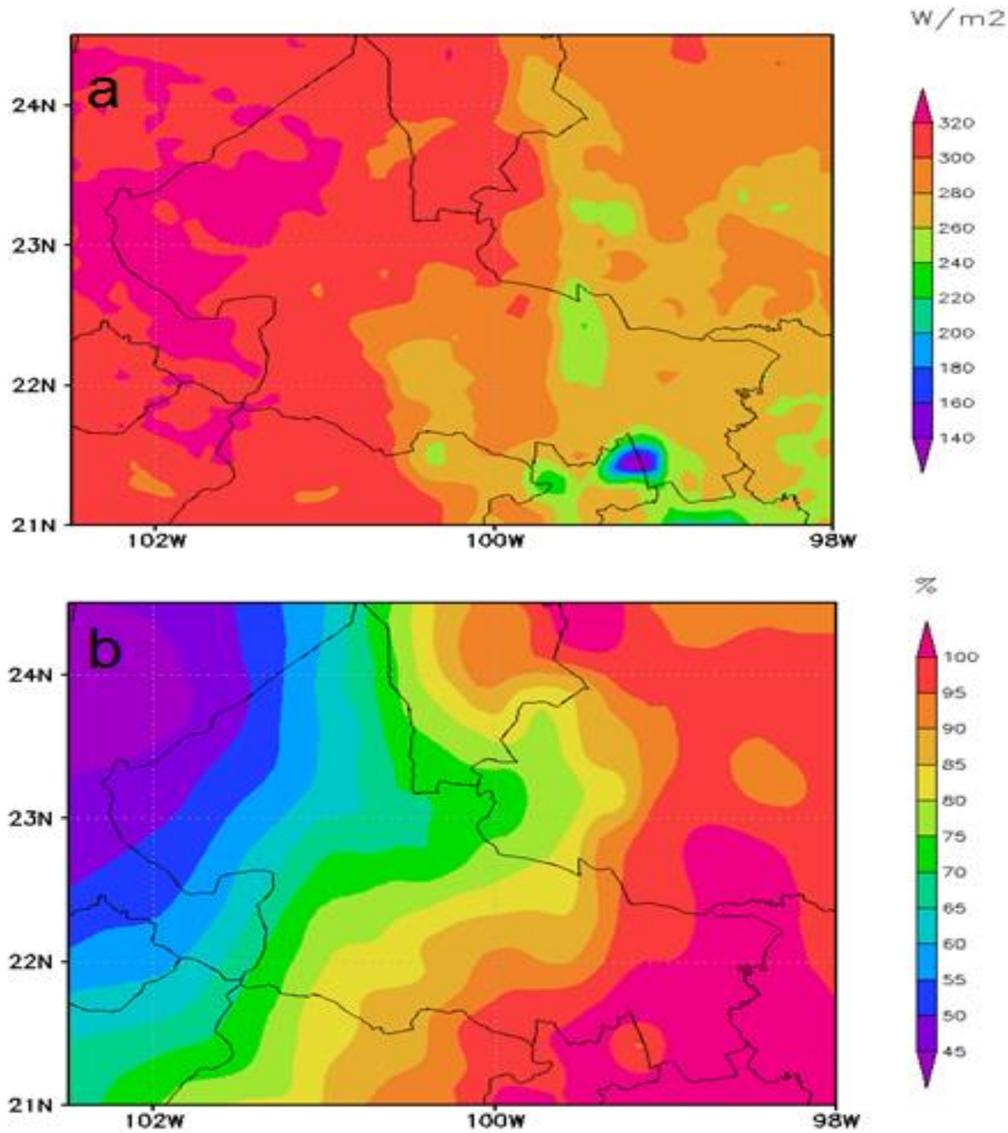

Figure 40: Distribution of monthly means of solar radiation (a) and relative humidity (b) for July 2011.
Source: Own Elaboration based on results of the analysis with the mathematical model WRF, 2013.

The intensity of the solar radiation achieves a maximum in the months of June and July. In the Highland and in the central region, it reaches values of about 300 W/m^2 (Figure

41a). The region of Xilitla shows minimum values. It is interesting to comment that in August there is a homogenization of the solar radiation in the whole Highland region. A gradient of relative humidity is observed in the Highland where it changes from 60 % to 35 % in a small region (Figure 41b). In the Huasteca zone, an area with very high (~90 %) relative humidity, is found. This high humidity contributes to characterize this area as a tropical jungle with rivers, waterfalls and karst topography, i.e. a geological formation consisting of carbonate rock such as limestone soils.

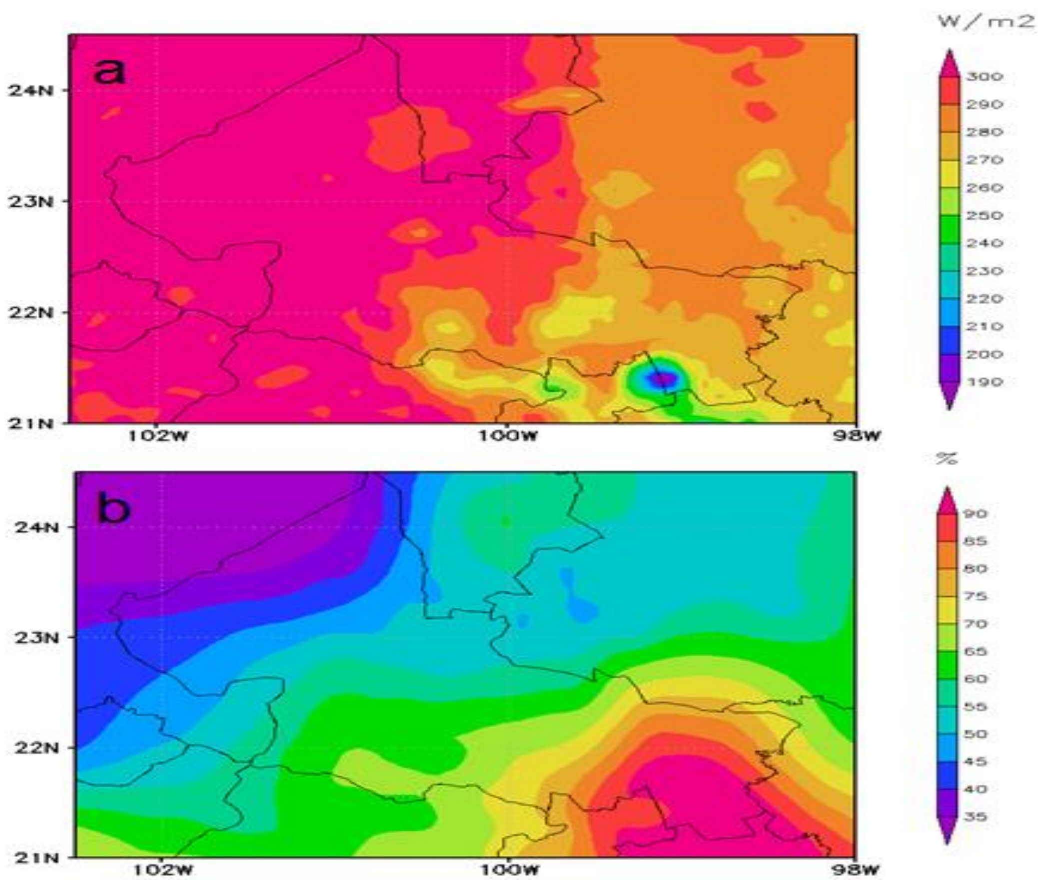

Figure 41: Distribution of monthly means of solar radiation (a) and relative humidity (b) for August 2011.
Source: Own Elaboration based on results of the analysis with the mathematical model WRF, 2013.

To have an idea on how the presence of humidity in the atmosphere attenuates the solar radiation, the values for September were compared between measurements carried out at the top of the atmosphere and at earth surface (Figure 42a). According to the measurements, the solar radiation varies strongly with the latitude and time in a yearly cycle. The State of San Luis Potosí is located between 21° N and 24° N. Considering the presence of humidity in the atmosphere and that it changes a lot from day to day and along a year, the monthly mean is a good indicator of the intensity of solar radiation. In the Highland (Figure 42a), the solar radiation reaches values of about 280 W/m^2 in September whereas the measurements at the top of the atmosphere for these latitudes is of the order of 450 W/m^2 (Petty, 2006). Of course, there are other gases in the atmosphere that absorb solar radiation, but humidity is very variable and therefore it plays an important role in the attenuation of the solar radiation. The conditions of the atmospheric circulation led I the study domain to a gradient in the relative humidity in the north-south direction (Figure 42b).

