Fachhochschule Köln
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Cologne

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA

PROGRAMAS MULTIDISCIPLINARIOS DE POSGRADO EN CIENCIAS AMBIENTALES

AND

COLOGNE UNIVERSITY OF APPLIED SCIENCES

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

PEAK LOAD CLIPPING FOR GREENHOUSE GAS EMISSION REDUCTION IN MANAGUA, NICARAGUA: THE ROLE OF SOLAR THERMAL WATER HEATERS AND PHOTOVOLTAIC SYSTEMS IN HOUSEHOLDS

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES

DEGREE AWARDED BY

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AND

MASTER OF SCIENCE

“TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

FOCUS AREA “ENVIRONMENTAL AND RESOURCES MANAGEMENT”

DEGREE AWARDED BY COLOGNE UNIVERSITY OF APPLIED SCIENCES

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COLOGNE, GERMANY AUGUST 2011

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Erklärung / *Declaración*

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I would also like to thank my dad, who although he is no longer here and I miss them terribly, I always felt him with me, giving me his support and wise words that live on in my memories and will never be forgotten.

Ramses Bermudez
August 2011

PEAK LOAD CLIPPING FOR GHG EMISSION REDUCTION IN MANAGUA, NICARAGUA

The Role of Solar Thermal Water Heaters and Photovoltaic Systems in Households

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Abbreviations and Acronyms

Economy

C$	:	Nicaraguan Córdoba
€	:	Euro
U$	:	United States American Dollar
EIT	:	Economy in Transition
GDP	:	Gross Domestic Product
LDC	:	Least Developed Country
OECD	:	Organization for Economic Co-operation and Development

Institutions

CNDC	:	Centro Nacional de Despacho de Carga *National Dispatch Center*
CNE	:	Consejo Nacional de Energía *National Energy Council*
ENACAL	:	Empresa Nicaragüense de Acueductos y Alcantarillados *Nicaraguan Sewage and Water Enterprise*
ENATREL	:	Empresa Nacional de Transmisión Eléctrica *National Electrical Transmission Enterprise*
ENEL	:	Empresa Nicaragüense de Electricidad *Nicaraguan Electricity Company*
INE	:	Instituto Nicaragüense de Energía *Nicaraguan Energy Institute*
INETER	:	Instituto Nicaragüense de Estudios Territoriales *Nicaraguan Institute of Territorial Studies*
MEM	:	Ministerio de Energía y Minas *Ministry of Energy and Mines*
EPA	:	US Environmental Protection Agency
GIZ	:	Deutsche Gesellschaft für Internationale Zusammenarbeit
IEA	:	International Energy Agency
IMF	:	International Monetary Fund
IPCC	:	Intergovernmental Panel on Climate Change
MP	:	Montreal Protocol
NASA	:	National Aeronautics and Space Administration
NOAA	:	National Oceanic and Atmospheric Administration
UN	:	United Nations
UNEP	:	United Nations Environment Programme
UNFCCC	:	United Nations Framework Convention on Climate Change
WMO	:	World Meteorological Organization

Chemical Compounds

Br	:	Bromine atom
CFC	:	Chlorofluorocarbon
CH_4	:	Methane molecule
Cl	:	Chlorine atom
CO_2	:	Carbon dioxide molecule
H_2O	:	Water molecule
HCFC	:	Hydrochlorofluorocarbon
HFC	:	Hydrofluorocarbon
N_2O	:	Nitrous oxide molecule
O_3	:	Ozone molecule
PFC	:	Perfluorocarbon
SF_6	:	Sulphur hexafluoride

Greenhouse Effect

GHG	:	Greenhouse Gas
LLGHG	:	Long Lived Greenhouse Gas
CO_2e	:	Carbon Dioxide Equivalent (unit used to express warming capacities of GHG)
GWP	:	Global Warming Potential (expressed as CO_2e)
ODP	:	Ozone Depleting Potential
ODS	:	Ozone Depleting Substance
RF	:	Radiative Forcing (expressed as W/m^2)

Temperature

°C	:	Degrees Celsius (temperature unit)
°F	:	Degrees Fahrenheit (temperature unit)
°K	:	Degrees Kelvin (temperature unit)

Length / Distance

µm	:	micro meter (length unit equivalent to 1×10^{-6} m)
m	:	meter (length unit)
km	:	kilometer (length unit equivalent to 1.000 m)

Area

cm^2	:	square centimeter (area unit)
m^2	:	square meter (area unit equivalent to 10,000 cm^2)
km^2	:	square kilometer (area unit equivalent to 1,000,000 m^2)

Volume

gal	:	US gallon (liquid)
		1 gallon US (liquid) = 3.7854118 grams (liquid)
Bbl	:	Barrels (volume unit usually referred to fossil fuels)
		1 barrel = 42 US gallons = 34.9723 imp gal = 158.9873 L

Mass / Weight

kg	:	kilogram (weight unit)
ton	:	metric ton (weight unit equivalent to 1,000 kg)

Energy and Power

J	:	Joule (energy unit)
MJ	:	Megajoule (energy unit equivalent to 1 x 10^6 J)
GJ	:	Gigajoule (energy unit equivalent to 1 x 10^9 J)
TJ	:	Terajoule (energy unit equivalent to 1 x 10^{12} J)
GCV	:	Gross Calorific Value (expressed in energy units, commonly joules or BTUs)
NCV	:	Net Calorific Value (expressed in energy units, commonly joules or BTUs)
W	:	Watt (power capacity unit)
kW	:	Kilowatt (power capacity unit equivalent to 1,000 W)
MW	:	Megawatt (power capacity unit equivalent to 1,000,000 W)
GW	:	Gigawatt (power capacity unit equivalent to 1,000,000,000 W)
Wh	:	Watt hour (energy unit)
kWh	:	Kilowatt hour (energy unit equivalent to 1.000 Wh)
MWh	:	Megawatt hour (energy unit equivalent to 1,000,000 Wh)
GWh	:	Gigawatt hour (energy unit equivalent to 1,000,000,000 Wh)

Other Acronyms

AM	:	Air Mass
CDM	:	Clean Development Mechanism
COP	:	Conference of the Parties
LPG	:	Liquefied Petroleum Gas
MPP	:	Maximum Power Point
MOP	:	Meeting of the Parties
NGO	:	Non-governmental Organization
PV	:	Photovoltaic
SWH	:	Solar Water Heater
SIN	:	Sistema Interconectado Nacional *National Interconnected System (Nicaragua's National Electricity Grid)*
UV	:	Ultraviolet

Exchange Rate

1 U$ = 22.5597 C$
1 € = 32.23596 C$

Exchange rates as of the 15th of August, 2011

***NOTE:** The English numerical system will be used in this document. The "," (comma) will be employed as a thousands, millions and billions separator; while the "." (dot or point) will be used as a decimal separator, to separate whole numbers from decimal numbers.
1 billion = 1,000,000 units

Abstract

In these days climate change and global warming have become topics of great importance. Global warming normally is a natural process that occurs on Earth throughout millions of years due to fluctuations in solar radiation, changes in the planet's orbit and its inclination, which are also known as the *Milankovitch Variations*, but it is believed that human beings have also played a big role in the acceleration of this natural process by altering the composition of the atmosphere.

One of the greatest causes of global warming is the emission of greenhouse gasses (GHG). The increased use of fossil fuels and reduction of sources that are able to absorb these gasses (plant life) have altered the composition of the atmosphere. An evident increase in the concentration of GHG has occurred since the *Industrial Revolution*, time at which massive amounts fossil fuels began to be used as a practical fuel source and deforestation started to take an important part of "development": fossil fuel consumption increased, the demand for energy per capita began to quickly rise, greater sources were required to satisfy the growing energy needs, and forests began to disappear; either for fuel source, raw material, or simply to make way to grow crops and build cities.

Carbon dioxide (CO_2) is the most important anthropologically emitted GHG. It consists of almost 80% of the total GHG emissions, making it one of the principal factors responsible for the increase in global temperature. The Electricity and Heat sector contributes with most CO_2 emissions (32%), forming 24.6% of the total GHG emissions.

This research investigation is focused on the decrease of peak electricity consumption with the use of solar water heaters (SWH) and photovoltaic (PV) systems in households, in order to reduce the GHG emissions from the electricity sector in Managua, Nicaragua. Peak load electricity is the most expensive type of electricity produced in a system, commonly produced by small, easy-to-start fossil fuel generators, what makes it easily susceptible to price increments due to the rise on oil prices. A reduction of peak load electricity consumption would signify a decrease in the fossil fuel requirements for electricity production, which also means a drop in CO_2 emissions. Furthermore the decrease in fossil fuel use represents a small break in the link between electricity prices and oil prices, implying greater independence from oil imports, greater energy security, and a reorientation of the investment capital previously used in the purchase of fossil fuels.

The purpose of this research is to demonstrate the potential electricity savings, fossil fuel reduction, and GHG reduction by evaluating the use of SWH and PV systems. This potential will be evaluated on a single size SWH and/or PV system based on real meteorological data (yearly averages) of the location. The savings will be given in electricity and economical savings in households, which later will be converted into fossil fuel and GHG reduction at a national level according to an estimated market penetration rate of the systems.

Keywords: *Managua, Nicaragua, solar energy, peak load clipping, solar thermal water heaters, photovoltaic, CO2 concentrations, GHG reduction.*

Resumen

En estos días los temas de cambio climático y calentamiento global son de gran importancia. El calentamiento global normalmente es un proceso que ocurre en el planeta a través de millones de años debido a fluctuaciones solares, cambios en la órbita e inclinación del planeta, factores que también son conocidos como las *Variaciones de Milankovitch*, pero los humanos han alterado la composición atmosférica, jugando una gran parte en la aceleración de este proceso natural.

Una de las principales causas de calentamiento global es la emisión de gases de efecto invernadero (GEI). Un incremento en la concentración GEI es claramente evidente desde la *Revolución Industrial*, época en la que se empezó a utilizar combustibles fósiles como una fuente de energía práctica y la reducción de la capacidad del planeta para absorber estos gases (vida vegetal), lo que ha alterado la composición atmosférica. El uso masivo de combustibles fósiles y la deforestación eran vistos como un factor importante del "desarrollo": el consumo de combustibles aumentó, la demanda de energía per capita subió, y más fuentes de energía eran necesarias para satisfacer la creciente demanda; los bosques también empezaron a desaparecer, ya sea para fuente de combustible, materia prima, tierras de cultivo, o simplemente para hacer lugar para construir ciudades.

El dióxido de carbono (CO_2) es uno de los GEI más importantes emitidos por los humanos. CO_2 consiste en casi 80% de las emisiones totales de GEI, lo que lo hace uno de los principales factores del incremento en la temperatura global. El sector de electricidad y calefacción contribuye con la mayoría de emisiones de CO_2 (32%), lo que significa 24.6% de las emisiones totales de GEI.

El enfoque de esta investigación es la reducción del consumo de electricidad pico utilizando calentadores solares y sistemas fotovoltaicos en domicilios, con el propósito de reducir las emisiones de GEI en el sector eléctrico de Managua, Nicaragua. La electricidad pico es la electricidad más cara de producir, comúnmente creada por un generador pequeño, fácil de activar, que es alimentado por combustibles fósiles; lo que hace que este tipo de electricidad sea muy susceptible al incremento de precios debido al aumento del precio del combustible. Una reducción en el consumo de electricidad pico significa un decremento en los combustibles fósiles requeridos en la producción eléctrica, lo que también simboliza una caída en la emisión de CO_2. Además, la reducción de uso de combustibles fósiles también representa una ruptura del enlace entre el precio de la electricidad y el precio del combustible, lo que implica una mayor independencia en las importaciones de petróleo, mayor seguridad energética y una reorientación de inversión del capital utilizado en la compra de petróleo.

El propósito es evaluar el potencial de ahorro eléctrico, combustibles fósiles y reducción de GEI a través del uso de calentadores solares y sistemas fotovoltaicos. El potencial será evaluado de acuerdo a un tamaño específico de calentador solar y sistema fotovoltaico con respecto a valores reales de datos meteorológicos (promedios anuales) de la ubicación. El cálculo del ahorro eléctrico y económico en los domicilios luego será transformado en reducción de combustibles fósiles y emisión de GEI a nivel nacional; todo de acuerdo a una tasa estimada de penetración en el mercado de los sistemas.

Palabras clave: *Managua, Nicaragua, energía solar, reducción de energía pico, calentador de agua solar, fotovoltaico, concentraciones de CO2, reducción de GEI.*

Zusammenfassung

In diesen Tagen sind Klimaveränderung und Erderwärmung Themen von großer Bedeutung geworden. Erderwärmung ist normalerweise ein natürlicher Prozess, der auf der Erde im Laufe von Millionen von Jahren wegen Schwankungen in der Sonnenstrahlung, Änderungen in der Bahn des Planeten und seiner Neigung vorkommt. Diese sind auch als die Milankovitch Schwankungen bekannt. Darüber hinaus nimmt man aber auch an, dass Menschen eine große Rolle in der Beschleunigung dieses natürlichen Prozesses gespielt haben, indem sie die Zusammensetzung der Atmosphäre verändern.

Eine der größten Ursachen der Erderwärmung ist die Emission von Treibhausgasen. Der vermehrte Gebrauch von fossilen Brennstoffen und die Verminderung von Ressourcen, die im Stande sind diese Gase zu absorbieren, haben die Zusammensetzung der Atmosphäre verändert. Seit der Industriellen Revolution hat die Konzentration von Treibhausgasen stark zugenommen – eine Zeit, in der fossile Brennstoffe begannen massiv als praktische Kraftstoffquelle verwendet zu werden und Abholzung zu einem wichtigen Teil "der Entwicklung" wurde. Somit nahm der Verbrauch fossilen Brennstoffs zu, die Energienachfrage pro Kopf stieg stark an, weitere Ressourcen waren erforderlich, um die wachsenden Energiebedürfnisse zu befriedigen und Wälder begannen zu verschwinden; entweder für die Kraftstoffquelle, den Rohstoff, oder einfach um Platz für den Getreideanbau oder neue Städte zu schaffen.

Kohlendioxyd (CO_2) ist das am meist verbreiteten anthropologische emittierte Treibhausgas. Mit fast 80% der Gesamtemissionen ist es eines der Hauptfaktoren, die für die Zunahme in der globalen Temperatur verantwortlich ist. Der Elektrizitäts- und Heizsektor trägt mit den meisten CO_2 Emissionen (32 %) bei, welche 24.6 % der Gesamtemissionen bilden.

Diese Forschungsarbeit zielt auf die Reduzierung des Spitzenlastverbrauchs mit Hilfe von solaren Warmwasserkollektoren (SWH) und Photovoltaik (PV) Systemen in Haushalten ab, um die Treibhausemissionen des Elektrizitätssektors in Managua, Nicaragua zu reduzieren. Spitzenlast ist die teuerste Art der Elektrizität, welche ein System produziert. Gewöhnlich wird sie durch kleine, leicht zu startende fossile Brennstoffgeneratoren erzeugt, welche sehr empfindlich auf einen Anstieg der Ölpreise reagieren. Die Verminderung des Spitzenlastverbrauchs würde eine Abnahme des Bedarfs an fossilen Brennstoff für die Stromproduktion bedeuten, welches gleichzeitig mit einer Reduktion von CO_2 Emissionen einhergeht. Durch den sinkenden Verbrauch fossiler Brennstoffe kann ein kleiner Einbruch der Verbindung zwischen Elektrizitätspreisen und Ölpreisen, größere Unabhängigkeit von Ölimporten, größere Energiesicherheit sowie eine Umlagerung des Kapitals, welches vorher in fossile Brennstoffen investiert wurde, erreicht werden. Zweck dieser Forschung ist, die potenziellen Elektrizitätsersparnisse, die Verminderung des fossilen Brennstoffs, und die Reduzierung der Treibhausgase durch den Gebrauch von SWH und PV Systemen zu demonstrieren. Dieses Potenzial wird auf einer einzelnen Größe SWH und/oder PV auf echte meteorologische Daten basiertes System von der Position bewertet. Die Einsparungen werden in Strom- sowie in wirtschaftlichen Ersparnissen von Haushalten wiedergegeben, welche später in die Verminderung von fossilen Brennstoff und Treibhausgasen auf nationaler Ebene umgewandelt werden.

Schlüsselwörter: *Managua, Nicaragua, Solarenergie, Reduzierung des Spitzenenergieverbrauchs, solare Wassererwärmung, Photovoltaik, CO_2 Konzentration, Reduzierung der Treibhausgase.*

Chapter 1: Introduction

Climate change and global warming have become topics of great importance and are being addressed by nations and organizations worldwide, affecting all of us, whether we want to or not. The first stage of climate change currently being addressed is a rise in the average global temperature, which is commonly known as *global warming*. This normally happens as part of a natural process due to fluctuations in the Sun's radiation, small changes in Earth's orbit and inclination *(Milankovitch Variations)*, but humans have accelerated the process by altering the gasses that constitute the atmosphere.

An increment in the concentration of specific gasses in the atmosphere contributes to the rise of average global temperature by absorbing and re-emitting *infrared thermal radiation*; sun radiation that is reflected by Earth's surface in the form of a longer wave radiation. A portion of this radiation is supposed to disperse into space, maintaining a balance in Earth's temperature, but the accumulation of these gasses create a layer that trap this radiation; not allowing it to go out to space, therefore incrementing Earth's average temperature and creating what has become known as the *Greenhouse Effect*. The thicker the layer gets (higher concentration of gasses), the more infrared radiation captured and the warmer the Earth gets. The gasses that produce this effect have become known as *Greenhouse Gasses* (GHG). (IPCC, 2007a)

1.1 Humans Role in Global Warming

An increase of Earth's average temperature is already occurring *(see Figure 1.1)*. GHGs are most likely responsible for this rapid increment of temperature, which will probably cause extreme climatic conditions that will affect our lives and way of living. The emissions of most of these gasses are primarily anthropogenic related, so in order to prevent a possible disaster it is up to humans - the principal emitters - to reduce the emission of these gasses into the atmosphere. Water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are GHGs that occur naturally on Earth, but the concentration of these gasses have dramatically increased due to human actions. While other gasses like chlorofluorocarbon (CFCs), halocarbons (HFCs; PFCs) and sulphur hexafluoride (SF_6) used in refrigeration systems, aerosols and other components, are completely human elaborated chemical compounds; making their presence completely our responsibility. These human elaborated compounds have a higher rate of heat trapping potential and a larger lifespan in the atmosphere than natural occurring gasses.

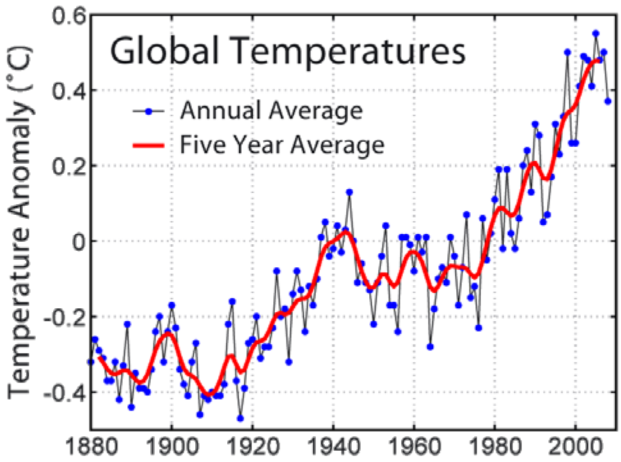


Figure 1.1: Global Temperature Variations
Source: *(Rohde, 2009)*

1.1.1 The Relationship between Energy and Population

Atmospheric measurements demonstrate a clear rise of GHG in the atmosphere since the *Industrial Revolution*; due to the use of massive amounts of fossil fuels as primary energy source, over exploitation of natural resources, deforestation and the fabrication of new types of gasses. Ice records clearly proof that for the last 400,000 years the concentration of carbon dioxide (CO_2) has never been higher (NASA, 2009); and without the need of ice records we can also be certain that some gasses have never existed in atmosphere, since they have been entirely manufactured by humans for aerosols and refrigeration equipment.