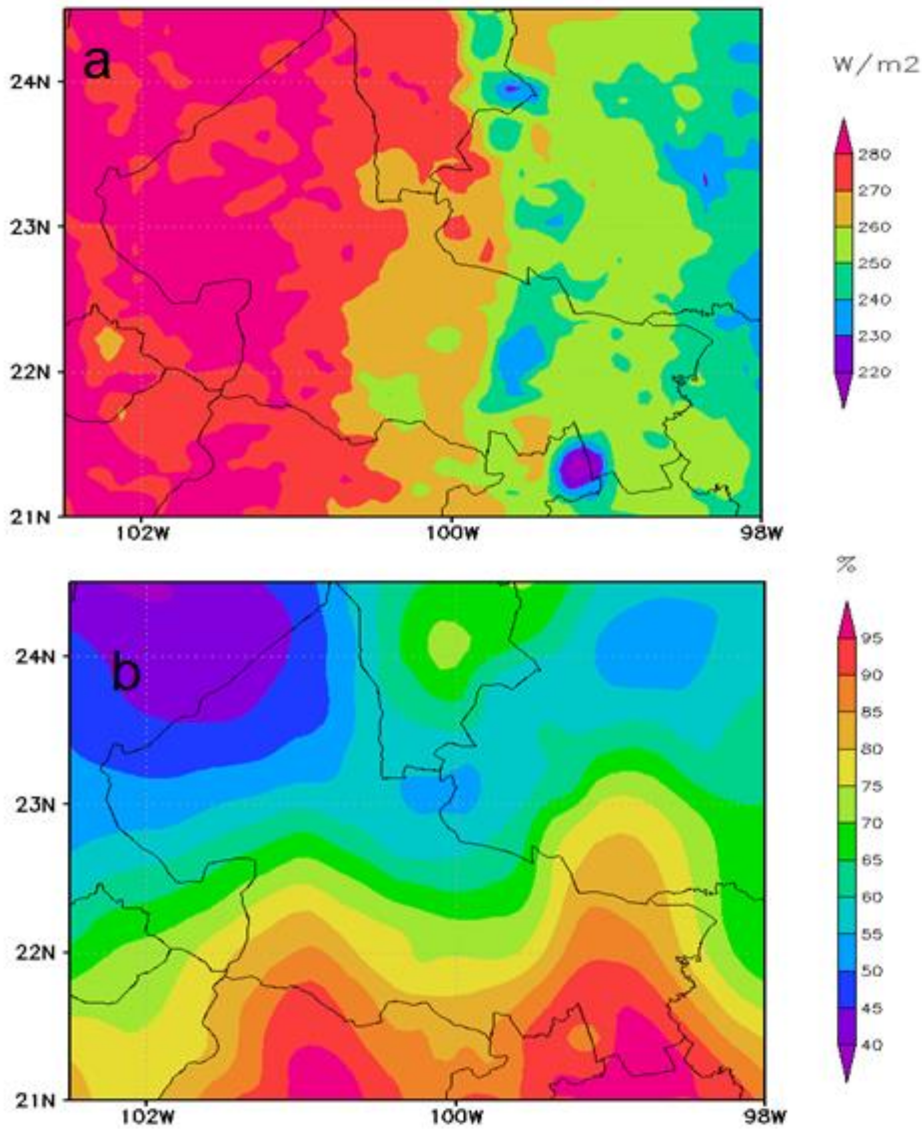

Figure 42: Distribution of monthly means of solar radiation (a) and relative humidity (b) for September 2011.
Source: Own Elaboration Own elaboration based on results of the analysis with the mathematical model WRF.

In October the intensity of the solar radiation begins to decrease reaching a maximum value of only 245 W/m^2 in the Highland region (Figure 43a). In the Huasteca zone (on the eastern side of the domain), the solar radiation achieves values ranging between 210 W/m^2 and 220 W/m^2. The smallest difference in solar radiation values among the Highland and Huasteca regions is of only 35 W/m^2. Two relative humidity gradients, one in the Huasteca and the other in the Highland region, are analyzed in October

(Figure 43b). The relative humidity is of about 45 % in the Highland, this value can be considered as high. The two relative humidity gradients have a north-south orientation. It is worth mentioning that in this month the values of relative humidity in the four zones are very different. The southern part of the Huasteca shows a relative humidity of 100%. The middle zone and the center zone have also high relative humidity during this period (70-85%).

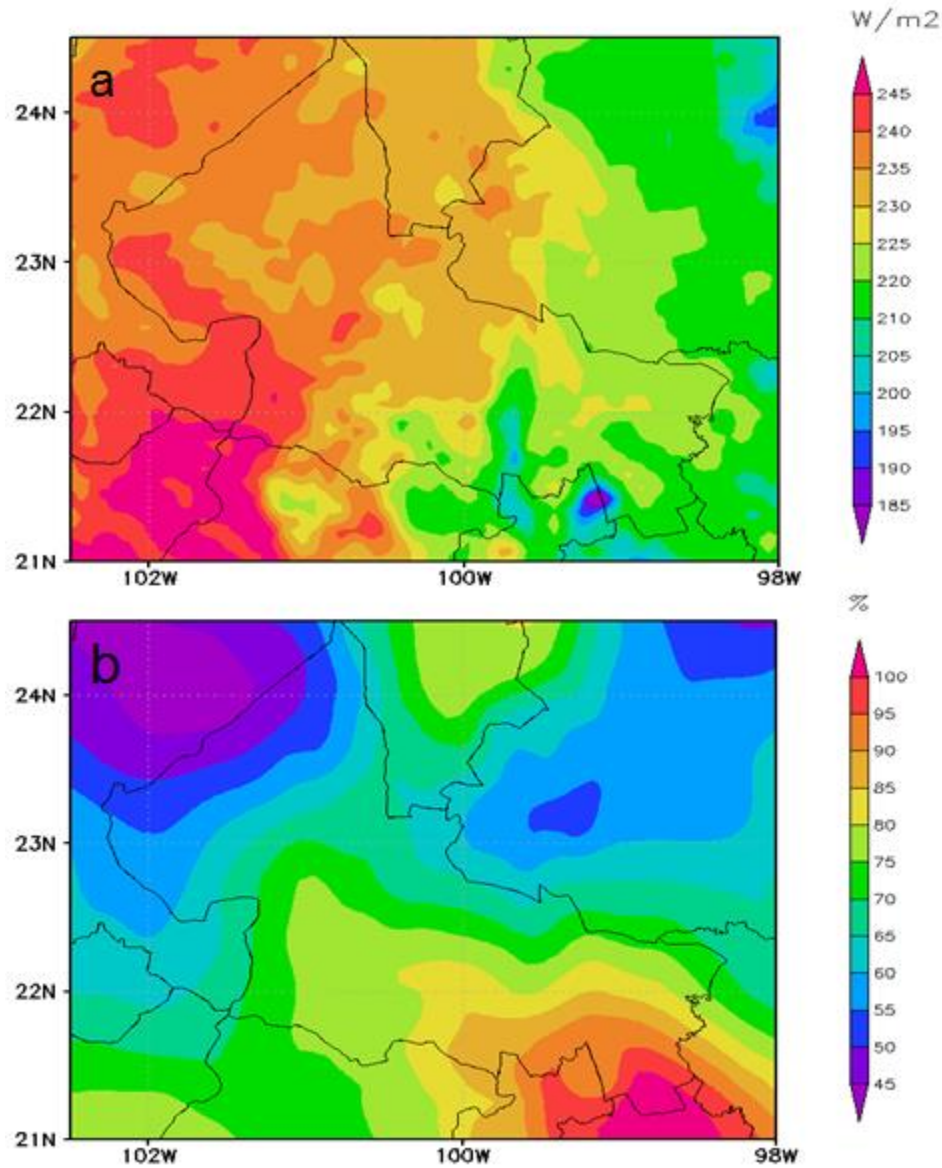

Figure 43: Distribution of monthly means of solar radiation (a) and relative humidity (b) for October 2011.
Source: Own elaboration based on results of the analysis with the mathematical model WRF, 2013.

In the transition period from fall to winter, the solar radiation in the study area shows a chaotic structure, as Figure 44a depicts intermittent areas with different values of solar radiation are observed. A maximum of 220 W/m^2 is found in the south-western area of the domain. In some areas of the Huasteca region values reaches only 160 W/m^2. On the contrary, relative humidity in the Huasteca region is well distributed, with a maximum in the Xilitla region (~85%) and a minimum in the northern part of the Highland (~30 %) (Figure 44b).

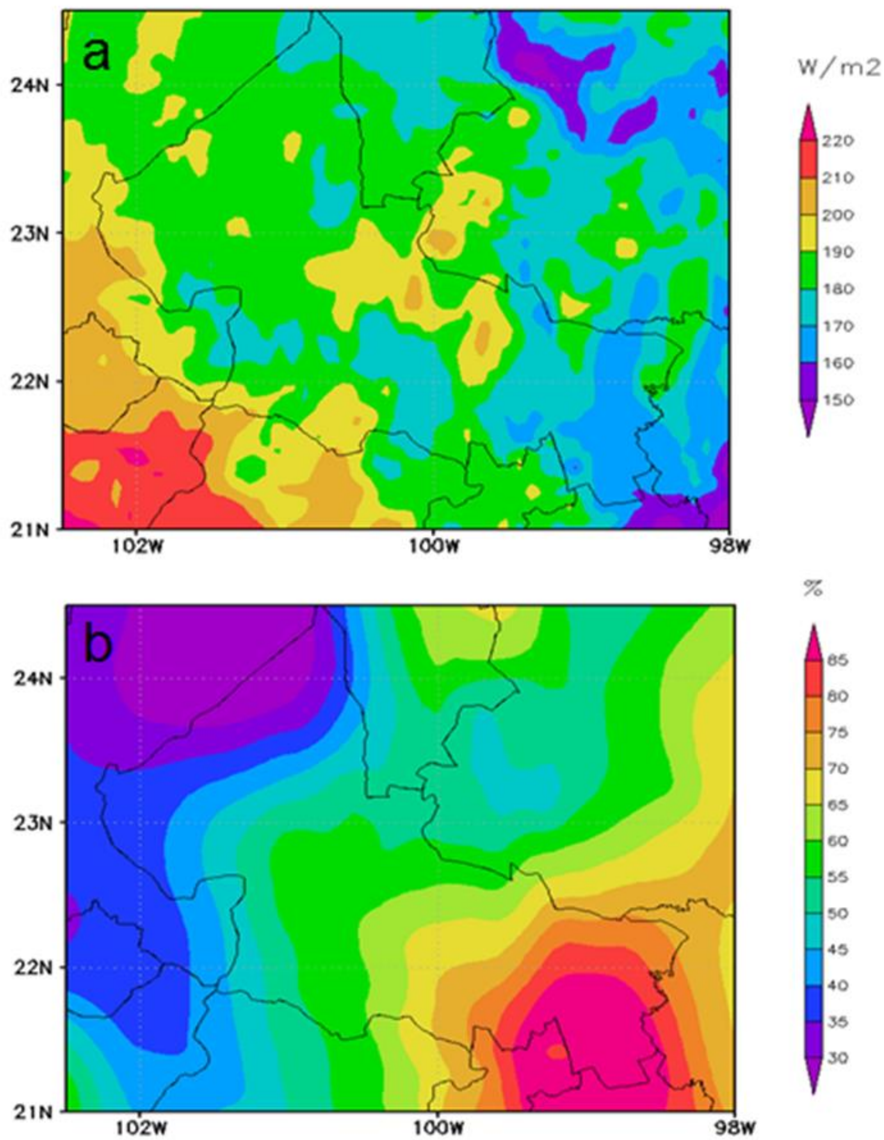

Figure 44: Distribution of monthly means of solar radiation (a) and relative humidity (b) for November, 2011.

Source: Own elaboration based on results of the analysis with the mathematical model WRF, 2013.

The solar radiation pattern is more ordered in December where the winter structure begins to be reestablished, i.e. a solar radiation maximum of about 200 W/m^2 in the Highland and a minimum of about 110 W/m^2 in the Huasteca area (Figure 45a). The relative humidity gradient located in the summer months in the Higland begins to displace eastwards. In the Highland, the relative humidity values reach values of only 20-25 % whereas in the Huasteca values until 75-80 % were calculated (Figure 45b).

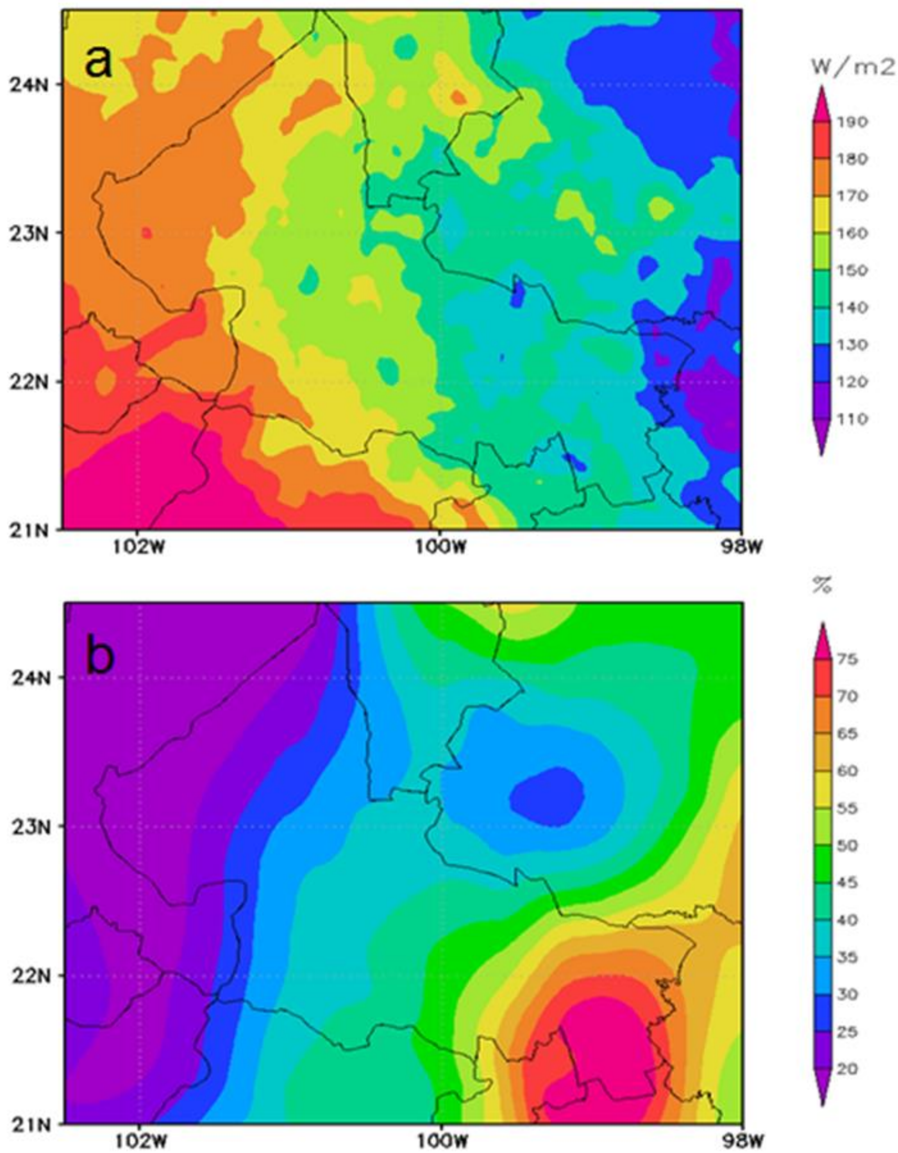

Figure 45: Distribution of monthly means of solar radiation (a) and relative humidity (b) for December, 2011.
Source: Own elaboration based on results of the analysis with the mathematical model WRF, 2013.

In order to study the attenuation of solar radiation by the presence of humidity in the atmosphere, the evolution of the humidity in a yearly cycle was simulated. The humidity is represented in the calculation as a parameter called relative humidity which is denoted in percentage. To simulate the atmospheric circulation in a complete year much computational time was needed in order to generate all the desired data. Of interest for this research work is the relative humidity because humidity attenuates the solar radiation.