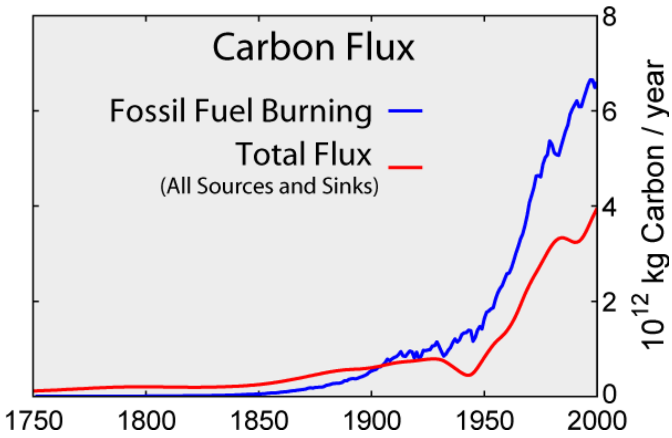


Figure 1.2: Carbon Dioxide Variation in the Atmosphere
Source: *(Rohde, 2009)*

The global concentrations of CO_2 have been steadily increasing since the Industrial Revolution, because people form part of an energy-hungry society that measures prosperity and development by showing how much energy they consume; exposing how much they can afford with material things acquired: a car, bigger house, TV, iPhone, computers, the latest technology, clothing, including food. Everything consumes energy in its manufacture, transportation, distribution, advertisement, storage, maintenance, and even during its final use. Most of this energy comes from the combustion of fossil fuels, which emits CO_2 even before its consumption: throughout its extraction, transportation, refinement, distribution, as well as pumping it into the end-user's gas tank. Over the years the consumption of energy per capita gets bigger and bigger, and so does the world population. As the amount of energy requirement rises, so does the amount of CO_2 emitted; since as previously mentioned, most of this energy comes from fossil fuels. The destruction of forests also plays a big role in the increase of CO_2. Humans destroy these natural CO_2 sinks to make way for new living spaces and grow enough food to supply the increasing energy-hungry population.

1.2 Greenhouse Gasses in the Atmosphere

The *Protocol of Montreal*, signed in 1987, was the first treaty to indirectly regulate *Greenhouse Gasses*. This protocol intends to control the use of gasses responsible for the deterioration of the O_3 molecule in the upper atmosphere. (Montreal Protocol, 1987) Although its initial purpose was not to reduce the global warming, most of the gasses controlled by this legislation have been found to produce an extremely high greenhouse effect; which were later addressed by the *Kyoto Protocol* in 1997. This protocol also included the regulation of other substances not controlled by the Protocol of Montreal: CO_2, CH_4, N_2O, SF_6, PFCs, and HFCs. (Kyoto Protocol, 1997) The following figure demonstrates the world emissions by sector of the gasses regulated in the Kyoto Protocol according to emission levels in.

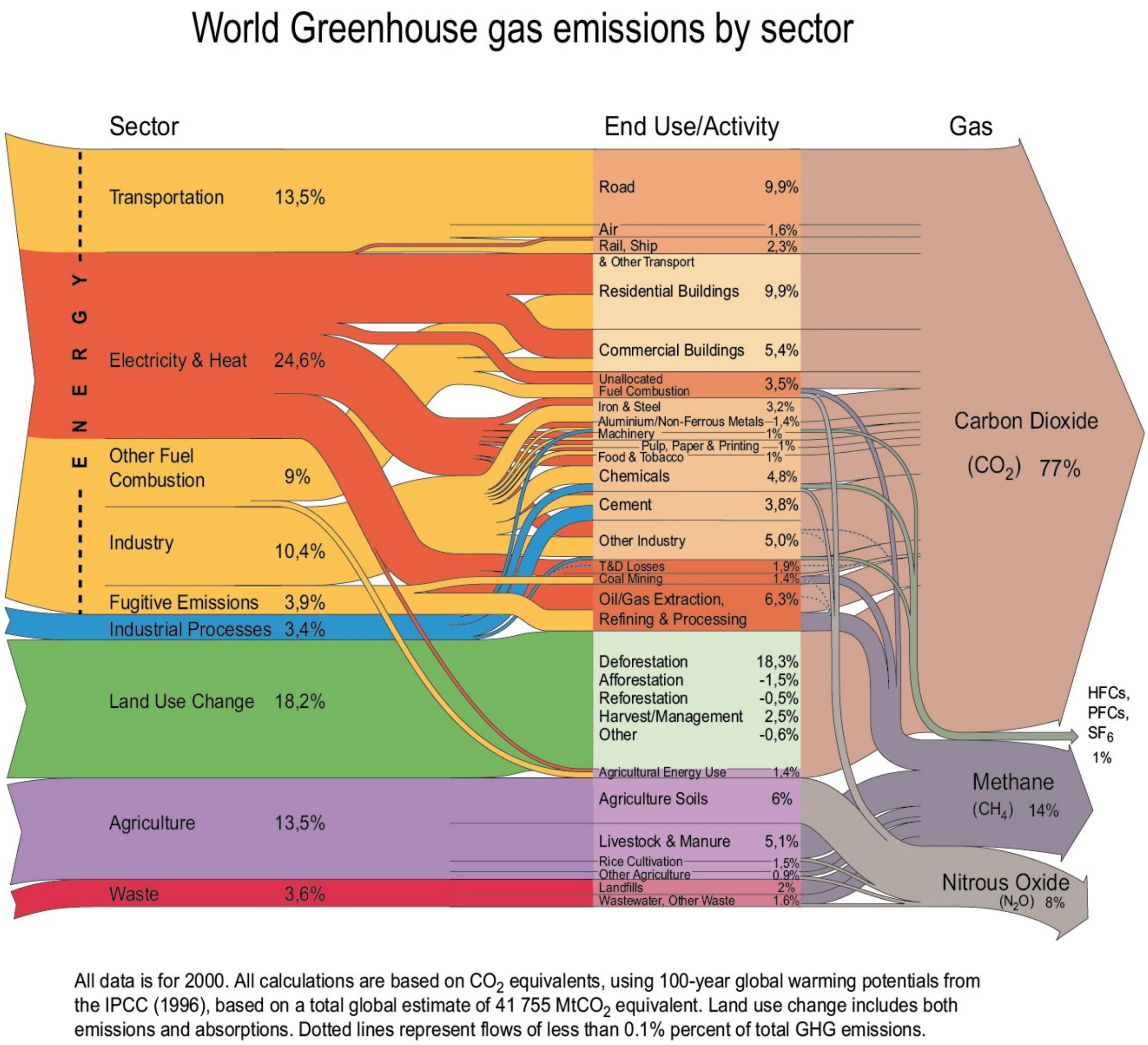


Figure 1.3: World GHG emissions by sector.
Source: *(World Resources Institute, 2010)*

Heat and electricity production from fossil fuels are the primary contributors of GHG emissions in the world. This sector is responsible for 24.6 % of the total GHG emissions and 32 % of total CO_2 emissions. (World Resources Institute, 2010) The annual emissions of CO_2 have increased by about 80 % from 1970 to 2004, from 21 to 38 gigatonnes (Gt), which is 77% of the total GHG emissions in 2004, making it the most important anthropogenic GHG. (IPCC, 2007b) In 2007 66.9 % of the electricity in the world was produced by fossil fuels: 41 % carbon, 5.8 % oil, 20.1 % gas; and only 18.3 % by renewable energies from which 16 % is attributed to hydropower and only 2.3 % to other renewables like: wind, solar and biomass. (IEA, 2009)

1.3 Nicaragua seeks a Future in Renewable Energies

Nicaragua is the biggest country in Central America, located in the tropics and with a great potential for solar energy, but this potential has not yet been exploited. The population in 2011 is estimated around 6 million people. (INIDE, 2007b) The economy in Nicaragua has greatly suffered since the 1970's, with regard to GDP per capita Nicaragua is considered as the second poorest country in Latin America and the Western Hemisphere; just after Haiti. (CIA, 2011)

Map 1: Nicaragua in Central America
Design: *Author*

The capital city of Nicaragua is Managua, located in the pacific region of the country. Managua was once the most developed city in Central America, but in 1972 it was completely destroyed by an earthquake and has not recovered since then. Now Nicaragua is in the verge of change and is seeking a future with renewable energies. In 2009 the first wind farm went online with an installed capacity of 39.9 MW and now has expanded its capacity to 63 MW. By 2017 Nicaragua is expected to generate 90% of its electricity from renewable energies. (EFE, 2011)

Considering that CO_2 is the biggest contributor of GHG emissions in the world, and that the heat and electricity sector are responsible for one third of the total emissions; this research is aimed to reduce the CO_2 emissions of the electricity sector in Managua, Nicaragua by decreasing peak electricity consumption through the use of solar water heaters and photovoltaic systems in households. Peak load electricity is the most expensive electricity generated; it is usually produced by fossil fuels because they are quick and easy to come online when additional power is required. In the case of Nicaragua, 60% of the total electricity generation is produced by fossil fuels. Fossil fuels also represent 100% of the peak load electricity production. A decrease in peak load electricity consumption would represent a decrease in total electricity production costs and a reduction of CO_2 emissions. It would also imply a diminution of fossil fuels used to generate electricity, which means more dependency from the already expensive fossil fuels, breaking the link of oil price and electricity costs. Furthermore, since Nicaragua does not produce any type of fossil fuel and relies entirely from imports, this would also signify greater energy security for the country.

1.4 Main Objectives and Hypothesis

The main objective of this research investigation is to **assess the potential for greenhouse gasses reduction through peak clipping with the use of photovoltaic and solar thermal water heater systems in households in Managua, Nicaragua**.

Since peak load electricity is produced exclusively from fossil fuels, the municipality should be enabled to reduce its electricity production costs, decrease the use of fossil fuels, and contribute in the reduction of global warming by avoiding the emission of greenhouse gasses. This would also represent a greater independence from imported fossil fuels, which means a greater stability in energy security and economical savings.

Specific Objectives

i. ***Identify the current electricity production scheme, electricity consumption, and hot water production in households.***
ii. ***Determine the potential electricity savings from the use of a solar thermal water heater system in a household according to solar radiation in Managua.***
iii. ***Determine the electricity production potential of a one-sized photovoltaic system in a household according to solar radiation in Managua.***
iv. ***Create scenarios of the new load profile and determine the electricity production-consumption savings, decrease of fossil fuel use, and the reduction of carbon dioxide emissions.***

This investigation is a descriptive-exploratory research that pretends to demonstrate the potential of solar energy systems in households to reduce peak load electricity consumption in Managua, Nicaragua. In the first chapters it will prepare the reader with basic information about climate change (Chapter 2), its international framework (Chapter 3), electricity power systems (Chapter 4), and solar energy technologies (Chapter 5). This will create a knowledge basis to understand better what the researcher pretends and why the decision of this investigation. While chapter 6 presents in a simple way the data required to achieve the objectives and how the researcher pretends to retrieve this information. Once the reader has knowledge of the what, why, and how, the investigation starts to develop on the particular case of study in Managua, Nicaragua: Chapter 7 contains information that is relevant to the investigation in Managua, and necessary in order to achieve the objectives; Chapter 8 discusses the results obtained for each of the objectives; And finally Chapter 9 gives conclusions and recommendations from the expert opinion of the researcher; obtained from previous knowledge, and throughout the development of this investigation.

Chapter 2: Climate Change

The Earth's climate has always changed and it has generally been part of a natural process that usually takes millions of years, but recently humans have accelerated the rate at which this change occurs. Climate change and global warming is something that is currently occurring, as a matter of fact the UNEP published in its last *Global Environment Outlook* of 2007 (GEO4): "*The trend of global warming is virtually certain, with 11 of the last 12 years (1995–2006) ranking among the 12 warmest years since 1850, from which time there has been systematic temperature.*" (UNEP, 2007)

Climate change is defined as a significant change in climate for a long period of time, from decades to millions of year. These changes include temperature, precipitation, or wind; caused by forcing mechanisms that may be internal or external. (EPA, 2011)

- Internal forcing mechanisms: Natural processes that occur within the climate system itself.
- External forcing mechanisms: Natural or anthropogenic processes that are not part of the climate system itself, but still affect it in a crucial way. (EPA, 2011)

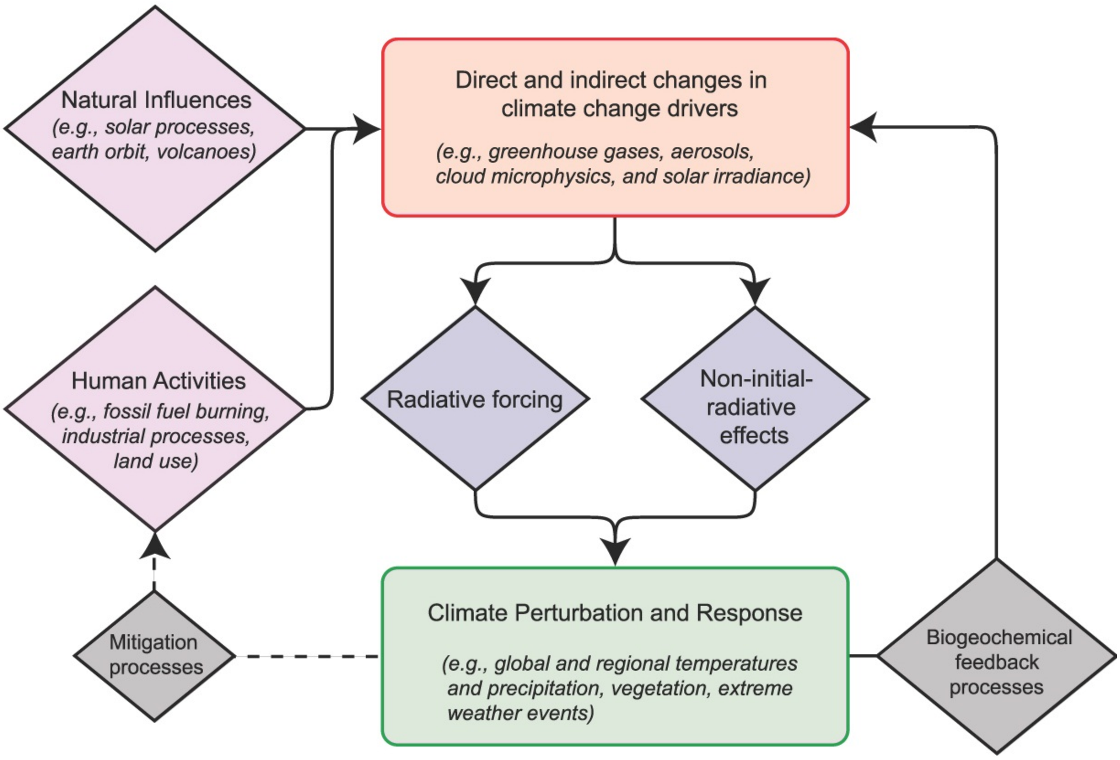


Figure 2.1: Components of the Climate Change Process.
Source: *(IPCC, 2007b)*

The change in Earth's climate is directly related with energy incoming from the sun and the specific characteristics of Earth and the atmospheres define how much energy is absorbed, reflected and re-emitted as infrared thermal radiation. The natural factors that affect this balance but are not directly linked to the climate system are referred to as natural external factors. (IPCC, 2007c) These factors include:

- **Volcanism:** Volcanic eruptions that release great quantities of gasses and dust into the atmosphere, which reflect solar radiation back into space, cooling down Earth's atmosphere.

- **Changes in solar radiation** (solar cycles, sun spots, faculae, sun flares) affect directly the energy received from the Sun, due to changes in the Sun's fusion reactions.
- **Orbital variations:** Changes in the Earth's orbit around the Sun. Variations on the Earth's orbit (eccentricity), changes in the tilt angle of Earth's axis and precession; Milankovitch cycles. (IPCC, 2007c)

The anthropological factors that contribute to climate change are mainly related to an alteration in the composition of Earth's atmosphere, creating a *Greenhouse Effect*, trapping more of the Sun's energy; energy that is reflected by the Earth's surface as infrared radiation. Some of the factors that contribute to this effect are land use management, fertilization methods, cement production, deforestation and the burning of fossil fuels. (IPCC, 2007c)

For the purpose of the United Nation Framework Convention on Climate Change (UNFCCC), *Climate Change* is defined as *"a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"* (UNFCCC, 2002). Therefore displacing all natural causes and focusing primarily in the anthropological factors, while the IPCC definition *"considers both natural and anthropogenic drivers of climate change, including the chain from greenhouse gas (GHG) emissions to atmospheric concentrations to radiative forcing to climate responses and effects."* (IPCC, 2007b) For the purpose of this investigation it will consider a primarily anthropological factor: the greenhouse gasses emitted from the burning of fossil fuels for electricity generation, with a focus on CO_2 emissions.

Possible effects from climate change:

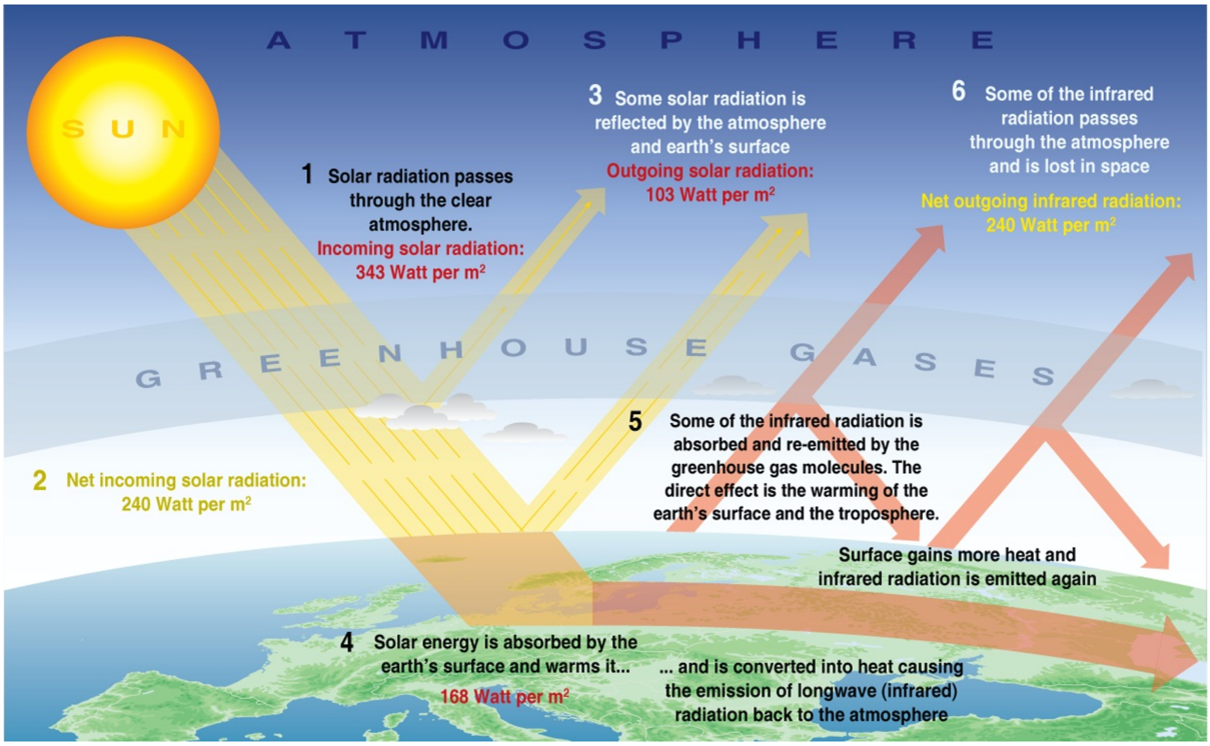
- Tropical storms will move further from the tropics
- Increase in temperature throughout the year
- Severe droughts and floods in different parts of the planet
- A rise in sea level due to thermal expansion
- Polar ice caps and icebergs have already started to melt
- Extreme weather conditions will be more likely to occur
- Some species will become extinct, and others will migrate
- Salt-water intrusion will reduce freshwater supplies
- Crops may become harder to grow in some regions and easier on others
- Higher temperatures may make it easier for some diseases to last longer and spread

(UNFCCC, 2010)

2.1 The Greenhouse Effect

The Earth's temperature, climate and life as we know it, has to do to a great extent with the amount of energy received from the Sun. About one third of the energy that reaches Earth is directly reflected back into space by the surface of the atmosphere, while the other two thirds are absorbed either by the Earth's surface or the atmosphere. To maintain a balance the planet must irradiate almost the same amount of energy back into space, but this balance has been altered by gasses in the atmosphere called *Greenhouse Gasses* (GHG). GHGs capture the thermal energy irradiated, causing an increase in temperature known as the *Greenhouse Effect*.