It is interesting to observe that altitude above the sea level is very important for the intensity of solar radiation at the earth surface. Similarly, the closeness of the Huasteca region to the Gulf of Mexico is very important for the high relative humidity values observed there. Since the principal aim of this work is to calculate the yearly mean of solar radiation, in order to locate the regions with highest values and the areas with smallest ones.

Figure 46 displays the yearly mean map of solar radiation. This picture reveals a smooth transition from high values in the Highland region (~280 W/m^2) to smaller values in the Huasteca (~230 W/m^2). Minimum values are detected in the area of Xilitla of about 210 W/m^2. Maxima values of solar radiation are found in the municipalities of Santo Domingo, Villa de Ramos, Catorce, Charcas, Salinas and Villa de Arriaga. Figure 48 and Table 12 to depict all these municipalities with their values.

The results show that if a field of solar cells is scheduled in the state of San Luis Potosí, all the analyzed places, the Huasteca, the Central zone, the Middle zone and the Highland, would be appropriated for a respective solar project. In fact all the Highland areas and part of the Central region would be also excellent for the construction of solar cell fields. To have an idea of the distribution of all municipalities, Figure 48 shows a political map of the state. Table 12 illustrates a list of all municipalities and the population structure.

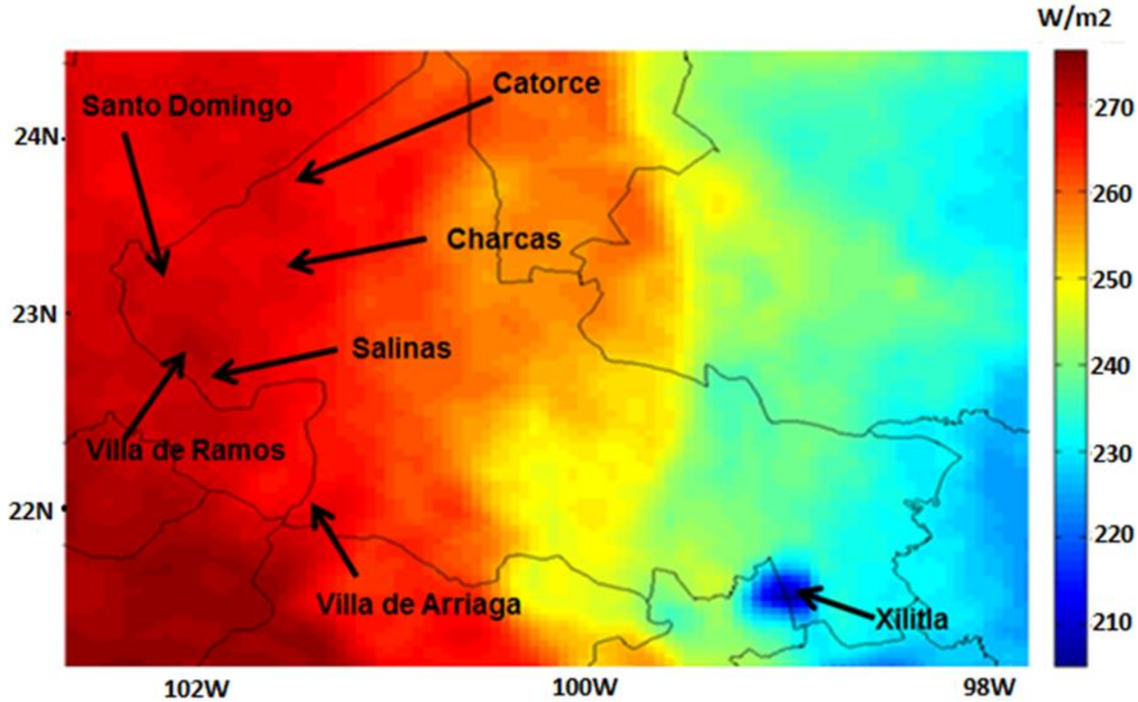

Figure 46: Distribution of the yearly mean of solar radiation for 2011.
Source: Own elaboration based on results of the analysis with the mathematical model WRF.

The yearly mean of relative humidity is shown in Figure 47. Minimum values of relative humidity are detected in the Highland, extending from south to north. The principal relative humidity gradients are found in the Middle zone and in the Huasteca region. In the Highland, the gradients are not strong. It is also relevant to mention that in the southeastern part of the domain relative humidity values reach almost 100 %. In general, this picture agrees with the distribution of solar radiation, i.e. high values of relative humidity implies low values of radiation and vice versa, in regions with low relative humidity values, high values of solar radiation are observed. It can be concluded that the humidity in the atmosphere in relation with the attenuation of solar radiation is very important to find the best places and to project the construction of fields of solar cells for the generation of electrical energy with a good efficiency.

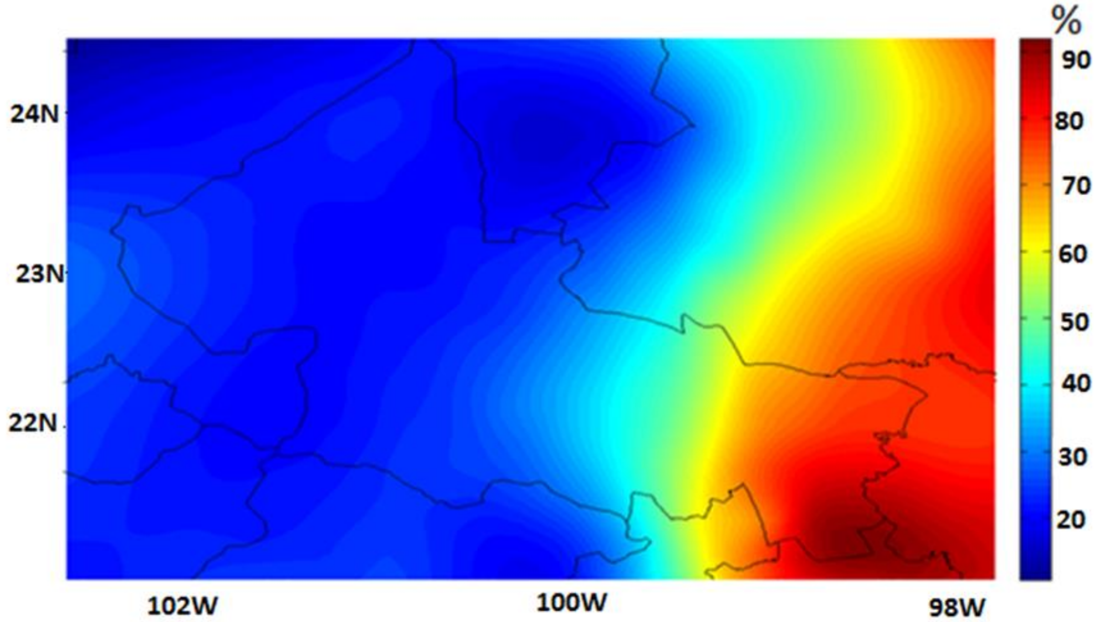

Figure 47: Distribution of the yearly mean of relative humidity for 2011.
Source: Own Elaboration based on results of the analysis with the mathematical model WRF, 2013.

Figure 48: Municipalities in the state of San Luis Potosí.
Source: De la Torre–Moreno, 2006.

Table 14 gives an overview of all municipalities of the state San Luis Potosí.

Table 14: Name and population of all municipalities in the state of San Luis Potosí.

Clave	Nombre del Municipio	Cabecera Municipal	Población
001	Ahualulco	Ahualulco del Sonido 13	19 192
002	Alaquines	Alaquines	8 781
003	Aquismón	Aquismón	42 782
004	Armadillo de los Infante	Armadillo de los Infante	4 889
005	Cárdenas	Cárdenas	18 824
006	Catorce	Real de Catorce	9 889
007	Cedral	Cedral	16 153
008	Cerritos	Cerritos	20 703
009	Cerro de San Pedro	Cerro de San Pedro	3 404
010	Ciudad del Maiz	Ciudad del Maiz	30 603
011	Ciudad Fernández	Ciudad Fernández	39 944
012	Tancanhuitz [1]	Tancanhuitz	19 904
013	Ciudad Valles	Ciudad Valles	146 604
014	Coxcatlán	Coxcatlán	17 352
015	Charcas	Charcas	21 070
016	Ébano	Ébano	39 687
017	Guadalcázar	Guadalcázar	25 359
018	Huehuetlán	Huehuetlán	14 289
019	Lagunillas	Lagunillas	6 538
020	Matehuala	Matehuala	78187
021	Mexquitic de Carmona	Mexquitic de Carmona	48 392
022	Moctezuma	Moctezuma	19 904
Clave	Nombre del Municipio	Cabecera Municipal	Población
023	Rayón	Rayón	15 790
024	Rioverde	Rioverde	88 991
025	Salinas	Salinas de Hidalgo	26 405
026	San Antonio	San Antonio	9 363
027	San Ciro de Acosta	San Ciro de Acosta -Pedro Montoya-	10 493
028	San Luis Potosí	San Luis Potosí ©	670 532
029	San Martín Chalchicuautla	San Martín Chalchicuautla	22 373
030	San Nicolás Tolentino	San Nicolás Tolentino	6 793
031	Santa Catarina	Santa Catarina	10 830
032	Santa María del Río	Santa María del Río	39 066
033	Santo Domingo	Santo Domingo	12 755
034	San Vicente Tancuayalab	San Vicente Tancuayalab	14 107
035	Soledad de Graciano Sánchez	Soledad de Graciano Sánchez	180 296
036	Tamasopo	Tamasopo	27 390
037	Tamazunchale	Tamazunchale	89 074
038	Tampacán	Tampacán	16 008
039	Tampamolón Corona	Tampamolón Corona	13 722
040	Tamuín	Tamuín	35 087
041	Tanlajás	Tanlajás	18 137
042	Tanquián de Escobedo	Tanquián de Escobedo	13 354
043	Tierra Nueva	Tierra Nueva	9 582
044	Vanegas	Vanegas	7 533
Clave	Nombre del Municipio	Cabecera Municipal	Población
045	Venado	Venado	14 205
046	Villa de Arriaga	Villa de Arriaga	14 623
047	Villa de Guadalupe	Villa de Guadalupe	10 378
048	Villa de la Paz	Villa de la Paz	5 135
049	Villa de Ramos	Villa de Ramos	34 432
050	Villa de Reyes	Villa de Reyes	40 602
051	Villa Hidalgo	Villa Hidalgo	14 989
052	Villa Juárez	Villa Juárez	10 956
053	Axtla de Terrazas	Axtla de Terrazas -Alfredo M. Terrazas-	31 405
054	Xilitla	Xilitla	49 578
055	Zaragoza	Villa de Zaragoza	21 962
056	Villa de Arista	Villa de Arista	13 747
057	Matlapa	Matlapa	28 319
058	Naranjo, El	Naranjo, El	18 898
		TOTAL	**2 299 360**

Source: De la Torre–Moreno, 2006.

The next chapter shows the principal municipalities, where the results of the present analysis show an increased solar incidence.

7 Discussion

The impact that the relative humidity factor has in the solar radiation intensity throughout a yearly cycle has been calculated for the state of San Luis Potosí, Mexico. With this it has been demonstrated that the humidity of this region's atmosphere strongly determines the variability of the solar radiation. The study area embraces a complex topography with several chain mountains delineating three main regions at different heights above the sea level; the Huasteca region (300 m.a.s.l.), the Middle zone (1000 m a.s.l.) and the Highland zone (2000 m a.s.l.). These different heights determine the length paths that the solar radiation has to travel through the atmosphere and through the presence of water vapor to reach the Earth's surface. All these effects are considered in the calculations. The regions with the largest solar radiation are identified and indicated in the calculated yearly means of solar radiation maps. The calculated averages or means were based on four daily data as it is common in solar radiation measurements along meteorological stations in Mexico. These four calculated and observed data on solar radiation are then representative for one day. This chapter discusses the practical implications of these results and the importance of the potential use of solar energy in the future. It is also critical to discuss about the actual use of fossil sources of energy and the consequences for the environment.

According to SENER (2012) Mexico is ranked first in solar irradiation levels throughout the country compared with other Latin American countries, having average irradiance levels between 5-6 kWh/m^2 in 90% of the territory. Taking advantage of only an area of Mexico of 22351 km^2 or 1.1% of the country's territory to generate electricity using solar power, it would be sufficient to cover the total national energy demand.

It is necessary to evaluate the energy resource as a first step. That is, to make a solar resource characterization. In this way, one can know the amount of solar resources available in a given area and to locate the main regional areas with largest values of solar radiation. Subsequently, it is necessary to make a proposal to manage the subject of solar radiation and its impact on the development, on the regulatory framework and on the costs of power generation. Another aspect to consider is the type of solar technology that will be installed. For example thermal collectors are based on the number of hours of sunshine, not on the total daily radiation energy. It's performance is acceptable only in the hours when the sun's rays directly reach the collector. Photovoltaic panels, on the other side, consider the total radiation energy and not the number of hours of sunshine, and also take advantage of the diffuse radiation.

Another important remark is that the technological differences and advancements between different manufacturers should also be taken into account when selecting solar energy systems.

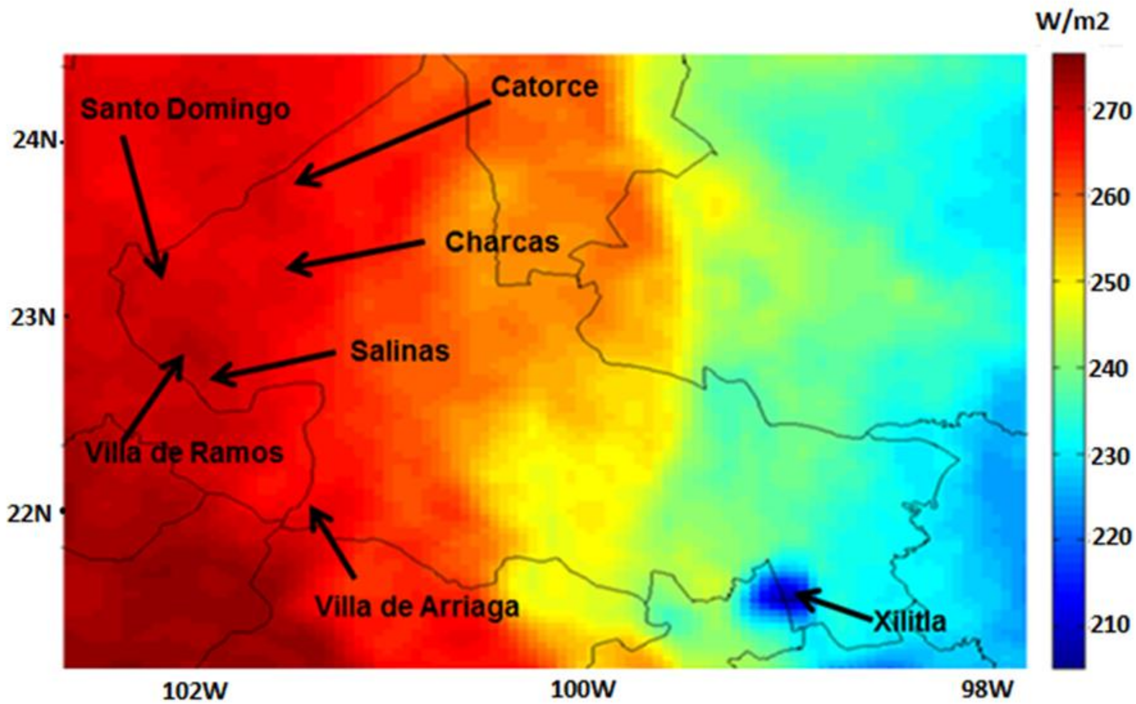

Figure 49: Municipalities selected according to the solar radiation (annual daily average).
Source: Own elaboration based on results of the analysis with the mathematical model WRF.