The *Greenhouse Effect* is not a bad thing, as a matter of fact this effect makes Earth a place where life as we know it can exist; without it the planet's surface would have an average temperature below water's freezing point. The augmentation of GHGs in the atmosphere increases the *Greenhouse Effect* and raises average global temperature, known as *Global Warming*. (IPCC, 2007b)



Source: *http://maps.grida.no/go/graphic/greenhouse-effect (Philippe Rekacewicz, UNEP/GRID-Arendal)*

Figure 2.2: Greenhouse Effect.

Humans have increased the *Greenhouse Effect* by releasing larger than natural quantities of GHG into the atmosphere. For example burning fossil fuels liberates the energy stored in carbon molecules and converts it into CO_2, releasing it into the atmosphere and increasing its concentration; which in return increases the *Greenhouse Effect*. (UNFCCC, 2006a) Plant life is a natural absorber of CO_2 or *CO2 sink*. It absorbs CO_2 in the atmosphere and stores it in its mass as carbohydrates through photosynthesis, but the deforestation cause by humans has greatly reduced the absorbing capacity of the planet, therefore increasing the amount of GHG accumulated in the atmosphere. (IPCC, 2007c)

2.2 Greenhouse Gasses (GHG)

Greenhouse gasses (GHGs) warm up the planet by allowing short wave radiation from the sun to enter the atmosphere, but when this short wave energy hits the Earth's surface and it is emitted (one part is absorbed) as long wave radiation (*infrared thermal radiation*), GHGs absorb it and re-emit it in all directions; elevating global temperature by not allowing this energy to be dispersed into space. (IPCC, 2007c)

The two most abundant gasses in the (dry) atmosphere are nitrogen (78%) and oxygen (21%), but these gasses do not cause the same effect as GHG; in fact they cause almost no greenhouse effect. (IPCC, 2007c) Water vapor (H_2O), which is the most influential greenhouse gas in the atmosphere, is not addressed as a controlled GHG because its concentration levels are not directly altered by human actions. While on the other hand, carbon dioxide (CO_2) is the second most important GHG in the atmosphere, and it is a fact that the concentrations of CO_2 in the atmosphere have begun to increase since the *Industrial Era*; time in which humans started to massively burn fossil fuels and cut down trees, which means that the increase of CO_2 is mainly due to human activities since no other global or solar event was observed in that period. The combustion of fossil fuels displaces the carbon stored in the lithosphere into the atmosphere as CO_2, warming up the planet as a result. A warmer atmosphere is able to hold more moisture (H_2O) than a colder one. When H_2O warms up the atmosphere it is automatically creating an environment that can hold more H_2O, which in turn warms up the atmosphere even more, making it a self-reinforcing cycle.

The *Kyoto Protocol* targets the reduction of 6 groups of greenhouse gasses: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6). Other GHGs were addressed earlier by the Montreal Protocol in 1997 by their ozone depletion capabilities: chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), also known as Long Lived Greenhouse Gasses (LLGHGs).

- **Carbon dioxide (CO_2)**: mainly caused by the use of fossil fuels for electricity generation, transportation, heating, cooling, cement production and the manufacture of other products. Cutting down forests diminishes the capacity of CO_2 being absorbed from the atmosphere and also releases CO_2 by the natural decay of organic matter. *Atmospheric lifetime*: Varies from 1.186 to 172.9 years.
- **Methane (CH_4)**: emissions have increased due to the use of landfills, agriculture and natural gas distribution, but CH_4 is also release as part of a natural decomposition process; for example in wetlands. *Atmospheric lifetime*: 12 years.
- **Nitrous Oxide (N_2O)**: released by humans into the atmosphere with the use of fertilizers and combustion of fossil fuels, but is also released naturally by oceans and soil. *Atmospheric lifetime*: 114 years.
- **Halocarbons (PFCs, HFCs, CFCs, and HCFCs)**: humans are mainly responsible for the increase of halocarbons in the atmosphere. Some occur naturally but in a minor amount, while others are chemical compounds that have been specially engineered by humans. Halocarbons destroy the ozone layer in the stratosphere by reacting with the ozone (O_3) particles. *Atmospheric lifetime*: Varies depending on the compound; from 0.7 to 1,700 years.
- **Sulphur hexafluoride (SF_6)**: man-made chemical compound used in high voltage electrical equipment as a gaseous dielectric medium; in other words as an electrical insulating material. It does not occur from natural processes. *Atmospheric lifetime*: 3,200 years.

(IPCC, 2007c)

2.2.1 Atmospheric Lifetime (Turnover Time)

Atmospheric lifetime refers to the *Turnover Time*, it is the ratio of the mass (M) of a reservoir and the rate at which a compound is removed from this mass (S); T = M / S. In simple terms it is the life expectancy of a chemical compound in the atmosphere; the time it will take to breakdown into other components. For some compounds it is easy to calculate the atmospheric lifetime, for others like CO_2 it is a bit more complicated. CO_2 has a turnover time of 4 years in the atmosphere, then it is absorbed by organisms and the oceans, but after a few years it returns to the atmosphere (Bern's Carbon Cycle). For that reason the life expectancy or *turnover time* of CO_2 is considered as the time it takes to be removed from the surface layers of the ocean to the deep layers. (IPCC, 2007a)

2.2.2 Global Warming Potential (GWP)

Each GHG has a different capacity for absorbing infrared radiation; therefore the same amount of one type (specie) of gas has a different warming capability than others. In the previous assessment reports the IPCC has calculated the different warming capabilities of each species of gas during a specific time period; called the *Global Warming Potential* (GWP). The GWP depends on the infrared radiation absorbing capabilities, the spectral wavelength absorbed, and the atmospheric lifetime of each gas species. GWP is based on the warming capacities of each gas compared to the warming capacity of CO_2. The units for GWP are quantified as CO_2 equivalents (CO_2 e) and are based on the atmospheric lifetime of carbon according to Bern's carbon cycle. (IPCC, 2001) For example, according to the last assessment report of the IPCC (AR4) the GWP of N_2O over a period of 100 years is equivalent to 298 CO_2 e, which means that the same amount of N_2O (for example 1 kg) will cause 298 times the warming effect of the same amount of CO_2 (1 kg). (IPCC, 2007b) This has been done so it is possible to analyze and quantify total warming potential of the different LLGHGs in a same unit.

GWP is calculated as the comparison of the integral warming force (potential) of an LLGHG against the same amount of another LLGHG's (in this case CO_2) integral force in a given time period.

$$GWP(x) = \frac{\int_0^{TH} a_x * [x(t)]dt}{\int_0^{TH} a_r * [r(t)]dt}$$

TH: time horizon for the calculation
a_x: radiative efficiency due to an increase of 1 kg of the GHG in the atmosphere ($W/m^2/kg$)
x(t): time dependent decay of the substance
**the denominator holds the values for the gas to be used as a reference, in this case CO_2.*

Equation 1: Global Warming Potential
Source: *(IPCC, 2001)*

2.2.3 Radiative Forcing (RF)

Radiative forcing is another way to analyze the heating potential of the different LLGHGs. RF is defined by the third assessment report of the IPCC as "*change in the net, downward minus upward, irradiance (expressed in W/m^2) at the tropopause (the boundary between the troposphere and the stratosphere) due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun.*" (IPCC, 2001) RF is given as a value in W/m^2, according to a change in net irradiance due to an increase in the concentration of the specific LLGHGs compared to an "undisturbed time"; for the purpose of the "undisturbed time" the IPCC uses the pre-Industrial Era concentrations' (1750). (IPCC, 2007b) In simple terms an RF of +3 W/m^2 means the tropopause receives a net irradiance of 3 watts more than that received in 1750.

Figure 2.3 shows the integrated radiative forcing of the of all GHG emissions in a time horizon of 100 years for the year 2000, clearly demonstrating the important role CO_2 emissions play in global warming by contributing to the biggest RF due to its massive emission amounts.

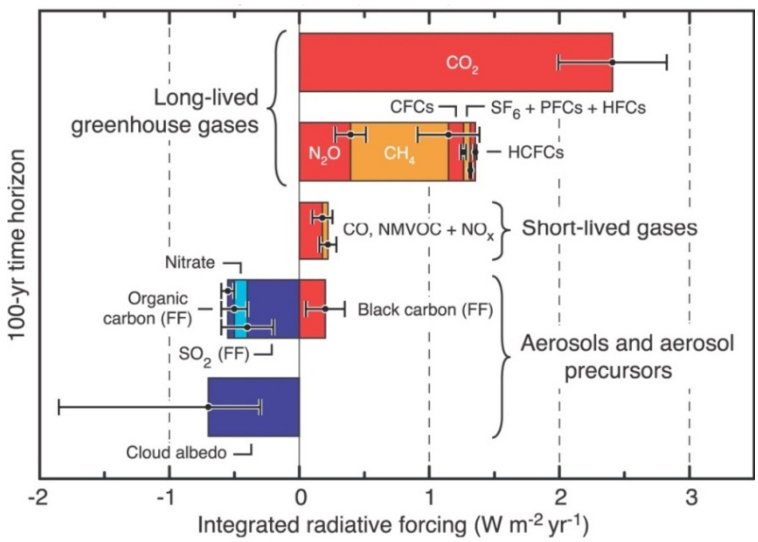


Figure 2.3: Integrated Radiative Forcing for World Emissions of 2000
Source: *(IPCC, 2007a)*

Figure 2.4 represents the probability of occurrence for levels of radiative forcing due to total anthropogenic emissions. In other words, it is the level of certainty for specific RF values to occur due to human activities.

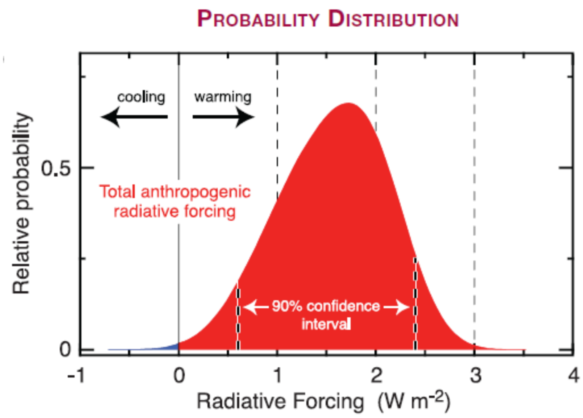


Figure 2.4: Total Anthropogenic Radiative Forcing Probability
Source: *(IPCC, 2007a)*

The following table contains the lifetime, radiative efficiency, and global warming potential of selected greenhouse gasses, for a complete listing please refer to *Appendice 1: GHGs Global Warming Potential and Radiative Efficiency*. It demonstrates the diverse GWP, radiative efficiency, and lifetime of selected GHGs. As seen below the radiative efficiency and global warming potential of CO_2 is not as high as the rest of greenhouse gasses, as a matter of fact it has the lowest values, but it is still the most important and influential anthropological GHG in climate change. This is mainly due to its lifetime and its massive amounts of emissions in comparison to other GHGs.

Greenhouse Gas	Formula	Lifetime (years)	Radiative Efficiency ($W/m^2/ppb$)	100-year GWP (SAR)	100-year GWP (AR4)
Carbon dioxide	CO_2	*See Below*	1.4×10^{-5}	1	1
Methane	CH_4	12	3.7×10^{-4}	21	25
Nitrous oxide	N_2O	114	3.03×10^{-3}	310	298
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	22,800
Hydrofluorocarbons (HFCs)					
HFC-23	CHF_3	270	0.19	11,700	14,800
HFC-32	CH_2F_2	4.9	0.11	650	675
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	0.40	1,300	1,640
Perfluorocarbons (PFCs)					
Perfluoromethane	CF_4	50,000	0.10	6,500	7,390
Perfluoroethane	C_2F_6	10,000	0.26	9,200	12,200
Perfluoropropane	C_3F_8	2,600	0.26	7,000	8,830
Perfluorobutane	C_4F_{10}	2,600	0.33	7,000	8,860
Perfluorocyclobutane	$c\text{-}C_4F_8$	3,200	0.32	8,700	10,300
Perfluoropentane	C_5F_{12}	4,100	0.41	7,500	13,300
Perfluorohexane	C_6F_{14}	3,200	0.49	7,400	9,300

Table 1: GHG Lifetime, Radiative Efficiency, and GWP
Source: *(IPCC, 2007a)*

CO_2 lifetime: Based on the revised version of the Bern Carbon cycle model using a background CO_2 concentration value of 378 ppm. The decay of a pulse of CO_2 with time τ is given by:

$$a_0 + \sum_{i=1}^{3} a_i * e^{-\frac{t}{\tau_i}}$$

Where:

$a_0 = 0.217$

$a_1 = 0.259$ $\quad \tau_1 = 172.9$ years

$a_2 = 0.338$ $\quad \tau_2 = 18.51$ years

$a_3 = 0.186$ $\quad \tau_3 = 1.186$ years

Equation 2: CO2 lifetime based on Bern's Carbon Cycle
Source: *(IPCC, 2007a)*

2.3 Global CO_2 Concentrations

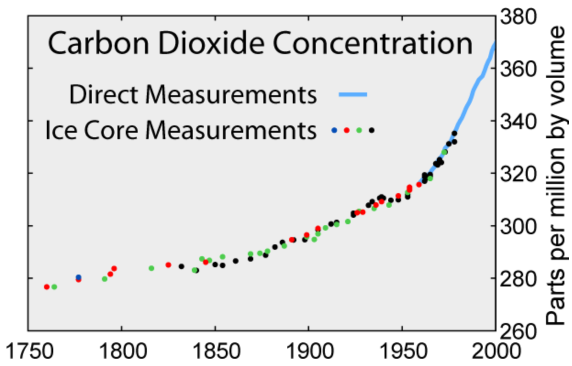


Figure 2.5: CO_2 Concentrations (1750-2000)

Source: (Rohde, 2009)

According to ice core data the CO_2 concentrations of the last century have been the highest for the last 800,000 years. (Lüthi et al., 2008) Now there are many laboratories that keep record of the latest atmospheric CO_2 and other GHGs measurements; their observations and measurements are available through worldwide databases that are maintained by the Carbon Dioxide Information Analysis Center (CDIAC) and World Data Centre for Greenhouse Gases (WDCGG) in the WMO Global Atmosphere Watch (GAW) programme. Most of the data sets collected by these laboratories can be obtained in the website of the WDCGG (http://gaw.kishou.go.jp/wdcgg/), which is currently maintained by the Japan Meteorological Agency and the WMO. (IPCC, 2007a)

The National Oceanic and Atmospheric Administration (NOAA) have the most extensive network of international air sampling sites in the world, operated by its Global Monitoring Division (GMD). This organization takes atmospheric CO_2 measurements from six different locations with continuous analyzers, and collects weekly air flask samples from a global network of almost 50 surface sites. (IPCC, 2007a) According to the atmospheric CO_2 concentration measurements obtained from NOAA, the global average annual increase of CO_2 per year from the last 30 years (1980-2010) is of 1.681935 ppm/year. The global monthly mean of atmospheric CO_2 for April 2011 is 391.92 ppm. (NOAA, 2011)

NOAA also has the longest record of direct CO_2 measurements in the world *(see Figure 2.7)*. They began with C. David Keeling of the Scripps Institution of Oceanography in March 1958 and then NOAA started its own measurements in May 1974, and now they run in parallel. (NOAA, 2011)

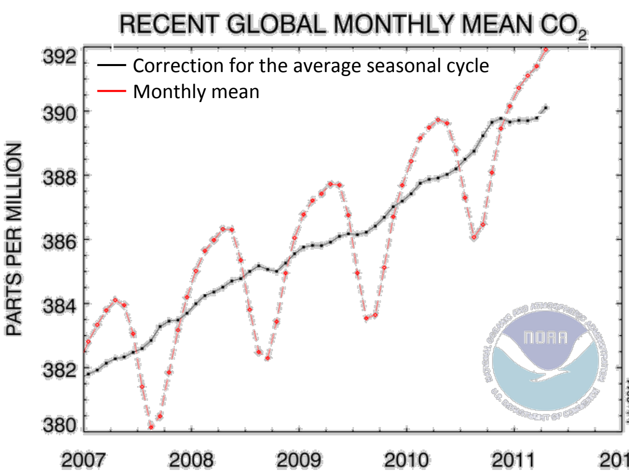


Figure 2.7: Global Atmospheric CO_2 Monthly Mean

Source: (NOAA, 2011)

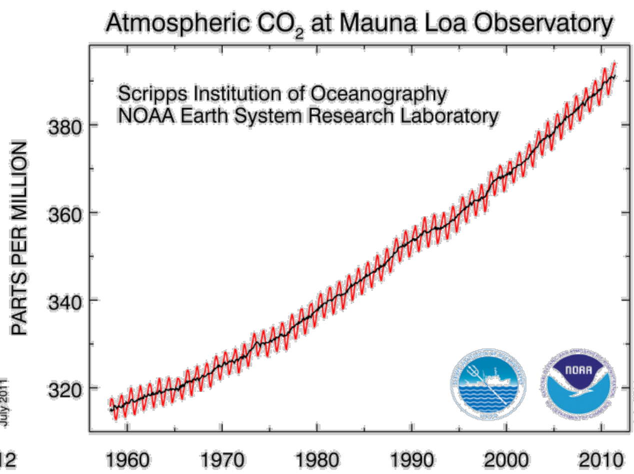


Figure 2.7: Manua Loa Atmospheric CO_2 Monthly Mean

Source: (NOAA, 2011)

Chapter 3: International Climate Change Framework

It all started with a report published by the Brundtland Commission, "*Our Common Future*". This report established the challenges of the interrelation between population growth, development, economy, social issues, and the environment. It opened the doors to discussions about sustainable development and how the human activities were affecting the environment, which in turn affected us directly; relationship that had been avoided for a long time. (UNEP, 2007)

The first world conference about climate change in Geneva in 1979 identified climate change as an issue that needed to be addressed to anticipate the possible outcomes. (UNFCCC, 2006a) The parties that attended established that a World Climate Programme was required to treat matters related to this topic. This resulted in the establishment of the *World Conservation Strategy* (WCS) in 1980. It also recognized that a long-term effort was required to address the issue at hand (UNEP, 2007); setting up the stage for the beginning of a long race against climate change: conventions, treaties, reports, agreements, protocols, new technologies, and much more. The *Vienna Convention* for the *Protection of the Ozone Layer* of 1985 was the first to address the issue about the ozone hole over Antarctica: how humans were contributing to make it bigger and the risks it implicated on human's health, crops and other living organisms. This convention gave way to one of the most successful climate protection protocols, the *Montreal Protocol*.

3.1 The Montreal Protocol

The *Montreal Protocol* on *Substances that Deplete the Ozone Layer* was adopted in Montreal, Canada on the 16th of September, 1987. The substances that deplete the ozone's O_3 molecules are known as *Ozone-Depleting Substances* or ODSs. These substances generally contain a chlorine (Cl) and/or bromine (Br) molecule that react to ozone (O_3) molecules in the stratosphere and troposphere. The ODSs are mainly man-made and are contained in aerosols, refrigeration equipment, and air conditioning systems. Some ODSs also occur from natural processes but the quantity produced is really small and not relevant for the purpose of this protocol since the major focus of the protocol is to control the production and consumption ODSs emitted by humans through the establishment of a legally binding phase out plan.

Article 5 of the *Montreal Protocol* delimits a special clause, under which developing countries can delay the compliance of the phase out plan for ten years after the ratification of the protocol. Therefore the distinction of many ratified parties is established as *Article 5 parties* (countries under development) and *non-Article 5 parties* (developed countries). For *non-Article 5* parties the MP enters into force 90 days after it has been approved; time at which all phase out plan regulations (*Article 2*) for the different gasses enter into play. To be included as an *Article 5 party* the country must be a developing country with annual emissions of less than 0.3 kg per capita for controlled substances under *Annex A* (some CFCs and halon substances). In order to continue being an *Article 5* party, the country cannot exceed annual emissions of 0.3 kg per capita for substances in *Annex A* and 0.1 kg per capita for the substances specified in *Annex B*. The trade of ODSs is also regulated to all party members in *Article 4*, specifying trade limitations with party-members and non-party-members. (Montreal Protocol, 1987) For the list of the substances in Annex A and Annex B of the Montreal Protocol please refer to *Appendice 2.*

3.1.1 Amendments and Ratification

The original *Montreal Protocol* (MP) and *Vienna Convention* (VC) was signed and approved (ratified) globally by 196 countries (parties), but the *Montreal Protocol* has gone several revisions / modifications (amendments) that have not been ratified by all parties. These amendments have occurred during general (assembly) meetings of the parties (MOP), which have agreed to convene annually ever since the signature of the original MP in 1987. (Montreal Protocol, 1987) The major amendments have occurred during the 2nd MOP in London (1990), 4th MOP in Copenhagen (1992), 11th MOP in Beijing (1999) and the last amendments were done in the 19th MOP in Montreal (2007), which only 168 parties have ratified this last amendment; as of 28th of June, 2011. (UNEP, 2011)

3.1.2 Ozone Depletion

The first chlorofluorocarbons (CFCs) where invented in 1928 as a compound called Freon. It was fabricated by Thomas Midgley, Jr. with the help of Charles Franklin, and currently E.I. DuPont de Nemours & Company holds its trademark in Wilmington, Delaware. (Carey & Encyclopedia Britannica, 2011) The original purpose of this compound was to be used as a refrigerant. The biggest driver for the implementation of the Montreal Protocol was the study known as "CFC-ozone depletion theory" in 1974, by the American chemists F. Sherwood Rowland, Mario Molina, and the Dutch chemist Paul Crutzen. (Montreal Protocol, 1987)

The *ozone layer* is located in the stratosphere; it is located from 6 to 10 kilometers above Earth's surface and it's called like this because it holds about 90% of the total ozone (O_3) molecules in the atmosphere; the other 10% is in the troposphere, located between Earth's surface and the stratosphere. Stratospheric O_3 molecules are produced naturally with the help of solar radiation. The energy contained in ultraviolet radiation breaks down an oxygen molecule (O_2) into 2 separate oxygen atoms (2O). Then, the two free oxygen atoms collide with an oxygen molecule (O_2) to form an ozone molecule (O_3). In total it takes 3 oxygen molecules and some sunlight (ultraviolet radiation) to form 2 ozone molecules (O_3). (WMO et al., 2011)

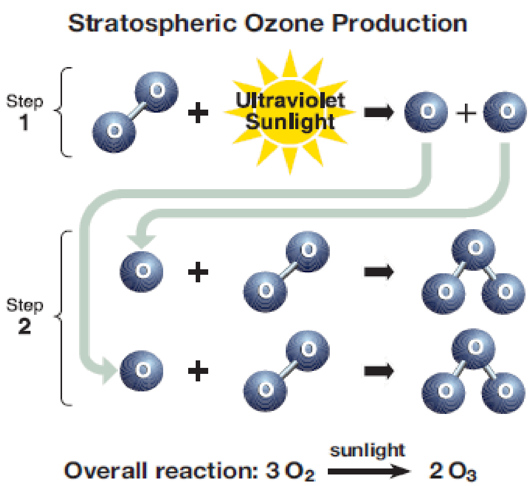


Figure 3.1: Ozone Production.
Source: *(WMO et al., 2011)*

Stratospheric ozone is really important to life forms on Earth, human beings in particular. It protects humans by absorbing ultraviolet B (UVB) radiation and preventing it from reaching the Earth's surface. (EPA, 2010) Ultraviolet (UV) radiation is the radiation from the electromagnetic spectrum which wavelength is shorter than the visible light, but longer than x-ray radiation. UV radiation is divided into several different categories, the classification and wavelength of the UVA, UVB, and UVC can be observed on Table 2: UV spectral range.. When talking about the electromagnetic spectrum it is important to keep in mind that the shorter the wavelength, the greater the energy they carry; (ISO 21348:2007(E), 2007) This means that the ozone layer protects us from the most dangerous radiation by reflecting all UVC, absorbing most UVB, and only allowing lower energy dense radiation (UVA) to reach the surface. The ozone layer also plays another important role by initiating the chemical breakdown of several GHG. (WMO et al., 2011)

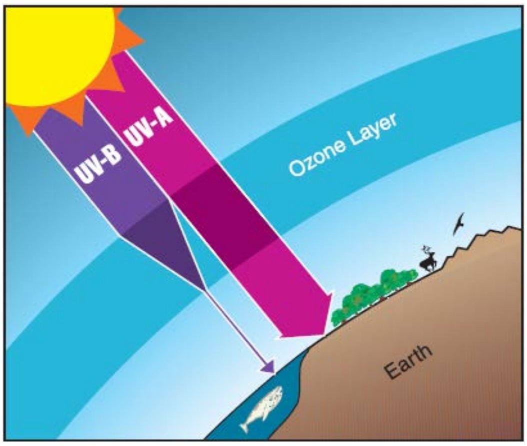


Figure 3.2: Ozone layer absorption of UVB.
Source: *(WMO et al., 2011)*

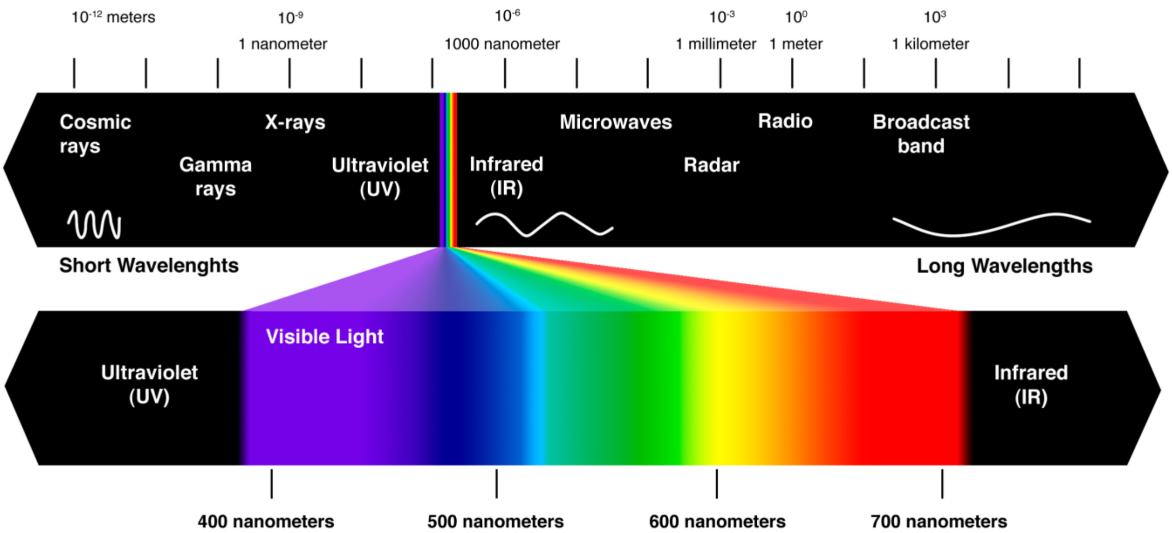


Figure 3.3: Electromagnetic spectrum.
Source: (Pajari, 2008)

The ozone molecules in the stratosphere are primarily destroyed through a catalytic reaction of chlorine (Cl) and bromine (Br) atoms with the O_3 molecules. ODSs are stable molecules that are not destroyed by regular cleaning mechanisms, such as rain, but instead they migrate to the upper atmosphere through convection and air movement. (Molina, 1995) Once ODSs are in the upper atmosphere their bonds are easily broken by ultraviolet radiation. For example, in the case of ODSs that contains chlorine (Cl): ultraviolet (UVB) radiation makes them easily release the Cl atom. (WMO et al., 2011) The Cl released is a highly reactive atom or "*free radical*" that easily bonds with other atoms. It is called a *free radical* because it is missing an electron in its outer shell, and it is desperately seeking to fill this gap and become "stable" by stealing or sharing an electron of another atom or compound. (Walling & Encyclopedia Britannica, 2011)

Spectral Subcategory	Wavelength Range (nm)
UVC	$100 \leq \lambda < 280$
UVB	$280 \leq \lambda < 315$
UVA	$315 \leq \lambda < 400$

Table 2: UV spectral range.
Source: *ISO 21348:2007(E)*

The catalytic reactions that occur with Cl and O_3 are as follows:

$$Cl + O_3 \rightarrow ClO + O_2$$
$$ClO + O \rightarrow Cl + O_2$$
$$\textbf{Net: } O + O_3 \rightarrow 2O_2$$

Equation 3: Chlorine Reactions in the Ozone
Source: *(Molina, 1995)*

At the end, the chlorine atom has used an O atom and an O_3 molecule to produce 2 O_2 molecules and now it is free to continue performing the same reactions.

3.1.3 ODS's relation to Global Warming

The knowledge of these substances is essential when dealing with GHGs. Most ODSs have a double effect on global warming: by depleting O_3 molecules they reduce the capacity of the atmosphere to breakdown some GHGs (like CH_4), and the ODSs have a great RF themselves. (WMO et al., 2011) From 1990 to 2010 the *Montreal Protocol* reduced the emissions of ODSs equivalent to a GWP of 135 billion tons of CO_2e with regard to the projected continued consumption. (UNEP, 2009) Due to the large contribution of the MP to prevent climate, Kofi Annan, the United Nations General Secretary referred to it as "perhaps the single most successful international environmental agreement to date". (UNEP, 2010) By the 1st of January 2010 all parties of the MP had phased out the consumption and production of chlorofluorocarbons, halons, carbon tetrachloride and other ODSs. It is believed that with these actions the ozone layer will return to it pre 1980s state around 2050. (UNEP, 2010)

A detailed list of the ODSs that have a rated global warming potential may be found in Appendice 3: Ozone Depleting Substance's ODP and GWP.

3.2 Intergovernmental Panel on Climate Change (IPCC)

In the *Conference on the Changing Atmosphere* of Toronto in 1988, all 340 parties (from 46 countries) recommended a "comprehensive global framework convention to protect the atmosphere". (UNFCCC, 2006b) Therefore the United Nations established the *Intergovernmental Panel on Climate Change* (IPCC), with the resolution A/RES/43/53, to "provide internationally co-ordinated scientific assessments of the magnitude, timing and potential environmental and socio-economic impact of climate change and realistic response strategies". This was the official birth of the IPCC,

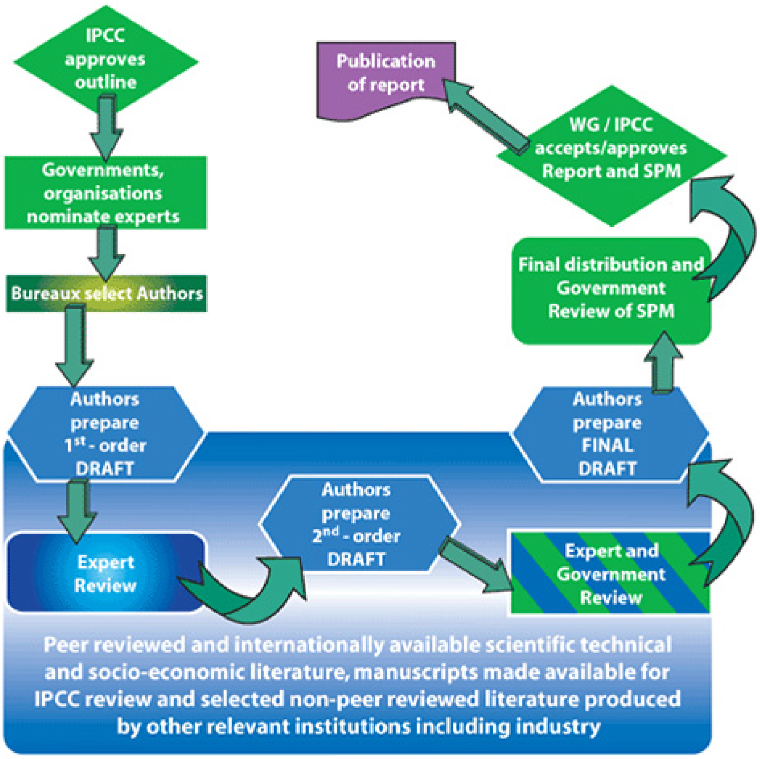


Figure 3.4: IPCC Publication Process.
Source: *(IPCC, 2011)*

founded by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), all due to the initial proposition of Malta entitled "Conservation of climate as part of the common heritage of mankind." (UN, 1988)

The IPCC does not perform any research or monitor any climate data, but instead it reviews scientific, technical and socio-economic information related to climate change conducted by scientists around the world; and according to these studies it produces reports to assess world organizations regarding the matter. (IPCC, 2011) So far the IPCC has published 4 official reports in 1990, 1995, 2001 and 2007; and now is working in the fifth assessment report that will be published in 2014. Each of the previous reports is known by its abbreviation from its chronological order: the first assessment report as FAR, second as SAR, third as TAR and the last published report as AR4. With the pass of each report, higher accuracy models are created that have a better resolution, more variables, and take more observations into account. FAR started with a resolution of ~500 km, while the last published report (AR4) has a resolution of ~110 km; the higher the resolution the more accurate the models can be. These reports and the work done by the IPCC are used worldwide by many nations and organizations in the confrontation against climate change and the reduction of greenhouse gasses.

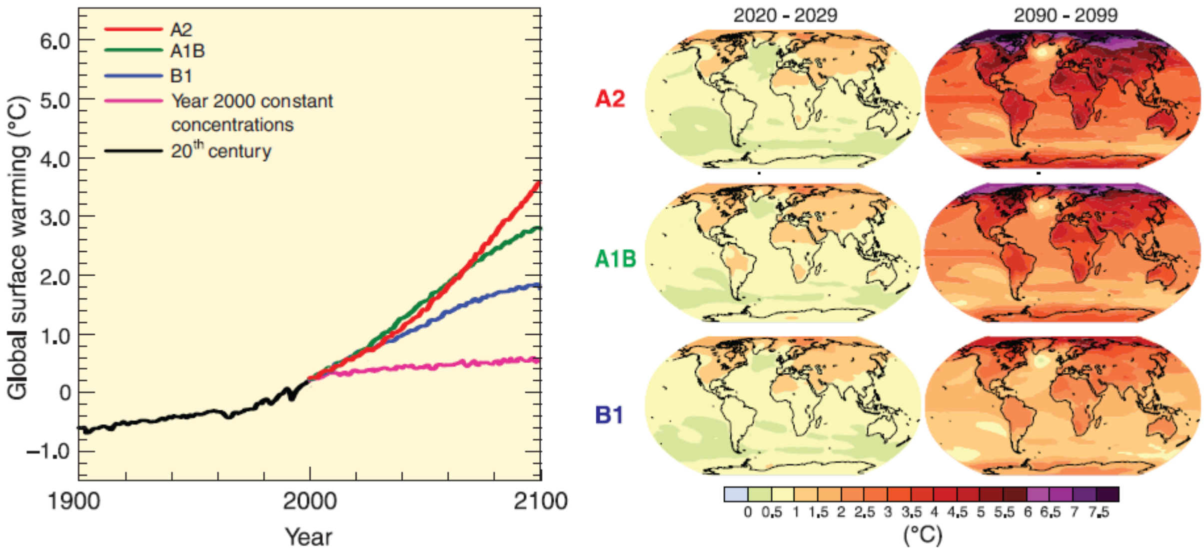


Figure 3.5: AR4 Scenarios
Source: (IPCC, 2007a)

The IPCC published in the AR4 the following different scenarios according to the concentrations of GHG in the atmosphere *(see* Figure 3.5: AR4 Scenarios*)*. Each scenario projects the different increases in global temperature according to rising levels of GHG.

3.3 United Nations Framework Convention on Climate Change (UNFCCC)

The United Nations Framework Convention on Climate Change (UNFCCC) is a non-legally binding international environment protection treaty. The primary objective is to reduce the GHG emissions to a point where their atmospheric concentrations can stabilize and start to diminish; in order to *"prevent dangerous anthropogenic interference with the climate system"*, which *"should be achieved* *within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner"*. (UNFCCC, 2006a) Although the UNFCCC is a non-legally binding treaty it has legally binding updates, called "protocols", to set emission limits.

The UNFCCC resulted from one of the most successful climate change conferences in the world, The United Nations Conference on Environment and Development (UNCED), commonly known as the Earth Summit, held in Rio de Janeiro, Brazil in June 1992. 172 governments of different countries attended the summit, along with 108 heads of state and many other NGO representatives. The convention was opened for signature in New York on May 9th, 1992, just in time for its introduction on the Earth Summit where 154 parties signed the convention. (UNFCCC, 2006a) As of the 1st of August 2011, 195 parties have approved the UNFCCC. (UNFCCC, 2011a) The party members of the UNFCCC meet annually at Conference of the Parties (COP) since the convention entered into force in 1994. (UNFCCC, 2006a)

As in the Montreal Protocol, the UNFCCC has classified the parties that have signed the treaty into essentially two groups: Annex I Parties, non-Annex I Parties. Annex I Parties are those industrialized countries members of the Organization for Economic Co-operation and Development (OECD) and those countries which are considered to have Economies in Transition, also referred to as EITs. These parties are considered to be wealthy countries that have higher per capita emissions than most developing countries, and that also have a greater financial and institutional capacity to tackle climate change. Non-Annex I parties is pretty self-explanatory, they are the rest of countries not included in Annex I parties. There also exists another sub-classification within each of the two party groups: Annex I parties are further classified into Annex II parties which have a special obligation assist developing countries financially in order to achieve the ultimate goal against climate change; and non-Annex I parties are further classified into the Least Developed Countries (LDCs). For a list of parties to Annex I, Annex II, and EITs, please refer to *Appendice 4: UNFCCC and the Kyoto Protocol.* (UNFCCC, 2006a)

3.3.1 Kyoto Protocol

This treaty aimed to reduce the emissions of some GHG, addressing 4 specific compounds: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6); and 2 groups of gasses: hydrofluorocarbos (HFCs) and perfluorocarbons (PFCs). The target emission reduction for the period of 5 years (2008-2012) is to reduce the GHG emissions of the gasses specified to 5% less than the base year. In this case the Kyoto Protocol takes 1990 as the base year, obliging the countries to reduce their emissions 5% below the emissions of the same country in 1990. (UNFCCC, 1997) Wherever GHG emissions are mentioned in reference to the Kyoto Protocol these exclude all emissions from gasses controlled by the Montreal Protocol; this is done in order to prevent effort duplication.