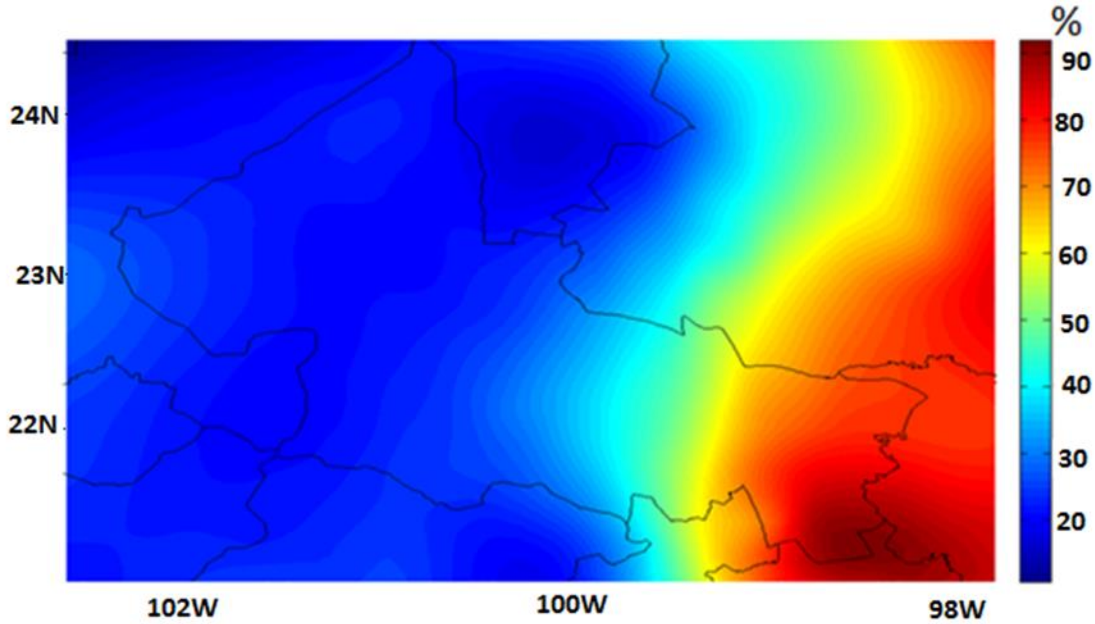

Figure 50: Annual average relative humidity in San Luis Potosí
Source: Own Elaboration based on results of the analysis with the mathematical model WRF.

Figures 49 and 50 show maps of annual average of daily solar radiation and of relative humidity. As mentioned before, the region with the highest solar potential is the Highland region with a range of values (annual average daily) from 260 to almost 300 W/m^2 followed by the Middle and Central regions with a range of values of 250-270 W/m^2. The Huasteca region is the region with smaller values of average solar radiation mostly in the ranges of 210-230 W/m^2. In order of importance in terms of amount of solar radiation received, the Highland area is ranked in first place, second place the Central zone, Middle zone third place and the last place is the Huasteca region.

The relative humidity prevailing in the Huasteca region reached average values over the year from 70% to 90% of relative humidity. The Highland region has an annual average of 20-30% relative humidity. In Middle and Central regions can be observed an average relative humidity of 30% mostly in places close to the Huasteca, where the average values become 40% relative humidity in these regions.

In the case of the state of San Luis Potosí, six regional foci were selected, based on the outcome map of annual average of solar radiation. These municipalities were selected according to the best geographic location, where solar radiation was at its maximum levels and the relative humidity at its minimum levels. In other words the selected foci were those that present the greatest potential for the generation of electrical energy from the available solar energy and where lowest levels of relative humidity were calculated. These municipalities are (Figure 49): Charcas, Catorce, Salinas, Santo Domingo, Villa de Ramos y Villa de Arriaga. A brief explanation of them is given below (INAFED, 2010):

Charcas

The Charcas municipality is located in the Highland, in the northern part of the state, about 2010 meters above sea level. Charcas limits with other municipalities like Catorce, Villa de Guadalupe, Santo Domingo and Salinas. It represents 3.58% of the state territory. The climate is mostly dry-tempered. The southern side of town is dominated by semi-warm weather and to east a semi-dry tempered climate prevails.

Mining is one of the main economic activities, and among the minerals resources found are gold, silver, zinc, copper, lead, onyx and marble. Another economic activity is the production of handicrafts internationally known. Many handicrafts are made of marble or onyx and toy making with hard fibers and wrought iron work. Among its tourist attractions include the paleontological area, the caves of the “Blue Cave”, the ancient granary, onyx articles, factories and the parish of San Francisco. Its land use is mainly for livestock.

In December the solar radiation reaches the smallest values, in this month in the town of Charcas average monthly values of solar radiation throughout the municipality are 150-180 W/m^2. The largest average values of daily solar radiation occur in the months from May to June and range between 320-335 W/m^2. This municipality offers the ideal conditions, the culture and the potential economy for the installation solar cell fields.

Catorce

It is located in the highlands at 2,680 meters above sea level, representing 3.08% of the state territory. Most of the area of this municipality is considered an ecological conservation zone (protected area). It is for the Wirrarica ethnic group and Wirikuta a sacred site. Mining is the most important natural wealth. The handicrafts that are produced in this county are mainly based on gold and silver. The average annual temperature is 16.6 ° C and the average rainfall is 400 mm. In the month of December, it has monthly mean values of solar radiation in the range of 150-180 W/m^2. In the months of May and June (the months with higher average daily solar radiation) it has values of 320-335 W/m^2. The city of Real de Catorce in the municipality of Catorce is considered in Mexico a magic town with a big number of tourists along the year. This municipality is also appropriated for the installation of solar cell fields.

Salinas

Salinas is located to the northwest of the state (plateau region) at 2070 meters above sea level. It occupies 2.88% of the state territory. The dominant climate is mild and dry, and with some regions of temperate dry climate. The average temperature of the town is 18.7 °C and the yearly accumulated rainfall is 391mm. The main economic activity of the municipality is agriculture, mainly engaged in farming of corn and beans, also engage in elaborating carved stone handicrafts, blankets, rugs and clothing knitted or yarn. It's land use, livestock, occurs in 80% of the territory. In the center of this municipality are gaps with presence of salts and some aquifers generally dry and free.

In May, the average monthly radiation presents the highest value compared to the other months of the year, which is between 330-335 W/m^2 and in December 160-180 W/m^2. This well communicated region is also a good place for the installation of solar cell fields.

Santo Domingo

It is located in the northwestern part of the state, in the Highland region, about 1970 meters above sea level, representing 7.34% of the state territory. Small hilly areas are located within this zone and it has a large number of ponds and intermittent streams. The dry climate is predominantly temperate, the average annual temperature is 17.5°C and the maximum temperature can be 37°C in July, with an average yearly accumulated rainfall of 474 mm. The vegetation is characterized by small plants that are drought resistant. In its fauna predominate: rattlesnakes, voles and hares. Its main economic activities are cattle raising, agriculture and trade. This area is one of the most difficult areas where to install a solar cell field due to its location far away from the largest economic activities and the population is not so big. However, from a physical point of view, the solar radiation is strong and it is recommendable for a solar cell field project.

Villa de Ramos

It is located in the highlands at an altitude of 2,200 meters above sea level. It represents 4.12% of the state territory. Most of the municipality is located on the plains and in its hydrography has loopholes so most of the year is dry with some intermittent streams. The predominant climates are dry and semi dry temperate climate. The maximum annual temperature is 30.45°C (July), the average temperature is 17.6°C. In January the lowest temperature values are observed (7°C). Considering the results of the calculated solar radiation, the potential for the generation of electrical energy from solar radiation is large. A solar cell field is justified in this region.

Villa de Arriaga

It is located in the southwestern part of the city of San Luis Potosí. It has an altitude of 2,160 meters above sea level. The climate is semi dry climate with an average temperature of 16.2 ° C. The monthly means of solar radiation are quite similar to those calculated for the other municipalities. The neighborhood with the city of San Luis Potosí makes this area ~~as~~ favorable for the installation of solar cell fields.

Table 15 show general data on the main municipalities with a high potential for the installation of solar cell fields. Xilitla, located in the Huasteca region, is the municipality with the lowest values of monthly and yearly means of solar radiation. It is also characterized by very high values of relative humidity in the whole year.

Table 15: General aspects of the selected municipalities.

Municipality	Territorial Extension	Total occupied housing	Total of households with Electricity	Users with electricity	Volume of sales of electricity (kWh) 2010 year
Charcas	2,164.66 Km^2	5434	4896	6364	17721000
Catorce	1,865.99 Km^2	2469	2208	3118	6795000
Salinas	1,745.31 km^2	6803	6538	---------	---------
Santo Domingo	4,446.94 km^2	3060	2931	144	242000
Villa de Ramos	1,745.31 km^2	9090	8731	----------	---------
Villa de Arriaga	860.50 km^2	3670	3364	----------	---------
Xilitla	414.95 km^2	11,723	10087	10878	16026000

Source: Own elaboration based on INEGI, 2010.