On the 11th of December 1997 the UNFCCC adopted the Kyoto Protocol; it was opened for signature and ratification in March 1998. As of July 2011, the treaty has been signed and ratified by 193 parties (192 states and 1 regional economic integration organization). (UNFCCC, 2011b) Annex I parties that sign the Kyoto Protocol should incorporate a national system to estimate the anthropological emissions by sources, and the removal by sinks, no later than 1 year after its signature. The methodologies to estimate the emissions are those accepted by the IPCC, and the GWP values used in these estimates should be those specified by the IPCC. (UNFCCC, 1997) The GWP and radiative efficiency of the last IPCC report can be reviewed in *Appendice 1*.

Annex I parties have the obligation to implement and elaborate measures and policies that pursue:

- Enhancements of energy efficiency
- Protection and enhancement of sinks of GHGs not controlled by the Montreal Protocol
- Sustainable forms of agriculture
- Research, promotion, development, and increased use of renewable energies
- Reduction and phasing out of market imperfections: subsidies to GHG emitting sectors
- Incorporate policies and measures that promote reduction of GHG emissions not controlled by the Montreal Protocol
- Measures to limit or reduce GHG emissions not controlled by the Montreal Protocol
- Limitation and reduction of methane emissions with the implementation of waste management, and in the production, transportation, and distribution of energy

(UNFCCC, 1997)

3.3.2 Carbon Market

Annex I parties should also should also collaborate with non-Annex I parties to reduce their GHG emissions by cooperation and financial support to achieve the measurements above. In order to achieve this goal the Kyoto Protocol implemented 3 market-based mechanisms:

- Emissions Trading, known as the Carbon Market
- Clean Development Mechanism (CDM)
- Joint Implementation (JI)

(UNFCCC, 1997)

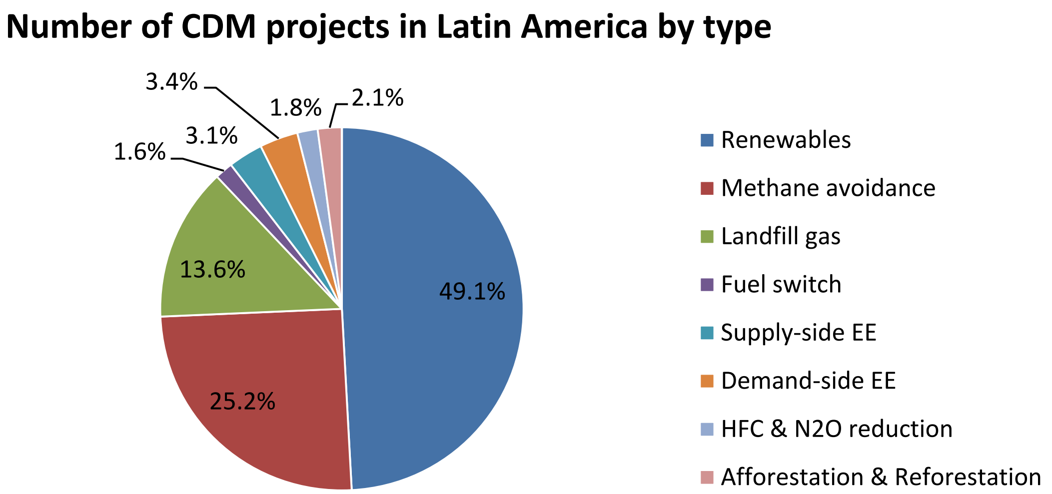
The different types of “carbon credits” established by the Kyoto Protocol used in the Carbon Market are the following:

- **Assigned Amount Units (AAUs):** The amount of emissions allowed.
- **Removal Unit (RMU):** Earned by the enhancement or promotion of GHG sinks based on Land Use and Land Use Change and Forestry (LULUCF)
- **Emission Reduction Unit (ERU):** Earned by a JI project activity
- **Certified Emission Reduction (CER):** Earned by a CDM project activity

(UNFCCC, 2011a)

3.3.3 Clean Development Mechanism (CDM)

The Clean Development Mechanism (CDM) allows countries in Annex I to comply with their allowed GHG emissions by obtaining credit for the emissions reduced in a non-Annex I country. If an Annex I country invests in a project registered in the CDM in a developing country, the investor country obtains CERs that count towards their own emission reductions. In this way the wealthy industrialized countries can achieve their emission reductions in a cheap way and they aid developing countries to achieve sustainability that otherwise would have been harder or almost impossible without foreign investment. (UNFCCC, 1997)



Graph 3.1: CDM Projects in Latin America by Type
Source: (UNEP RISØ Centre, 2011)

There are a total of 540 projects registered in Latin America under the CDM, from which Brazil and Mexico have 60% of the total share with 323 projects. It is evident that Nicaragua is not taking full advantage of this opportunity, since it just has submitted 9 projects: 1 was rejected, 5 were approved, and 3 are in validation *(See Table 3.2)*. (UNEP RISØ Centre, 2011)

ID	Title	Province/State	Status
CDM4529	EL Bote small hydroelectric Plant	Jinotega	**Rejected**
CDM0452	Monte Rosa Bagasse Cogeneration Project (MRBCP)	Chinandega	Registered
CDM0087	San Jacinto Tizate geothermal project	León	Registered
CDM0284	Vinasse Anaerobic Treatment Project - Compañía Licorera de Nicaragua, S. A. (CLNSA)	Chinandega	Registered
CDM3814	Amayo 40 MW Wind Power Project - Nicaragua	Rivas	Registered
CDM4840	Southern Nicaragua CDM Reforestation Project	Rivas & Río San Juan	Registered
CDM4069	La Mora Hydroelectric Project	Matagalpa	*At Validation*
CDM3289	La Fe Wind Farm Project	Rivas	*At Validation*
CDM6134	Amayo Phase II Wind Power Project	Rivas	*At Validation*

Table 3: Projects Submitted to the CDM in Nicaragua
Source: *(UNEP RISØ Centre, 2011)*

There are several approved methodologies for CDM projects; SWH and PV systems in households fall under the sector of *Zero Emission Renewables (see Table 3.3)*. One of the main limitations for home owners to invest in such systems is the high investments cost, which makes it difficult to see the potential savings in a near future. Nicaragua could take advantage of this opportunity to partially finance the investment of these types of systems with the support of the CDM. The support of CDM in such a project would probably give a boost to the amount of system installed in countries with limited financial resources, but rich natural resources, such as Nicaragua. Currently there absolutely NO projects registered under the methodology of *AMS-I.J.: Solar Water Heating Systems (SWH)*, but there are several thousand projects registered for *ACM2: Grid-connected electricity generation from renewable sources*; which indicates that it is a possibility, but probably due to a lack of knowledge of the CDM or limited know-how of the process needed to needed to follow in order to submit a project.

ID	Methodology Sector	Projects
	Zero emission renewables:	
ACM2	Grid-connected electricity generation for renewable sources (no biomass)	2310
AM19	Renewable Energy project replacing the electricity of one single fossil plant (excl. biomass)	
AM26	Zero-emissions grid-connected electricity generation from renewable sources in Chile or in countries with merit order based dispatch grid	8
AM72	Fossil Fuel Displacement by Geothermal Resources for Space Heating	1
AMS-I.A.	Electricity generation by the user	46
AMS-I.B.	Mechanical energy for the user	4
AMS-I.C.	Thermal energy production with or without electricity	516
AMS-I.D.	Renewable electricity generation for a grid	2185
AMS-I.F.	Renewable electricity generation for captive use and mini-grid	41
AMS-I.J.	Solar water heating systems (SWH)	

Table 4: CDM Methodologies: Zero Emission Renewables
Source: *(UNEP RISØ Centre, 2011)*

Chapter 4: Power System Fundamentals

4.1 Load Curve

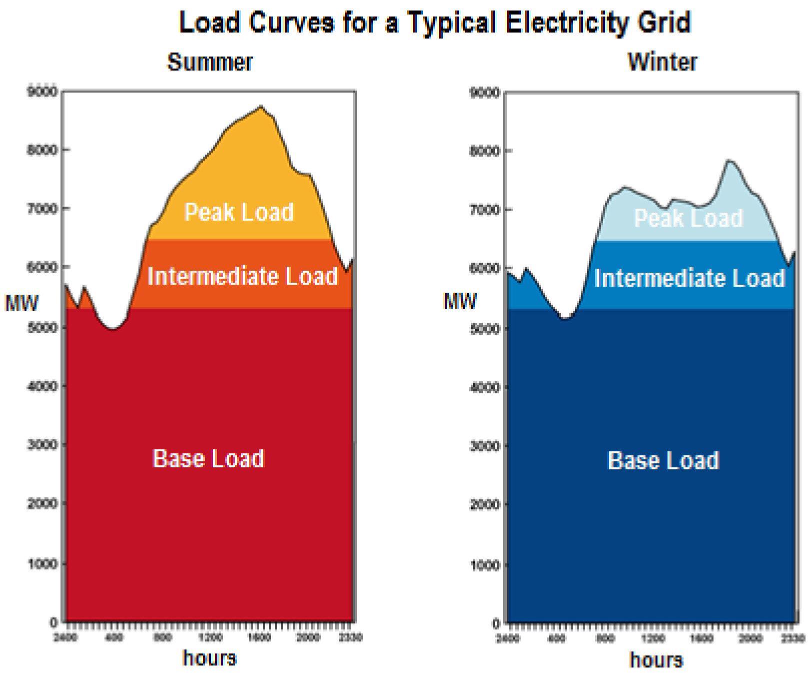


Figure 4.1: Typical load curves of an electricity grid. ***Source:*** *(WNA, 2011)*

The load curve plots the variation of demand over time. It is most common for time to be represented in the horizontal axis and demand on the vertical. (Energy Vortex, 2011) The daily load curve shows the variation during one day; time units usually are of 1 hour and the plotted time is of 24 hours, representing the demand behavior throughout the day. According to previous data, a load profile is created from average load curves. The load profile can be used to plan the resources used in electricity generation.

At night, when most people are a sleep is one of the moments in the day when the load curve is most commonly at its lowest point since users are not demanding much energy from the grid, instead the energy demanded from the grid is mainly for outdoor lighting, refrigerators, standby equipment and probably some air conditioning or heating. The load curve or energy demand typically starts rising as people wake up, turn on equipment and begin to get ready for work or school. It reaches one of its peaks at noon, when BOTH businesses/industries, food service companies, and households are demanding electricity from the grid. Enterprises continue to demand electricity while people go out for lunch: food service companies and households begin to demand electricity. Then the load curve goes slightly down when lunch hour is over and goes up again when everyone starts to go home after the labor day, which most likely coincides with no more sunlight; so street and outdoor lighting turn ON once the sun is gone, and people start to go home and demand electricity for TV, music, lights, microwave, ventilation, preparing food, etc. Therefore, there are generally two peak loads during the day: at noon and early in the evening.

The load curve varies from region to region, depending on the country's main energy necessities, geographic location, and climate. It may also change during the year in the same country (from summer to winter); while in other countries it may remain almost the same, like in the tropics where there is not too much variation in sunlight hours per day or temperature differences throughout the year. Sunlight per day varies greatly during the year in countries located at high latitudes; the closer to the North or South Pole, the greater the change throughout the year. During summer the hours of sunlight in these locations is greater than in winter. In winter it is likely to require less energy for air conditioning than in summer, but probably a lot more energy for lighting due to the few sunlight hours, and even more for heating. On the other hand, tropical country's sunlight hours just changes slightly during the year and the overall temperature may vary just a little, requiring ventilation or air conditioning during the summer, but most likely no heating during the winter.

4.1.1 Base Load

Base load is the energy demand/supply that is most likely to remain unchanged during the day. According to estimates based on previous consumption patterns, usually between 35 – 40% of the total load is base load. This electricity is supplied by the cheapest energy producers, commonly: nuclear power, coal fired, geothermal, hydroelectric, and other renewable energy power plants. They produce electricity at a relatively low cost per unit, since some of them do not rely on an expensive fossil or benefit economies-to-scale, producing a lot of energy at a cheap cost per unit. These types of power plants also form part of the base load energy production because their technology is hard to turn on and off; requiring a lot of time and/or resources each time they have to be started up, making it inefficient to alternate during the day. On the other hand hydroelectric is easy to turn on and off, but it is common to be used as base load since it can generate big amounts of "clean energy" at a low price. (Energy Vortex, 2011)

Base load generators typically have high fixed costs, high plant load factor, and very low marginal costs, which are more rentable and efficient when they are working at full capacity. For this reason nuclear, coal, biomass and geothermal power plants are working at full capacity almost all year round, except for refueling and maintenance periods.

Taking into consideration low GHG emissions, intermittent renewable energy sources may be considered for base load or medium load generation (category between base and peak load), having priority over all fossil fuel productions. For example large photovoltaic (PV) facilities or big solar thermal generation plants can be considered for base load production generation during the day, while the hydroelectric reservoirs get full for production during the night when solar based production cannot be achieved. Such actions involve careful planning and may be considered a good and efficient electricity production plan.

4.1.2 Peak Load

On the other hand, peak load is the energy required by the system for a few hours a day. Peak load is powered by easy turn on / turn off power plants fueled by fossil fuels. This type of power plants commonly have low fixed costs, low plant load factor, but HIGH variable costs, which means it is the most expensive electricity to generate, and even more with the price increase of fossil fuels as they turn scarce.

4.2 Demand Side Management (DSM)

Demand side management consists on a set of policies and measures implemented in order to balance the load curve, trying to prevent high peak loads in order to delay or avoid the need of more generators, infrastructure expansion, and pricy energy production, while at the same time reducing GHG emissions by not requiring more fossil fueled fired generators. This can be done by promoting a change in consumption pattern, for example differential energy pricing or "smart metering"; cheap energy prices when there is a low demand and high prices at peak hours. Another DSM policy may be a programme that exchanges old electrical inefficient devices with new and more efficient devices that will lower the overall electricity demand. Or even a campaign to educate people, making them aware and more self-conscious of the consequences of electricity misuse, and how they can contribute to a better and more effective consumption pattern to benefit themselves and others. (Renewable Energy Institute, 2007)

There several types of ways to reduce peak load electricity. Figure 4.2 shows the different ways to reduce peak load. Peak clipping is simply reducing the amount electricity consumed. Valley filling is done by the promotion electricity consumption at times where there are no peaks, causing a more or less stable consumption of electricity throughout the day, making most of the electricity produced generated by base load producers; big scale generators at a cheap price per unit. Load shifting shifts the demand in the peaks to times where there is less demand.

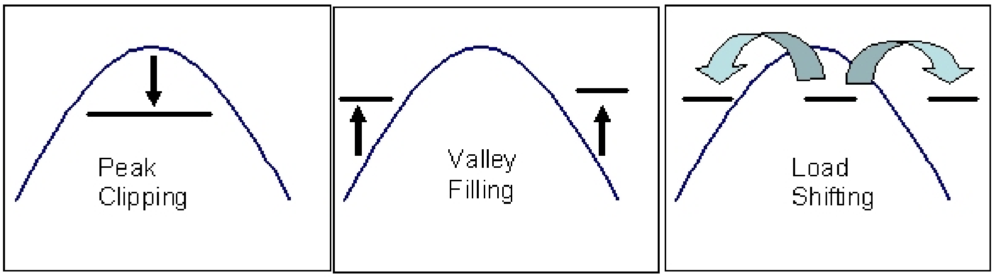


Figure 4.2: Peak Load reduction alternatives
Source: *(IEA, 2010)*

4.3 Power System Terms

The following are electricity terms that will be used in this document.

- **Producers (suppliers):** Responsible for generating electricity and feed it into the grid.
- **Consumers (end-users):** Use the electricity produced by the suppliers. Different types of consumers by sector: domestic, industrial, commercial, governmental, agro-industrial, water supply, etc.
- **Electricity Injection (feed-in):** Supplying the electricity produced into the electricity grid to be consumed somewhere else.
- **Installed Capacity:** Total capacity of all the power plants connected to the grid.
- **Nominal Capacity:** Total power of the generator operating at full capacity; rated by the manufacturer.
- **Net Capacity:** The total load that can be available to feed into the grid when the generator is operating at full power.

- **Gross Generation:** Total electricity generated.
- **Own Consumption:** Electricity consumed by the producer for its internal operations.
- **Net Generation:** The electricity that is actually fed into the grid.
- **Grid infrastructure:** Network of cables, transformers, switches, meters, power stations, and everything in between that is required to provide electricity to the end-users.
- **Transportation:** High voltage power lines that transport the electricity from the producers to substations, where it is transformed into medium voltage and distributed to the different sectors.
- **Distribution:** Consists of medium/low voltage, transformers, electricity meters, and many other components required to supply the demanded electricity from the substations to the end-users.
- **Net Metering:** Type of metering used when a consumer also supplies (injects) electricity into the grid. The electricity charged to the consumer is the difference between the amount consumed and the injected.

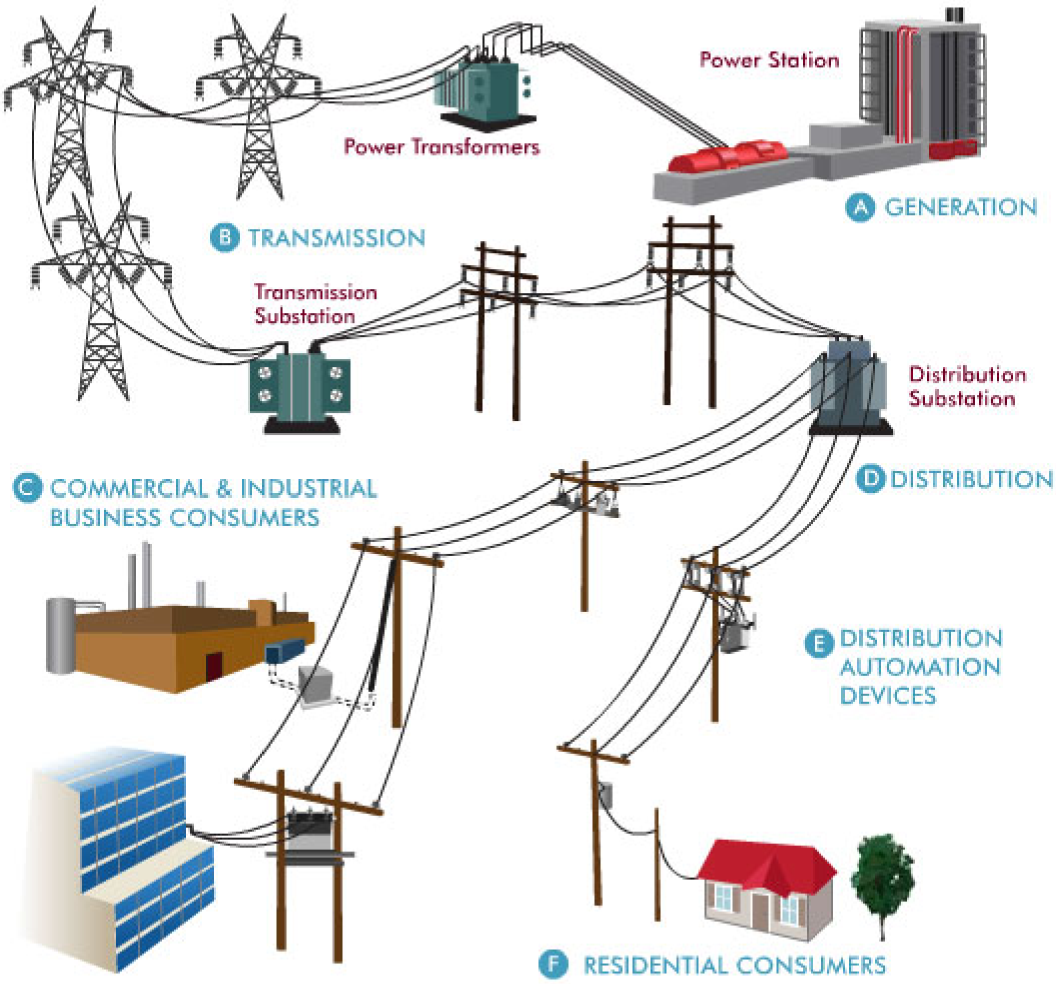


Figure 4.3: Basic components in an electricity grid
Source: *(Venture Beat, 2010)*

Chapter 5: Solar Energy Technologies

Solar energy technologies are all those technologies that harness the energy contained in solar radiation into some sort of energy that can be used on a specific application.