Xilitla, as it can be observed in table 16, has the lowest levels of solar radiation with an annual average irradiance of 210 W/m^2/day (5 kWh/m^2/day or 1800kWh/m^2/annual). However, these values surpass solar radiation values of many countries using photovoltaic or solar thermal technology.

An comparison example is Spain which, in 2011 had a total installed capacity of 4099 MW based on the photovoltaic (REE, 2012) and it is in the top ranks of the European Union in receiving higher levels of solar radiation (1.48 -3.56kWh/m^2) (Saizarbitoria-Heras et al., 2011). The sum yearly maximum values of solar irradiation in this country are 1800-1900 kWh/m^2 as they appear in Figure 51.

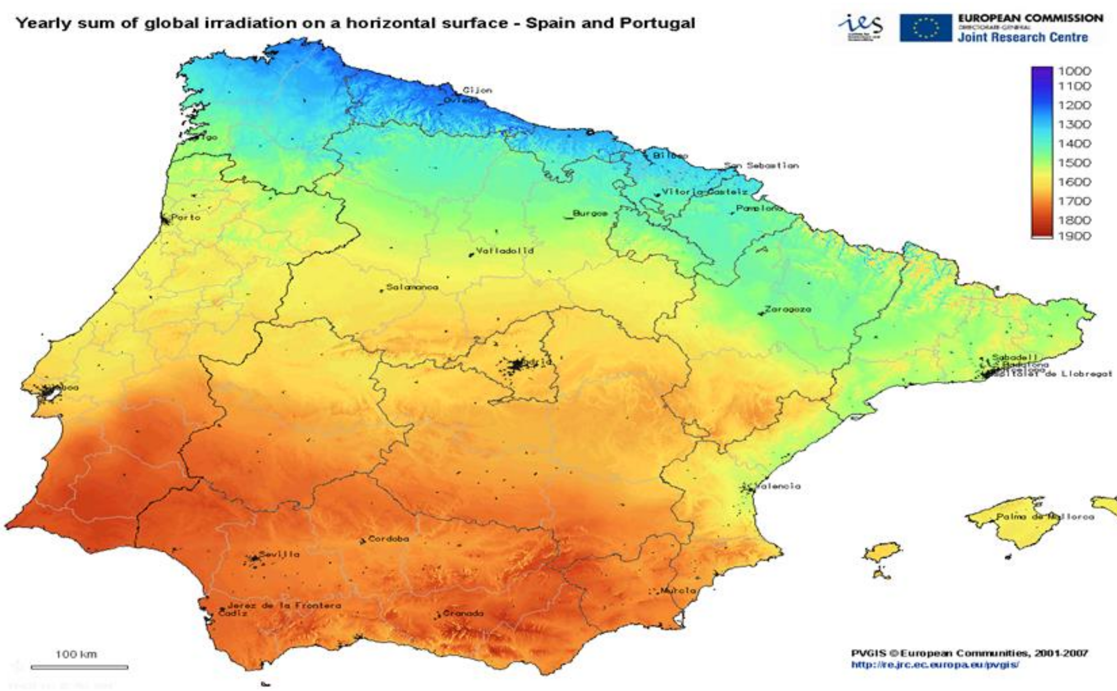

Figure 51: Annual Solar Irradiation in Spain and Portugal in kWh/m^2.
Source: Deutsche Solar, 2013.

Another example is Germany, which is a country with low levels of solar radiation. Figure 6.4 shows that the annual average production of electrical energy from solar radiation reaches maximum value which varies in the range of 1150 to 1200 kWh/m2. It is also one of the leading countries in investment and research into new renewable technologies and key leaders in energy production from solar energy. As a reference, in 2011 0.8% of the final energy consumption in Germany was generated by making use of photovoltaic energy. This is equivalent to GJ 9204 (BMU, 2012).

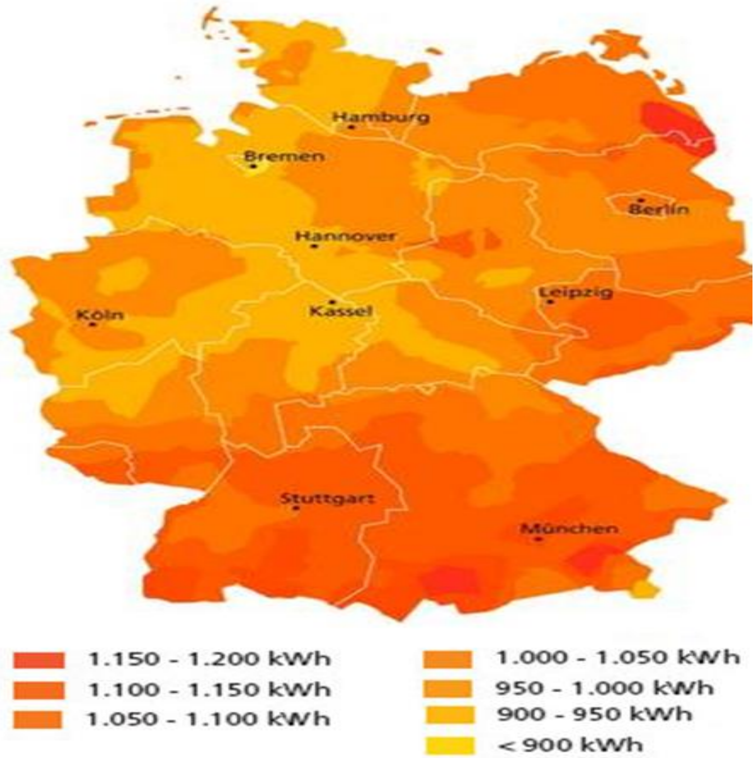

Figure 52: Annual Solar Irradiation in Germany in kWh/m^{2}.
Source: Solar feed in tariff, 2013**.**

In Mexico, there are two solar technologies already in use, one of them consists of solar thermal systems and the other one of photovoltaic systems for electricity production. It is considered that the largest photovoltaic power potential niche, is using photovoltaic panels in household or residential areas. Currently, there are Mexican public policies that support this niche, including the interconnection contract to the grid to solar energy sources to small scale. The interconnection system of CFE grid avoids the use of batteries (CIE-UNAM, 2011).

The connection system, as a first step, exhausts the solar energy produced by the panel, if this energy is not sufficient to meet demand is taken directly from the mains of CFE. That is, solar panels can generate electricity all or part of it and CFE takes the difference between electricity consumption and production by solar panels, in the case that production is more than consumption generates a favorable balance for use within a period of 12 months at no cost (SAYCE, 2013; ECOTECNIA, 2013)

Figure 53: Photovoltaic System connected to the network. An urban day is as follows: during daylight hours with solar radiation, the system produces electricity, the network of Federal Electricity Commission is used as a bank (or batteries) and stores the excess energy produced that was not used during the day to use at night.
Source: ECOTECNIA, 2013.

Figure 54: Urban Photovoltaic System for the Night.
Source: Powerstein, 2013.

Table 16 shows the available solar irradiance throughout the year. It is observed that solar radiation levels are very high in the selected municipalities, it is noteworthy that despite selecting these municipalities, the whole area of the Plateau, the middle region and central region have similar values of relative humidity and solar radiation throughout the year, which makes these regions as the greatest solar resource potential at present in the state of San Luis Potosí.

Table 16: Available solar irradiance throughout the year.

Municipality	Average daily of solar radiation annually in W/m^2	Average daily of solar radiation annually in MW/Km^2	Average daily solar radiation in kWh/m^2 per hour	Average annual solar radiation In kWh/m^2
Charcas	270	364500	6.48	2365.2
Catorce	269	363150	6.456	2356.44
Salinas	270	364500	6.48	2365.2
Santo Domingo	272	367200	6.528	2382.72
Villa de Ramos	275	371250	6.6	2409
Villa de Arriaga	265	357750	6.36	2321.4
Xilitla	210	283500	5.04	1839.6

Source: Own Elaboration.