5.1 Understanding the relation between Sun and Earth

When dealing with solar technologies it is important to understand the origin of this energy. To be able to efficiently plan correctly the use of a solar technology is necessary to understand why certain solar variations occur and if they can be predicted. In order to obtain the most energy possible it is also important to know what affects the amount of energy harnessed from the sun and what the user can do to prevent this.

The next section will provide a better understanding about the sun and the solar radiation emitted to Earth.

5.1.1 Solar Radiation

The sun provides energy to sustain life on Earth. In one hour Earth receives enough energy to satisfy its energy needs for about a year. The sun is composed by a mixture of gasses, mainly hydrogen. It acts as a giant themonuclear fusion machine, converting hydrogen into helium; maintaining the surface of the sun at an approximate temperature of 5800 K (5526.85 °C). (Messenger & Ventre, 2010)

The energy radiated from the sun retains a close behavior to Planck's blackbody radiation formula:

$$w_\lambda = \frac{2h\pi c^2 \lambda^{-5}}{e^{\frac{hc}{\lambda kT}} - 1}$$

$h = 6.63 \times 10^{-34}$ W s² (Planck's constant)
$c = 2.998 \times 10^{8}$ m/s (speed of light in vacuum)
$k = 1.38 \times 10^{-23}$ J/K (Boltzmann's constant)
T = temperature of blackbody in K.

Equation 4: Spectral power density
Source: *(Messenger & Ventre, 2010)*

This equation results as the energy density at the SURFACE of the sun in W/m^2/unit wavelength in m. When the time this energy has reaches Earth, travelling 150 million km through space, the total extraterrestrial energy density has decreased to 1367 W/m^2, which is also known as the solar constant. (Messenger & Ventre, 2010)

Once sunlight enters the atmosphere a part is absorbed, some is reflected and other passes without any effect by molecules in the atmosphere and is absorbed or reflected by objects on the Earth's surface. Each molecule affects differently the parts of the solar spectrum. When sunlight is absorbed by molecules it increases their energy and raises their temperature. For example, the sky is blue due to the molecules in the atmosphere; they absorb and scatter sunlight through the atmosphere, if it wasn't for these molecules the sky would be black and sunlight would only illuminate objects that come into direct contact with it. (Messenger & Ventre, 2010)

All these different types of sunlight have names. Direct sunlight, are parallel rays of sunlight that have not been obstructed or scattered, and this is known as direct radiation. Diffuse radiation, is sunlight that has been scattered or obstructed. And albedo radiation is the sunlight that is reflected by a surface. The sum of all these types of radiation is called global radiation.

Direct radiation can be focused, diffuse radiation cannot. Take the example of focusing sunlight through a magnifying lens, this only works when undisturbed sunlight (parallel rays) reaches the lens; diffuse radiation cannot be focused because its energy rays come from all directions.

- **Irradiance:** measure of power density of sunlight, measured in W/m^2.

The irradiance at the top of the atmosphere is known as extraterrestrial irradiance that has not been disturbed (obstructed, absorbed or reflected); the value for this radiation is considered of 1367 W/m^2. In other words this radiation at the top of the atmosphere has not passed through any molecules of our atmosphere or AM 0. AM is a measure of atmospheric air mass. AM 1 is considered to be the direct path of sunlight through the atmosphere until it reaches sea level. At AM 1 the extraterrestrial irradiance is reduced to ~ 1000 W/m^2, approximately 70% of its power due to absorption of the molecules in the atmosphere mass. AM 1.5 is accepted as the standard calibration spectrum for photovoltaic cells. (Messenger & Ventre, 2010)

- **Irradiation:** measure of energy density of sunlight, measured in Wh/m^2

In other words, irradiation is the integral of power over time of irradiance. Irradiation can also be expressed as peak sun hours (psh). A peak sun hour is basically the length of time in hours needed to produce the daily irradiation from all daylight hours, at an irradiance level of 1000 Wh/m^2. For a better perception of the concept of peak sunlight hours see Figure 5.1.

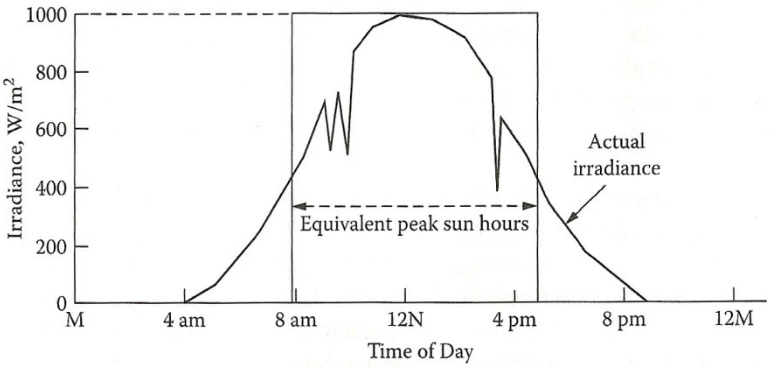


Figure 5.1: Peak sun hours (psh)
Source: *(Messenger & Ventre, 2010)*

5.1.2 The Sun and Earth

The Earth's orbit around the sun has an elliptical form with the sun at one of the foci. The distance of the sun to Earth can be given by the following equation at any given day of the year:

$$d = 1.5 * 10^{11}\left\{1 + 0.017\sin\left[\frac{360\,(n-93)}{365}\right]\right\} m$$

$\mathrm{n} = \text{day of the year, with January 1 as day 1}$

Equation 5: Distance to the sun any given day.
Source: (Messenger & Ventre, 2010)

The Earth also rotates on its own axis and it takes 1 full day (24 hours) to complete this rotation. The Earth's axis of rotation, or polar axis, has an inclination of 23.45° with respect to its elliptical orbit plane around the Sun. This inclination causes the variation of daylight hours during the different seasons, and it is also the reason why the sun appears higher in the sky than in the winter. In the first day of summer in the Northern Hemisphere the sun appears directly vertically over the Tropic of Cancer, latitude 23.45° N, and during the first day of winter it appears over the Tropic of Capricorn. The angle of deviation of the Sun from directly above the equator is called the declination, and will be represented by δ in future references in this document. It can be calculated by the following equation at any given day of the year (-23.45° ≤ δ ≤ 23.45°):

$$\delta = 23.45° \sin\left[\frac{360\ (n-80)}{364.256}\right]$$

$$\text{n} = \text{day of the year, with January 1 as day 1}$$

**A positive angle indicates the sun north the equator, while a negative shows the sun south of the equator.*

Equation 6: Solar declination
***Source:** (da Rosa, 2009)*

The Earth does one full spin, 360°, on its axis in one day (24 hours); meaning that the Sun changes it relative position 15° per hour (360° / 24 hours) until it returns to its original position with respect to the previous day (after one full spin). Based on this principle, it should be rather easy to find out the solar noon with respect to clock noon in all longitudes between 15°'s multiples; solar noon is the point at which the Sun is highest over the horizon. Since 1 hour has a constant value of 60 minutes, it is easy to figure out how many degrees the Sun's position has changed after a specific amount of minutes (15° / 60). (Messenger & Ventre, 2010) The following equation can be used to determine solar noon with respect to clock noon:

$$t = 12 + \frac{L1 - L2}{15} * 60 = 12 + t \min = 12{:}\, t\ pm$$

$$\text{L1: Latitude where you want to determine the solar noon time.}$$
$$\text{L2: Latitude at which solar noon matches clock time with respect to its time zone.}$$

Equation 7: Solar noon at specific latitude.
***Source:** (Messenger & Ventre, 2010)*

5.1.3 The Sun's Position

Three coordinates are required in order to specify the Sun's position, but if the distance to the Sun is considered to be a constant, the Sun's position can be specified using two angles: solar altitude and azimuth.

- **Solar altitude (α):** is the angle between the horizon and the incident solar beam in the plane determined by the zenith and the Sun. (-90° ≤ α ≤ 90°) (Messenger & Ventre, 2010)
- **Azimuth (γ):** is the deviation angle of the sun directly from the south, in other words the Sun's east or west. Solar noon occurs when the azimuth angle is equal to cero. A vertical plane oriented in a north-south direction can be considered as the basis for the azimuth angle, increases to the east and decreases to the west. (-180° ≤ γ ≤ 180°) (Messenger & Ventre, 2010)
- **Zenith angle (θ_2):** Angle defined by a vertical line above the observer and the line of sight towards the sun. (0° ≤ θ ≤ 90°) (Norton, 1992)
- **Angle of incidence (θ):** Angle between the insolation beam incident on a surface and the normal to that surface. (0° ≤ γ ≤ 90°) (Norton, 1992)
- **Latitude (ϕ):** Location in relation to the equator. (North [+]; South [-]) (Norton, 1992)
- **Hour angle (ω):** Angular displacement of the sun. (Afternoon [+]; Morning [-]) (Norton, 1992)
- **Day of the year (n):**
- **Time (T):** Time at which the Sun's position wants to be known. (0.0 ≤ γ ≤ 24.0); 08:30 » 8.5

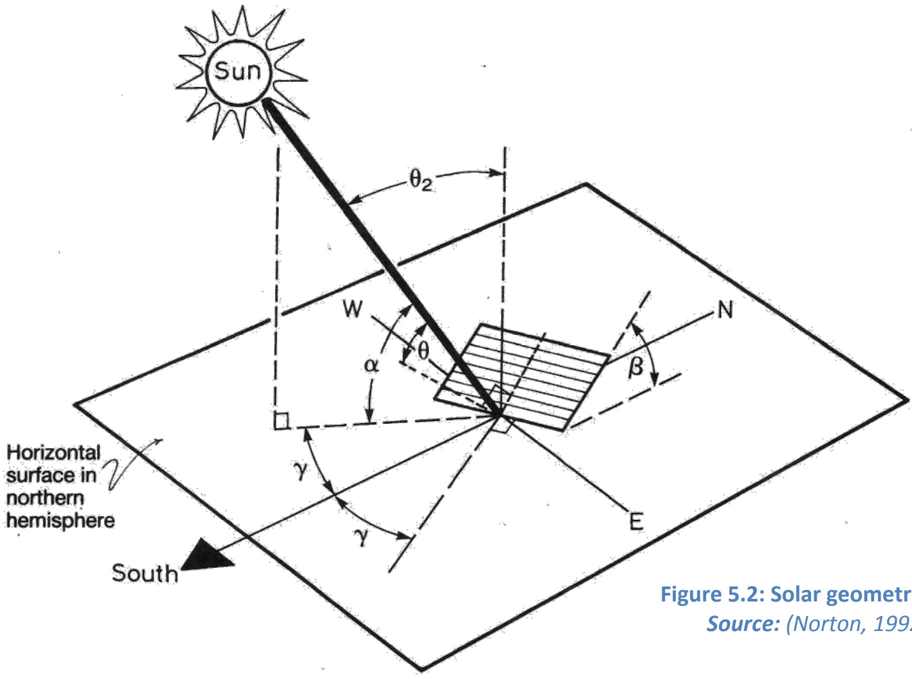


Figure 5.2: Solar geometry.
Source: (Norton, 1992)

$$\boldsymbol{\delta} = 23.45° \sin\left[\frac{360\ (n-80)}{364.256}\right] \qquad \boldsymbol{\omega} = \frac{12-\boldsymbol{T}}{24} x\ 360° = 15(12-\boldsymbol{T})°$$

$$sin\boldsymbol{\alpha} = sin\boldsymbol{\delta}\ sin\boldsymbol{\varphi} + cos\boldsymbol{\delta}\ cos\boldsymbol{\varphi}\ cos\boldsymbol{\omega} \qquad cos\boldsymbol{\Psi} = \frac{\sin\boldsymbol{\alpha}\sin\boldsymbol{\varphi} - sin\boldsymbol{\delta}}{\cos\boldsymbol{\alpha}\ cos\boldsymbol{\varphi}}$$

Equations 8: Solar angles and position variables.
Source: (Messenger & Ventre, 2010)

5.2 Solar Thermal

Solar thermal technologies utilize the energy in solar radiation to produce heat and use it in different applications, like: space cooling, space heating, water heating, water purification, water desalination, steam production, heat for industrial processes, and electricity generation.

These technologies can be divided into different categories: non-concentrating and concentrating technologies, either with tracking or non-tracking systems. In non-concentrating technologies the collector area is equal to the absorber area. In other words the area that intercepts solar radiation is equal to the area that absorbs the energy and generally the collector area IS the absorber. On the other hand, concentrating technologies do exactly what the name implies: they concentrate solar radiation into a focal point, making the collector (aperture) area greater than the absorber (receiver) area, and therefore achieving higher temperatures than those with non-concentrating technologies. (EIA, 2011) They can also be further classified into tracking and non-tracking systems. Tracking systems can follow the sun's trajectory in either 1- or 2-axes. Normally only concentrating technologies use tracking systems, because non-concentrating technologies have a low temperature output and its efficiency would not be greatly influenced by a tracking system. (Deutsche Gesellschaft fur Sonnenenergie, 2005)

5.2.1 Concentrating Solar Thermal (CST)

There are two ways of focusing and concentrating sunlight, by lens-refracting or mirror-reflection. These types of sunlight concentration may also be used in photovoltaic applications. (da Rosa, 2009) Concentrated solar thermal technologies frequently use reflector-type mirrors to concentrate sunlight into a central area. A one-axis tracking system follows the sun's movement from east (sunrise) to west (sunset), and reflects the sunlight onto a focal line. A tube with heat transfer fluid normally is placed within this focal line to act as the absorber. The two-axis system tracks the sun in two planes (azimuth and zenith angles): from east to west during the day, and the solar altitude over the horizon. Unlike one-axis tracking systems, two-axis system focuses sunlight onto a focal point and not onto a focal line; making it possible to concentrate more solar radiation in a small area and therefore achieving higher temperatures. (Deutsche Gesellschaft fur Sonnenenergie, 2005)

Two important concepts are required when dealing with concentrating collector performance:

- **Concentration:** can be defined by the ratio of the collector area to the absorber area, or by the power density concentrated at the receiver. (da Rosa, 2009)
- **Acceptance angle:** angle at which the collector can be misaimed, from the sunlight beam to the receiver, without greatly affecting the power density at the receiver. (da Rosa, 2009)

Table 5.1 lists the major *Concentrating Solar Power* (CSP) systems functioning in the world today with their corresponding concentration ratio and temperature range.

Collector Type	Motion	Concentration Ratio	Temperature Range (°C)
Parabolic Trough	1-axis	15 - 45	60 - 250

Linear Fresnel	1-axis	10 - 40	60 - 300
Heliostat Field: Solar Tower	2-axes	100 - 1500	150 - 2000
Parabolic Dish	2-axes	100 - 1000	100 - 500

Table 5: Major Concentrating Solar Power Systems.
Design: *Author;* ***Data Source:*** *(Kalogirou, 2004)*

5.2.1.1 Parabolic Trough

The parabolic trough system basically consists in an open U-shaped cylinder-type parabola. The parabola is made of reflective material that concentrates sunlight onto a focal line, where an evacuated tube lies with a heat transfer fluid inside. (NREL, 2011) Some systems use a high-temperature oil as a heat transfer fluid to produce steam in a heat exchanger, while others contain water and steam is directly produced by the system without the need of a heat exchanger. The steam is commonly used to turn a turbine and generate electricity, and although a heat exchanger is not used for steam production, one is required to cool down the steam and be able to reuse the water and latent heat, instead of just letting it out to the ambient. (EERE, 2011) Even though heat is valuable factor in a thermal system, it always requires a way to cool down in order to prevent overheating and avoid temperatures that may not be productive or may even be dangerous because the equipment cannot handle such high temperatures. Another important factor to keep in mind when mentioning the parabolic trough system is that they have a north-south orientation, and in order to keep reflecting all of the sunlight received by the parabola onto the focal line they require a 1-axis tracking system to follow the sun's trajectory from east to west.

Picture 1: Parabolic Trough System: DISS
Source: *(Ciemat, 2010)*

5.2.1.2 Linear Fresnel

The Fresnel technology derives from the invention of the *Fresnel lens* developed for lighthouses by French physicist Augustin-Jean Fresnel. (Encyclopedia Britannica, 2011) It focuses the light produced from one source into one direction, therefore the directed light reaching further distances. This same concept is used for *Linear Fresnel Reflector* (LFR) technologies and concentrated PV (CPV). The LFR reflects the direct sunlight received over an area into a smaller area

Picture 2: Linear Fresnel Reflector (LFR) layout: FRESDEMO
Source: *(PSA, 2011)*

(receiver) using series of shallow-curved or even flat mirrors.

The picture to the right shows a LFR mirror configuration in the *Plataforma Solar Almeria* experimental facility in Spain. Linear Fresnel technologies also have a north-south orientation with a single axis tracker that follows the sun's trajectory from east to west. Each mirror row is moved individually according to the sun's position in order to reflect its light onto the absorber located above. (PSA, 2011) The absorber area generally has another level of concentration with a *Compound Parabolic Concentrator* (CPC) that concentrates sunlight even further, reflecting it onto a tube that contains the heat transfer fluid. The CPC has greater acceptance angle (da Rosa, 2009); projecting the beam of light that comes from different directions into the focal line. The tube in the focal line is typically a vacuum insulated double-tube (evacuated tube) that reduces heat losses due to convection. (Novatec, 2011)

Linear Fresnel technologies may be used in different applications that require high temperatures of up to 285 °C. The first LFR to generate commercial electricity entered operations in 2009 in Calasparra, Murcia, Spain. (Novatec, 2011)

5.2.1.3 Heliostat Field: Solar Tower

A heliostat is a device that holds a reflective surface of mirrors on a flat plane and is able to move this plane in 2-axes. The heliostats in a field are connected to a system that tracks the sun; directing the heliostats to move in accordance to the sun's position in order to reflect the sunlight onto a focal point or receiver located above the heliostat field (solar tower). The receiver in the solar tower is commonly made of a porous volumetric material able to handle high temperatures. A heliostat field is capable of achieving temperatures above 500 °C; depending on the total aperture surface and solar irradiance. This type of technology is used to generate electricity or as a test platform for new materials that should tolerate high temperatures. (Ciemat, 2010)

Picture 3: Heliostat Field: Solar Tower CESA-I
Source: (Ciemat, 2010)

5.2.1.4 Parabolic Dish

The parabolic dish is similar to a large satellite dish with a mirror-covered surface with a focal point a few meters from its center; depending on the parabola's curvature. It uses a 2-axis tracking system in order to reflect sunlight onto the focal point and produce high temperatures. Normally a Stirling engine is placed at the focal point to produce electricity. This system has demonstrated to be

Picture 4: Parabolic Dish: EURODish
***Source:** (Ciemat, 2010)*

effective, but has not yet been widely-spread in worldwide applications. (Ciemat, 2010)

5.2.2 Non-concentrated Solar Thermal

As mentioned before, non-concentrated solar thermal technologies have the collector surface equal to the absorber surface area. These types of systems are generally used in applications that do not require high temperatures (< 70 °C); space & water heating, water purification, and other simple applications.

5.2.2.1 Evacuated Tubes

The evacuated tube collector consists of a series of evacuated tubes that are directly exposed to sunlight. The tubes are made of two concentric tubes, one inside of the other, with a vacuum between the outer and inner tube. The vacuum is created to reduce losses due to convection; if there are no molecules that can move and come into contact with a different temperature gradient the heat losses are reduced. The collector is frequently lined with a reflective surface in order to reflect and take advantage of the sunlight that passed through the evacuated tube array and did not get absorbed. (da Rosa, 2009)

This type of system is generally used in applications where higher temperatures are required, like solar cooling. The vacuum in the system allows it to reach higher temperatures due to its reduction of heat losses, but special care must be taken in consideration. A rigorous maintenance program should be established to ensure that all the components are working properly. The vacuum in the tubes frequently contain a pure barium coating that acts as getter that will absorb any gasses left inside after the vacuum has been established. If the vacuum in the tube is lost the barium will become white and foggy when it is exposed to oxygen; reducing greatly the performance of the system, not allowing solar radiation onto the absorber tube and breaking the convection barrier previously established by the vacuum. Also to prevent the system from overheating the flow of fluid inside the tubes MUST be ensured when it is receiving solar radiation, otherwise the collector will most likely achieve greater temperatures than those it was original design to operate with, ruining some of its components. (Ramlow & Nusz, 2010)

5.2.2.2 Flat Plate Collectors

Flat plate collectors are the most common type of collector used in the world for solar water and space heating application. (Ramlow & Nusz, 2010) It works with both, direct and diffuse radiation, and is able to reach temperatures of up to 70 °C. (da Rosa, 2009) The collector basically consists of a surface that intercepts and absorbs solar radiation with a surface through which a fluid passes through (air or liquid), using the solar energy absorbed to heat up the fluid. (Norton, 1992) It is generally fixed into place and do not use a tracking system. (Kalogirou, 2004) The heat gain of this type of system is greatly affected by the weather (wind, ambient temperature) (Norton, 1992). Flat plate collectors can have an efficiency of over 90%; as the demand for a big temperature differences increases its efficiency decreases. (da Rosa, 2009)

The collector is shaped as a shallow rectangular box that serves as housing for the absorber surface, which is generally made of copper or aluminum fins that are attached to tubes through which the fluid flows. (Ramlow & Nusz, 2010) The back and sides of the housing is insulated and the top part is glazed with transparent material that allows sunlight to pass through and keeps infrared radiation in, allowing greater heat gain and reducing ambient heat losses. (Norton, 1992)

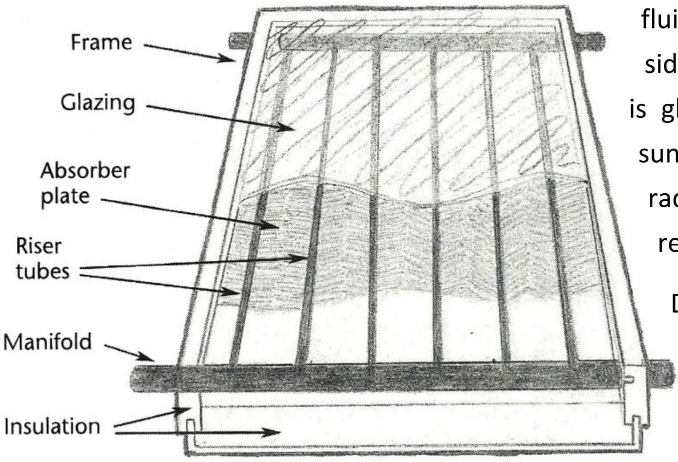


Figure 5.3: Flat plate collector diagram
Source: *(Ramlow & Nusz, 2010)*

Due to its performance, simple operation, popularity, worldwide acceptance, durability, and low cost components, it has been chosen as a preliminary recommendation for implementation in household water heating systems in Managua, Nicaragua. The collector, its components and other essentials will be further discussed in the next section, *Solar Water Heater Systems*.

5.3 Solar Water Heater System: Flat Plate Collector

Flat plat collectors are the most widely used collectors for domestic solar water and space heating applications in the world. (Ramlow & Nusz, 2010) Due to its versatility and different characteristics, it fits right in with the needs in Managua, making it the most appropriate type of collector for the application needed in this research investigation. The next section is to have a better understanding of its components, as well as to know what affects its performance, and why it has been selected for this research.

5.3.1 Components

Collector Frame

The frame should be made of a durable and solid material; able to withstand strong winds, transportation, installation and other situations that may occur during operation. The housing should be properly sealed, not allowing dust, moisture, insects or anything else to get inside the collector. The frame and mounting hardware should be made of compatible metals; incompatible metals may corrode one another. It is common for FPC’s to be me fabricated in such a way that the inlet and outlet connections (upper and lower manifold) can be connected in series in order to provide the temperatures demanded or the amount of hot water required. (Ramlow & Nusz, 2010)

Glazing

A good glazing material should have a high transmittance of the visible spectrum (short wave radiation) and a low transmittance of infrared (long-wave) radiation in order to take advantage of re-radiated heat emitted by the absorber plate. (Norton, 1992) The glazing material also reduces convection loses by restraining the stagnant air layer between the absorber and the cover, creating a sort of greenhouse effect. (Kalogirou, 2004)

A transparent glass or plastic is commonly used as glazing material. Plastic weighs about 10% of the same area of glass, but it does not have a high tolerance to prolonged exposures of UV light; with time it becomes opaque, not allowing as much sunlight to go through. (Norton, 1992) On the other hand low iron tempered glass withstands long exposures to UV light; low iron glass is recommended since the iron content in the glass may absorb some of the solar radiation, reducing the irradiance incident on the absorber plate and decreasing its efficiency. (Ramlow & Nusz, 2010) Low iron glass is highly transparent with a high transmittance of solar radiation (approximately 85-90% at normal incidences) and basically zero transmittance for long wave infrared radiation (5.0 – 50 μm) emitted by sun-heated surfaces. (Kalogirou, 2004) The downside to using glass is its weight, high costs, and low shatter resistance. (Norton, 1992) The glass used in flat plate collectors is usually patterned on one side in order to maximize sunlight transmittance by reducing the glare and reflection of a flat surface. (Ramlow & Nusz, 2010)

The glazing material is usually secured to the collector's frame with a rubber gasket, this is done in order to protect the glass and to create a good seal to reduce heat losses due to convection. In some cases a silicon material is used, but this makes it difficult to perform maintenance operations; since it makes it almost impossible to remove the glazing material to make repairs. (Ramlow & Nusz, 2010) A good seal prevents moisture, insects, and dust from getting; protecting the transmittance coefficient of the glazing material, the absorbance factor of the absorber plate, and other thermal losses due to convection.

The following attributes are important when selecting a good glazing material:

- High short wave transmittance during the whole collector's lifespan
- Low long-wave transmittance
- Low reflection
- Protection from cooling effects of the wind and convection
- Protection from moisture
- Durable in regards to mechanical loads: broken branches, hailstones, scratches, etc.
- Weight
- Cost (Deutsche Gesellschaft fur Sonnenenergie, 2005)

Insulation

To reduce thermal losses the collector should be lined with insulation material on the sides and back. The material should be able to withstand high temperatures, and close attention should be put to the adhesive used with the insulation, since this adhesive may vaporize at high temperatures and reduce the transmittance of the glazing material. (Deutsche Gesellschaft fur Sonnenenergie, 2005) As insulation material it is common to use polyisocyanurate, rigid expanded polyurethane (PUR), mineral wool (fiberglass, rock wool) (Ramlow & Nusz, 2010); and other non-combustible-CFC-free polyurethane foam sheets. (Deutsche Gesellschaft fur Sonnenenergie, 2005)

Absorber

The absorber plate should absorb as much incident solar radiation as possible, convert it to thermal energy, and transfer it to the heat medium; all these with as minimum losses as possible. (Kalogirou, 2004) Copper is a good thermal conductive material, but it is expensive and without an appropriate coating it reflects a great part of incident solar radiation. (Deutsche Gesellschaft fur Sonnenenergie, 2005) The absorber coating is rated with two parameters: absorbance rate (α) and emissivity rate (ε). The coating should have a high absorbance rate to solar radiation and a low emissivity of infrared thermal radiation (Kalogirou, 2004); this type of coating is called *spectral-selective coating*. Most spectral-selective coating have α = 90-95% and ε = 5-15%. This can be achieved with black chrome or black nickel coating, using the latest high-tech methods: sputtering, electroplating, or physical vapor deposition (PVD). (Deutsche Gesellschaft fur Sonnenenergie, 2005) To calculate the net heat gain the energy emitted is subtracted from the absorbed. (Ramlow & Nusz, 2010)

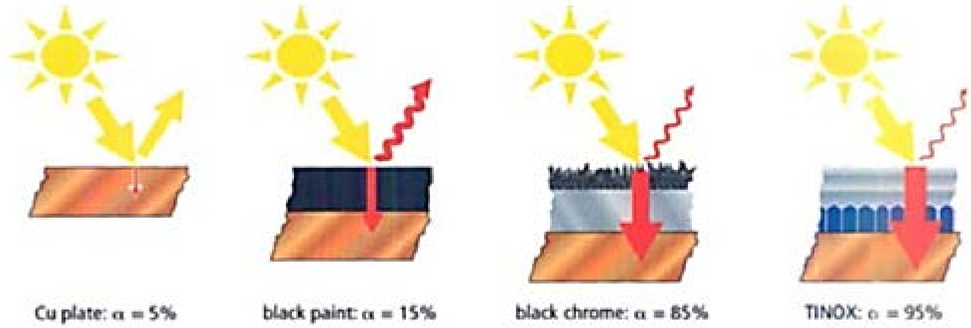


Figure 5.4: Absorption and emissivity of different coatings.
Source: *(Deutsche Gesellschaft fur Sonnenenergie, 2005)*

5.3.2 Efficiency

When short wave solar radiation (0.3-3.0 µm) hits an object it is reflected according to its surface structure, depending of its material, roughness, and color; for instance, white reflects more short wave radiation than dark colors. The Fresnel law also states that the proportion of reflected depends of the angle of incidence upon the surface. If the radiation is not reflected, it is absorbed, or in the case of translucent material it allows much of it to pass through. Once it is absorbed a portion of the short wave radiation is converted into infrared / long wave thermal radiation (3.0-30.0 µm). These radiation flows can be described as reflection (ρ), absorption (α), transmission (τ) and emissivity (ε) rates; the sum of all these portions should add up to 100% (1.0) of the incident radiation. (Deutsche Gesellschaft fur Sonnenenergie, 2005)

$$\rho = \frac{Reflected\ Radiation}{Incident\ Radiation} \qquad \alpha = \frac{Absorbed\ Radiation}{Incident\ Radiation}$$

$$\tau = \frac{Transmitted\ Radiation}{Incident\ Radiation} \qquad \varepsilon = \frac{Emitted\ Radiation}{Absorbed\ Radiation} x\ Incident\ Radiation$$

Equations 9: Radiation Flow Ratios
Source: *(Deutsche Gesellschaft fur Sonnenenergie, 2005)*

When talking about solar radiation the Stefan-Boltzmann law is also important, it states that an object emits radiation according to its temperature; the temperature to the 4th power.

$$Q = \sigma T^4$$

Q: represents the emitted thermal radiation in W/m2
σ: is Stefan-Boltzmann constant = 5.67 / 10^8 (W/m^2K^4)
T: is the absolute body temperature of the object in Kelvin.

Equation 10: Stefan Boltzmann Law
Source: *(Messenger & Ventre, 2010)*

Figure 5.5, shows the energy flows of a flat plate collector. When short wave solar radiation (G_0) hits the glazing material (glass) in a FPC, a part of it is reflected by the glass (ρ_1), a small portion is absorbed, and the rest is allowed through. A portion of the radiation that passes is also reflected by the absorber (ρ_2) and the rest is absorbed (α) and converted into heat (τ). Part of the radiation absorbed another is emitted (ε) as long wave radiation. It is also important to have in mind thermal losses of the absorbed energy due to convection (ε_1) and conduction (ε_2). At the end the useable energy is just the thermal power left after all these energy flows. Therefore the efficiency of the collector is measured by the ratio of useable thermal heat obtained and the irradiated energy of incident solar radiation.

$$n = \frac{Useable\ Thermal\ Heat}{Incident\ Solar\ Radiation}$$

Equation 11: Collector's Efficiency
Source: *(Deutsche Gesellschaft fur Sonnenenergie, 2005)*

In order to improve the efficiency of the collector it is necessary to reduce the optical losses due to the reflection of the glass (ρ_1) and absorber (ρ_2), and the losses due to convection (ε_1) and conduction (ε_2).

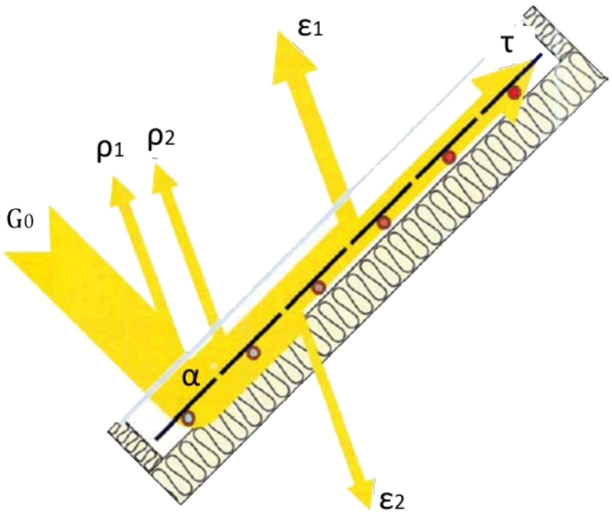


Figure 5.5: Flat Plate Collector Energy Flows
Source: *(Deutsche Gesellschaft fur Sonnenenergie, 2005)*

5.3.3 System Types

Open Loop (Direct) Systems

An open loop system refers to a system that does NOT have a recirculating heat fluid through the collector. In the case of solar water heating system cool domestic water goes into the collector, which is heated by solar radiation, and then the same fluid (water) is later used in domestic applications as heated water; it does not recirculate to the collector.

Closed Loop (Indirect) Systems

A close loop system uses a heat transfer fluid that is recirculated to the collector. The fluid is heated up by the collector and then goes through a heat exchanger, where the solar heat is transferred to the end-use fluid (domestic water) and then goes back to the collector. The heat fluid is in a close loop within the collector and heat exchanger; it is never consumed by the end user. Normally an antifreeze solution is used as the heat transfer fluid; the best solution today is a high-temperature propylene glycol. Although this fluid is not consumed by the end user, it should be changed periodically, since it eventually breaks down and looses its thermal characteristics; under normal operating conditions it should be changed every 10 to 15 years. (Ramlow & Nusz, 2010)

Passive Systems

Passive systems do NOT use pumps to circulate the fluid through the collector; instead they use the same pressure from the domestic water supply. They basically have few or no moving parts, and do NOT require external energy to operate. They are simple and easy to maintain, which also makes them rather inexpensive. Due to its simplicity and operating principles, careful attention must be employed when installing it; considering inclination angles, connections, and piping system. They also tend to be less efficient than active systems, since they depend on the domestic water supply pressure; optimal operating flows may not always be achieved.

Active Systems

Unlike passive systems, active systems DO employ pumps to circulate the fluid to the collector; therefore requiring external energy that may be supplied by the electricity grid or by an additional solar panel. This type of systems ensures the operational flows required by the system to function correctly.

5.3.4 Selecting the Appropriate System

Several factors must be considered when selecting an appropriate system: type of application, solar radiation, climate, sunlight hours, space available for installation, budget, demand, and many others. There is no perfect solution, but the closest match possible should be made according to the end-user needs. The following considerations for selecting an appropriate system have been obtained from *Solar Water Heating: A Comprehensive Guide to Solar Water and Space Heating Systems* by Bob Ramlow and Benjamin Nusz.

5.3.4.1 Collector Efficiency

The type of collector used should be selected according to the desired application and the conditions under which it will operate. Pool collectors have a better efficiency than flat plate collectors and evacuated tubes when the difference between the ambient and the inlet temperature is small. In other situations when the temperature difference is greater a flat plate collector or evacuated tubes should be selected. When the temperature difference is above a certain point, evacuated tubes are recommended. Please see Mean Collector Efficiency Rating in Figure 5.6 to see which collector performs better according to the temperature difference range of the location.

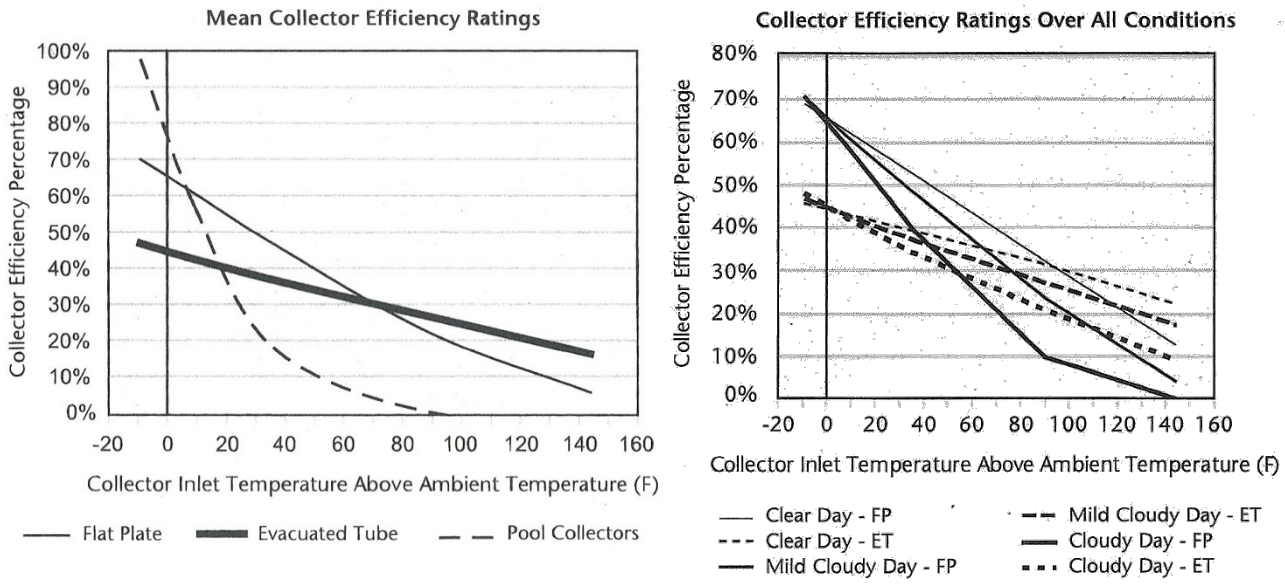


Figure 5.6: Collector Efficiency Ratings

Source: *(Ramlow & Nusz, 2010) obtained of data from the SRCC*

The collector's efficiency also varies according to the cloud coverage under which they operate. *Collector Efficiency Rating over All Conditions* in Figure 5.6 displays flat plate collector (FP) and evacuated tubes (ET) efficiency ratings under different climatic conditions.