Example:

That is why in this chapter the feasibility of the use of solar panels in the state of San Luis Potosí is evaluated. It is taken as an example for installing solar panels on a residence. Considering than in Mexico the average annual electricity consumption for an average household is 2643.57 kWh per year (Baena Garza et al., 2010),), data from the annual average of Solar Radiation shown in Table 16 and the formula of the Solar PV system sizing for single resources and technology. the Peak power value, The Peak power value (Ppeak),which also referred as nominal power in the photovoltaic industry (SMA, 2013) will be calculated in orden to know the necessary peak power for a power consumption of an average household in San Luis Potosí. The formula is as follows (Bhandari, 2012):

$$\mathrm{Ppeak} = \frac{\mathrm{E_{el}} * \mathrm{I_{stc}}}{\mathrm{E_{glob}} * \mathrm{Q}}$$

$\mathrm{Ppeak} = \text{Peak Power of PV array under STC } (\mathrm{kW_p})$

$\mathrm{Eelec} = \text{Real electric output of the system } (\mathrm{kWh})$

$\mathrm{Istc} = \text{Peak Power of PV array under STC } (1\ \mathrm{kW/m^2})$

$\mathrm{Q} = \text{Quality factor of the system } (0.75)$

$\mathrm{Eglobal} = \text{Annual global solar radiation } (\mathrm{kWh/m^2})$

$$\text{Ppeak Charcas} = \frac{(2643.57\ \mathrm{kWh}) * (1\ \mathrm{Kw/m^2})}{(2365.2\ \mathrm{kWh/m^2}) * (0.75)}$$

$$\text{Ppeak Charcas} = 1.49026\ \mathrm{kWp}$$

$$\text{Ppeak Catorce} = \frac{(2643.57\ \text{kWh}) * (1\ \text{Kw/m}^2)}{(2356.44\ \text{kWh/m}^2) * (0.75)}$$

$$\text{Ppeak Catorce} = 1.4958\ \text{kWp}$$

$$\text{Ppeak Santo Domingo} = \frac{(2643.57\ \text{kWh}) * (1\ \text{Kw/m}^2)}{(2382.72\ \text{kWh/m}^2) * (0.75)}$$

$$\text{Ppeak Santo Domingo} = 1.4793\ \text{kWp}$$

$$\text{Ppeak Salinas} = \frac{(2643.57\ \text{kWh}) * (1\ \text{Kw/m}^2)}{(2365.2\text{kWh/m}^2) * (0.75)}$$

$$\text{Ppeak Salinas} = 1.49026\ \text{kWp}$$

$$\text{Ppeak Vila de Ramos} = \frac{(2643.57\ \text{kWh}) * (1\ \text{Kw/m}^2)}{(2409\text{kWh/m}^2) * (0.75)}$$

$$\text{Ppeak Villa de Ramos} = 1.4631\ \text{kWp}$$

$$\text{Ppeak Vila de Arriaga} = \frac{(2643.57\ \text{kWh}) * (1\ \text{Kw/m}^2)}{(2321.4\text{kWh/m}^2) * (0.75)}$$

$$\text{Ppeak Villa de Arriaga} = 1.5118\ \text{kWp}$$

$$\text{Ppeak Xilitla} = \frac{(2643.57\ \text{kWh}) * (1\ \text{Kw/m}^2)}{(1839.6\ \text{kWh/m}^2) * (0.75)}$$

$$\text{Ppeak Xilitla} = 1.9160\ \text{kW}$$

With these calculations, the outcome shows that it is necessary a power of 2kWp to supply an average house in Mexico with values of 5kWh of solar radiation using solar cells (ENNERA, 2013). The results shows that given the levels of solar radiation in the selected municipalities, it takes much less power to supply an average house. The estimated area required is also shown in table 17.

Table 17: Results table. According to INEGA (2013), 1 kWp needs approximately an area of 8 to 10 m^2.

Municipality	Ppeak (Kwp)	Approximate Area in m^2 of Photovoltaic Panels Considering $8m^2$ per Kwp	Approximate Area in m^2 of Photovoltaic Panels Considering $9m^2$ per Kwp	Approximate Area in m^2 of Photovoltaic Panels Considering 9m2 Per Kwp
Charcas	1.49026	11.9221	13.4123	14.9026
Catorce	1.4958	11.9664	13.4622	14.958
Salinas	1.49026	11.9221	13.4123	14.9026
Santo Domingo	1.4793	11.8344	13.3137	14.793
Villa de Ramos	1.4631	11.7048	13.1679	14.631
Villa de Arriaga	1.5118	12.094	13.6062	15.118
Xilitla	1.9160	15.328	17.244	19.160

Source: Own Elaboration

It is interesting to mention that it takes a few square meters to meet the blocks demand of average annual solar radiation. This is due to the high levels of solar radiation received in the municipalities' regions.

Using solar panels would also bring environmental benefits, one of which is the reduction of CO_2 in the atmosphere. For this it is necessary to calculate the amount of annual CO2 emissions to the atmosphere for an average household. Data provided by the Mexico's Ministry of Environment and Natural Resources (SEMARNAT, 2013) establish an average emission factor of 1 kWh electricity equivalent to 0.5333 kg of CO2 that go directly to the atmosphere and the annual average power consumption (in kWh) that spends a regular residence in Mexico is 2365.2 kWh (Baena Garza, Max Alonso et al., 2010). Doing the calculation, taking into account the average emission factor and the average power consumption that spend a regular house, the consumption of solar energy would avoid a total CO_2 emissions of 1261.43 Kg. per year per household which represents a lot when you take into account that one tree inhales 12 kg of CO_2 (UNEP, 2013). 102,619 trees would then be annually needed to inhale the CO_2 emitted to the atmosphere by an average house in Mexico each year.

According to the company requested South Renewables, the solar panels installed in areas with high levels of solar radiation also bring economic benefits. As already mentioned the average home needs a 2kWp demand, the approximate price is $5769.00 USD including proceedings before the FIDE and CFE, the savings is 100% and one would only pay a $2.00 USD monthly amount to CFE.

A final conclusion is that it is feasible to install solar panels across the state including the city of Xilitla. This research work is ended with following remark: "It is observed that it is feasible to install photovoltaic panels throughout the state of SLP, since, according to ~~a~~ this study, the roofs of houses in Mexico receive a lot of sunlight to produce 200 times the consumption amount" (Crónica, 2013)".

8 Conclusions

The WRF (Weather Research and Forecasting) model was applied to calculate the evolution of the atmospheric circulation and of physical parameter like the relative humidity and solar radiation in a yearly cycle in the state of San Luis Potosí, Mexico. Since the principal interest was to investigate the potential of generation of electrical energy by solar radiation and since it is known that the solar radiation is strongly attenuated by the presence of water vapor in the atmosphere, maps of monthly means and yearly means of the relative humidity and solar radiation were calculated.

The numerical modelling consisted of two nested domains one of them including completely the state of San Luis Potosí. The resolution for each domain was of 27 Km. for the large domain and of 9 Km. for the smaller domain. These resolutions were accurate enough for the aims of this research work. Although the topography is very complex in the study area, with a series of mountains and strong topographic gradients, the model was calibrated so that the difference between calculated and observed data was of the same accuracy as in other reported research works. The comparison between observed and modelled data was carried out for places located in different regions (Huasteca zone, 300 above sea level, Middle zone, 1000 m above sea level and Highland zone, 2000 m above sea level). Several statistical formulas were applied to measure the deviations of the calculated values from those observed.

Once the model was adapted acceptably for the numerical modelling of the atmospheric circulation and for the calculation of the yearly evolution of the relative humidity and of solar radiation, a statistical analysis was performed to obtain monthly means and yearly means of the relative humidity and of the solar radiation. The changes of the patterns of relative humidity and of solar radiation were evaluated and documented. It was very interesting to demonstrate that the relative humidity and solar radiation are inversely proportional, i.e. a large relative humidity in a region yielded a lower solar radiation. Although the solar radiation changes with latitude, i.e. it diminishes from the equator to the poles, in these calculations the presence of humidity in the atmosphere was more determinant in the calculated values of the solar radiation.

The calculated maps of monthly and yearly averages give fundamental information about the seasonal evolution of the relative humidity and about the attenuation of the solar radiation along the year. They yielded information about the distribution of the relative humidity and solar radiation in the whole domain. The knowledge of the spatial distribution allows taking decisions about where a solar cell field could be installed. The intensity of the calculated yearly mean of solar radiation was compared with the radiation in other places of the world.

The principal conclusion of this research work is that solar cell fields are a powerful alternative to supply electrical energy to communities located in the whole state of San Luis Potosí. Although the calculated patterns of solar radiation revealed differences in the intensity of the yearly mean of insolation, still the lowest values are economically viable for the installation of solar cell fields.

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