5.3.4.2 Durability

There always have been people that are trying to sell cheap products in order to make an attractive offer to their market and obtain a fast income, but many of these companies do not have the end-users best interest at heart; they are just trying to make quick money. A solar heating system should be deigned to last at least 40 years, so it is important to choose wisely. Although there is no recipe for finding the most durable system, there are some guidelines that can help on ensuring a smarter choice.

Warranty

An indicator of quality may be the warranty offered with the collector. Some may offer up to 10 years, while other might offer an extension for up to 15 years, but this does NOT guarantee that the collector is of good quality and durable. By the time the solar heating systems starts giving problems the company from which you bought it from may not even exist anymore, so it is always wise to check the company's history. How long have they been in business? Are there any comments on the internet about their products?

Fabrication Place

Something else to consider is where the products are manufactured. If they are produced locally or in a nearby country it might be easier to get a spare part or a good response from the manufacturer. If they are in the other side of the world, it may take months to receive a spare part or any help whatsoever on your situation. Selecting a local manufacturer may also help on reducing the shipping and transportation costs included in the initial investment of the collector and in any spare parts that may be required in the future.

5.3.4.3 Climate and Location

Snowfall

Some locations may be prone to snow fall, the accumulation of snow on the collector's surface may greatly diminish its heating capacity. In order to prevent snow accumulation on the collector FPC's function really well on shedding snow from its surface, the glazing material will loose heat helping the snow to run off. While on the other hand evacuated tubes are such good insulators that barely any heat will be emitted from the absorber and the snow may remain on its surface for long periods of time; even the whole winter season. And the surface of this type of collector is so irregular that the snow may be allocated between the tubes until it melts away.

Freezing Point

Compounds normally contract as they loose energy, cooling down, and eventually solidifying. Water, unlike any other compound, expands when it freezes (solidifies); as it cools down it becomes denser, with its densest point just before freezing, but when it freezes (converting to what is commonly known as ice) it expands, becoming less dense than water at its liquid state. If it was not for this unusual behavior life on Earth would be completely different. Ice on lakes, rivers and oceans would not float, but it would instead sink to the bottom, killing all the plants and animals under it. This would also make it harder for water bodies to unfreeze. Since the ice on the surface acts as an insulation layer, slowing down the freezing process; without this insulation layer lakes, rivers and oceans would eventually freeze solid and probably never unfreeze. Ice would also increase the albedo effect on Earth and the energy absorbed from the sun would be greatly reduced.

This interesting effect is also responsible for landscaping some of the world's most amazing sites. Water gets in small cracks in rocks, and breaks the rocks as it freezes and expands; a powerful force that not many would imagine. This same thing can happen with water in a solar collector; as water in its pipes freezes it expands and if it exceeds the pipes limits it can burst the pipes and render the collector useless. Therefore it would be wise to use an antifreeze fluid in a close loop system if the temperatures in the location where the collector is being installed may EVER reach freezing point or temperatures close to freezing point. It is important to remember that a collector should last around 40 years and if the temperature is expected to drop below 0 °C in a near future a close loop system with antifreeze would be recommended.

Constant Sun and Template Climate

If the location has a template climate and receives plenty of sunlight throughout the year, a cheaper solar collector with less efficient absorber coating can be selected without affecting the overall performance of the collector.

Water Quality

In some locations the water quality of the domestic water supply may have a high content of minerals; this is commonly considered as "hard water". If hard water is heated the mineral content in the water may precipitate out of the water and solidify, forming a layer of minerals that can reduce the efficiency of the collector by acting as insulation and reducing the amount of thermal energy transferred to the heat fluid. In some cases the mineral buildup may be so great that it can clog the pipes of the collector, putting it out of operation. In these locations it is recommended to use a water softener in the water inlet of the solar water heating system in order to prevent mineral buildup.

5.3.4.4 Density of the Absorber Area

An important factor when selecting a solar collector is the absorber's area. Manufacturers and certification companies use terms like gross collector area, net aperture and absorber area. The *gross collector area* refers to the total area used by the collector; including the frame; *aperture area* is the size of the glass that will receive sunlight; and the *absorber area* is the surface that will be absorbing the solar radiation and converting it into thermal energy.

Basically the entire gross area of a flat plate collector consists of absorber area, with exception with the small spacing around the frame. On the other hand, an evacuated tube's gross collector area consists mostly of the space between each tube and the vacuum around each absorber. In most cases an FPC occupies 25% less gross area than an evacuated tube collector with the same absorber area.

In disregard to the absorber area, the evacuated tube collector absorbs solar energy more efficiently than an FPC and therefore requires less absorber surface to have an equal energy output under the same conditions. This is especially true when there are greater differences between the inlet temperature and the ambient temperature, as explained in *Section 5.3.2 – Efficiency*; but is the efficiency difference enough to complement the absorber area difference? This all depends on the type of climate, temperature difference (ambient/input) and temperature output required. Of course, when choosing a collector it does not just depend about the previous factors, but also the investment cost, availability and technical know-how; if the company installing the collector does not know how to install it properly it will naturally underperform.

5.3.5 Positioning and Sizing

The collectors sizing should be depending on the climate conditions of the location, solar radiation incident on the collector's surface and hot water needs. The systems should be position to face the equator, this means that if the location is in the northern hemisphere the system should be facing south, but this may vary according to the house orientation or obstructions. The optimum inclination for the collector's surface is usually the same as the location's latitude, but some solar thermal systems require a greater inclination to function properly.

5.4 Photovoltaic

5.4.1 Photovoltaic Effect

The photovoltaic effect is basically the interaction with photons in the solar spectrum radiation in order to absorb or transform its energy into a movement or flow of electrons. The energy transfer must obey the rules of momentum conservation and energy conservation. Since zero-mass photons have very little momentum compared to electrons their momentum transfer is insignificant. The energy in a photon can be determined by the equations below. Since energy at an atomic level is commonly expressed in electron volts (eV), and 1 eV = 1.6 x 10^{-19} J, then it is easy to calculate the energy in a photon into electron volts by using the formula to the right:

$$E = h\nu = \frac{hc}{\lambda}\ (joules) \qquad\qquad E = \frac{1.24}{\lambda}\ (eV)$$

Equation 12: Energy in a Photon
Source: *(Messenger & Ventre, 2010)*

h = 6.63 x 10^{-34} W s^2 (Planck's constant)
c = 2.998 x 10^8 m/s (speed of light in vacuum)
ν = Frequency of the photon in Hz (hertz)
λ = Wavelength of photon in μm (micrometers)

As mentioned in previous sections, terrestrial sunlight approximates the spectrum irradiated by a 5800 K blackbody; therefore PV cells are made from materials which convert the energy in this specific spectrum as efficient as possible; the material typically used in solar cells is a semi-conductor material. (Goetzberger & Hoffmann, 2005) A typical PV cell produces less than 5 W at approximately 0.5 V, so they must be connected in series or in parallel in order to produce power high enough for daily applications. (Messenger & Ventre, 2010)

The semi-conductor material is characterized to behave as a perfect insulator at absolute zero temperatures (0° K). As the temperature rises, the electrons of the atoms in the material are easily moved with a small quantity of energy from the valence band to the conduction band. When the electron move from one atom to another they leave a whole behind which can be occupied by another moving electron. The valence band is the amount of allowable energy of valence electrons bond to the specific atom, while the conduction band represents the allowable energy received by any mechanism, which allows the electrons not to be bound to the host atom. (Messenger & Ventre, 2010)

If the valence band is completely occupied by electrons, this means that there is no allowable energy in the conduction band, therefore no energy can be absorbed from an external source; the conductor is an insulator. What differentiates a conductor from an insulator is the energy gap between these two bands, also known as band gap. Insulators have a bigger band gap that requires great amounts of energy in order for an electron transfer to occur. Semi-conductors have a band gap that lies between a few tenths of eV to ~ 2 eV. (Goetzberger & Hoffmann, 2005) The photon's energy must be greater or equal to the band gap energy required in order to be absorbed and free an electron, creating an electrical current. If the photons energy is greater than the band gap energy it can still only one electron movement, the rest of the energy is lost to the cell as thermal energy, heating up the PV cell. (Messenger & Ventre, 2010)

The semi-conductor material in PV cells is typically doped with another element to facilitate the movement of electrons. For example Silicon (Si) and Phosphorus (P): Si is from group IV with 4 electrons in its valence band, while P is from group V with 5 electrons on its valence band, so only 4 of the P electrons bond to the crystal structure of the Si and the remaining electron is loosely bound, therefore it can be easily moved or "ionized". In this case P is acting as a donor, by donating one of its electrons to the electrical flow, but a semi-conductor can also be doped with elements from group III, creating a hole in its bond with Si to facilitate the movement of electrons. (Messenger & Ventre, 2010)

Bypass diodes are used in order to protect PV module's performance when one or more cells that are connected in series are degraded or shaded. If a cell is shaded it can decrease greatly the overall performance of the PV module, causing the cell to heat up; therefore the PV module uses the bypass diodes so the current can flow through the diode instead of the cell, not affecting performance that greatly. (Messenger & Ventre, 2010)

5.4.2 Grid-Connected Utility Interactive System

Several requirements must be fulfilled in order for a PV system to be connected to the grid and inject the electricity produced. Since high-voltage currents are produced, and house structure is modified, it involves the regulation from several construction, safety, and quality codes/standards, they depend greatly on those that may apply to each country. In the United States there are as many as 22 codes and standards that may apply to PV systems.

Grid-connected PV inverters must comply with IEEE 1547-2003, *"to provide a uniform standard for interconnection of distributed resources with electric power systems."* (Messenger & Ventre, 2010) The IEEE 1547 Standard specifies several pre-requisites that must be satisfied in order for a PV system to be connected to the grid. One of these pre-requisites defines specific "clearing times" for an inverter to observe in case of abnormal grid conditions, if the clearing time for a specific range is exceeded the inverter must disconnect from the grid and monitor the grid conditions, it should not restore its connection until after 5 minutes of observing normal grid conditions. (Messenger & Ventre, 2010) Some of the pre-requisites of Standard IEEE 1547-2003 can be viewed below:

Clearing Times for PV Inverters under Abnormal Grid Voltage and Frequency Conditions

Voltage Range in % of Base Voltage	*<50%*	*50% - 88%*	*110% - 120%*	*≥120%*
Clearing Time (s)	*0.16*	*2.0*	*1.0*	*0.16*

****The frequency clearing time for a PV inverter under 30 kW is of 0.16 seconds when:***

F < 59.3 Hz or F > 60.5 Hz

Maximum Allowable Harmonic Amplitudes

Harmonic Range	*n < 11*	*11 ≤ n < 17*	*17 ≤ n < 23*	*23 ≤ n < 35*	*35 ≤ n*
% of Rated Current	*4.0*	*2.0*	*1.5*	*0.6*	*0.3*

(Messenger & Ventre, 2010)

Chapter 6: Methodology

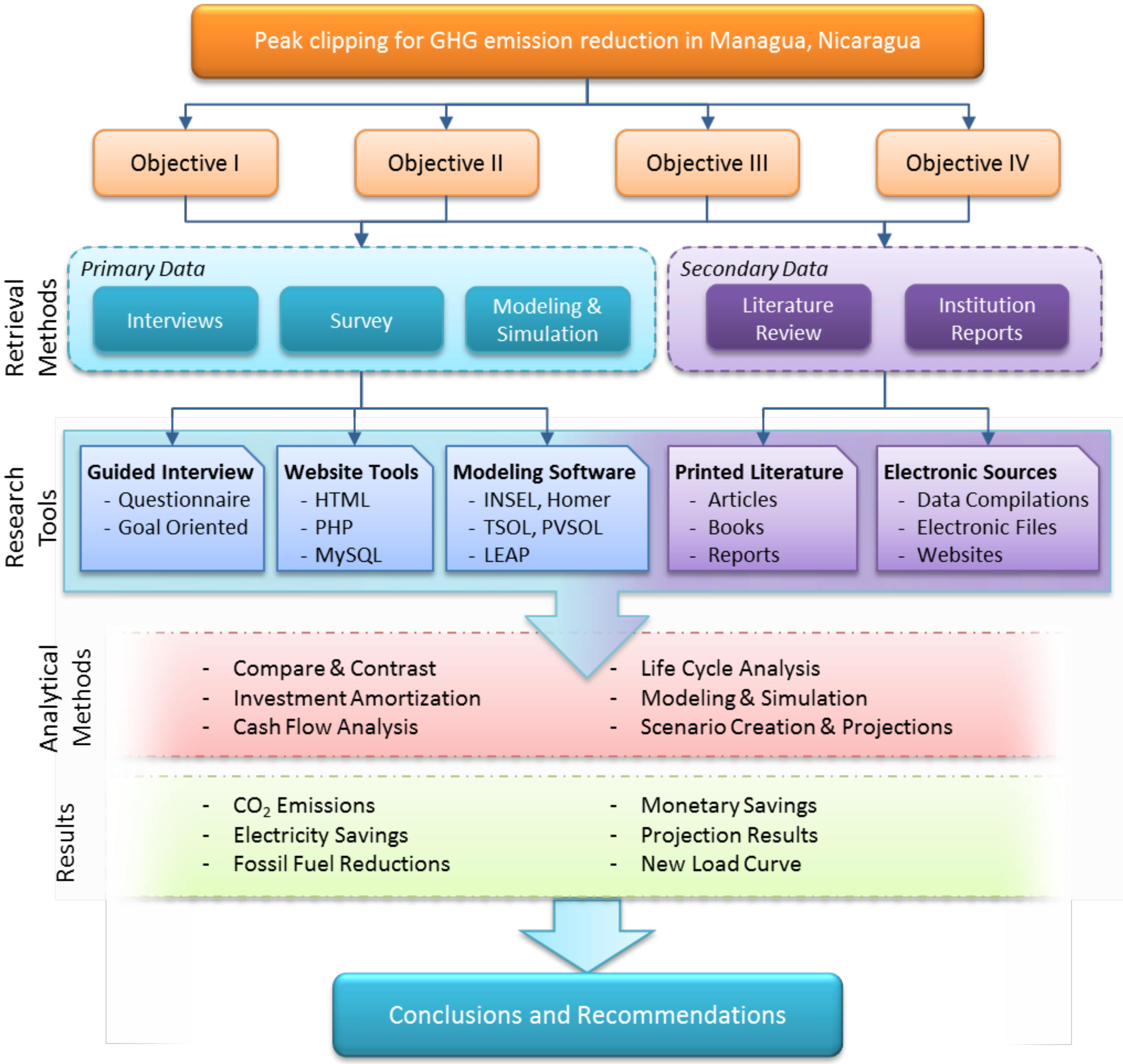


Figure 5.1: Methodology Scheme
***Source:** Author*

This research investigation has limited time frame of 5 months. During this period all data needed to be compiled, sorted, classified, analyzed, and processed to obtain the necessary results in order to draw conclusions and recommendations. Figure 5.1 displays the methodological scheme used throughout the development of the research, as well as some of the retrieval methods, research tools, and analytical methods it relied on to acquire the results.

The timeframe was divided into two periods: 2 months in Managua, Nicaragua at the beginning of the investigation to acquire necessary data by visiting institutions related to the field of study, perform interviews, and get a general overview of the situation. The 3 remaining months were used to classify, process, and analyze the data collected; although these tasks were carried out throughout the whole investigation, along with the redaction of the final documentation.

6.1 Data Needs

A limited list of the data required is listed below. It is important to remember that this is some of the data needed, but it is not limited only to the ones specified. Throughout the investigation great amounts of data are compiled and sorted according to the final objectives, to later on be integrated into the different components of the research. For example the information obtained through observation is recorded during the whole investigation, but it is hard to classify into a single category.

Electricity Sector
- Production
- Consumption
- Fuel Use
- Electricity Tariffs
- Subsidies
- Load Behavior

Meteorological Data
- Atmospheric Clarity
- Ambient Temperature
- Global Radiation
- Diffuse Radiation
- Precipitation
- Wind Speed

Fossil Fuels
- Imports
- Production
- Consumption
- Fuel Costs
- Fuel Characteristics
- Emission Factors

Demographic Data
- Population
- Household Information
- Financial Data

Solar Field
- Solar Companies
- Products Offered
- Sales Volume
- Pricing
- Incentives

Hot Water
- Consumption Patterns
- Devices Used
- Rated Power of Device
- Energy Consumed

6.2 Data Collection and Classification

During the whole investigation data is being collected, sorted, and classified, so it can be easily accessible in the section it is needed. The first objective is to process the collected data and create a compilation of data that is required by the following objectives. The data used was retrieved through the methods displayed in Figure 6.1. Institutions in the field of energy, meteorology, research, and others were visited in order to obtain reports produced by them and interview people related to the field of interest. The interviews were guided by goal/task orientation and/or a previously established questionnaire. Most of the time the questions could not be answered directly, but additional information that had not been previously contemplated could always be acquired from such a method. An online survey was also employed to get an overview of the use of hot water in households.

6.3 Modeling and Simulation

With the aid of several softwares it was possible to model a representation of the specific situation in Managua, Nicaragua in order to carry out a simulation and obtain various data. The following are some of the softwares used and their application in this investigation:

- **Homer, Insel, PVSOL, PVWATTS:** Model and simulate a PV system to obtain its energy production and CO_2 emissions avoided according to specific meteorological data of the location.
- **TSOL:** Model and simulate different solar thermal collectors that satisfy the hot water needs of a typical household in Managua to acquire their energy yield and CO2 emissions avoided.
- **LEAP:** A long-range energy alternatives planning system to create scenarios of the use of SWH and PV systems in order to create projections of the different fluctuations due to the introduction of possible variations.

6.4 CO_2 emissions from the Stationary Combustion of Fossil Fuels

The IPCC method described in this section was used in order to obtain the CO_2 emissions produced from the electricity sector. The energy sector is usually responsible for most of the CO_2 emissions in a country and for almost 70% of the emissions of the total GHG emissions in developed countries. For the purpose of GHG inventories IPCC defines *fuel combustion* as "the intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process, or for use away from the apparatus." (IGES, 2006) This has been done in order separate the use of fossil fuels (hydrocarbons) for energy purposes or other uses (like industrial processes).

During the combustion of fossil fuels most of the carbon (C) is converted into CO_2, releasing heat when the chemical energy stored in the carbon molecule is broken down and oxidized into CO_2 (in simple terms oxidization means the joining of one atom with one or more oxygen (O) atoms). Generally this heat is used to produce mechanical energy that is used for transportation or to produce electricity. The emissions of CO_2 depend greatly on the carbon (C) content of the fuel, but it is not the only factor to be considered, it also depends on the amount of C being oxidized into CO_2. The carbon may also be released as carbon monoxide (CO), methane (CH_4) and other non-methane volatile organic compound (NMVOCs). The carbon oxidized into CO_2 depends significantly on the technology used, specific C content in that particular fuel used, maintenance of the device used, along with other factors; but eventually all the non-CO_2 emissions oxidize into the atmosphere as CO_2. (IGES, 2006)

Typically, the CO_2 emissions for the combustion of fossil fuels are calculated depending on 3 different approaches in the *2006 IPCC Guidelines for Greenhouse Inventories*. Each approach or methodology is called Tier and go from Tier 1 to Tier 3; Tier 1 being the less specific approach and Tier 3 being the most detailed one.

- **Tier 1** is the less specific approach used when only the statistics on the amount and type of fuel used are available. The CO_2 emissions are estimated from the amount C content in the fuel type and the default emission factors for that fuel.
- **Tier 2** uses data used in Tier 1, but instead of using the default emission factors it uses country specific emission factors. The country specific factor depends mainly on the development of the country, the energy efficiency practices and Depending on the technology used, specific C content in that particular batch of fuel used, maintenance of the device used, etc.

- **Tier 3** is the most specific approach that requires detail emission models and data of gas emissions for each individual plant; where a Continuous Emissions Monitoring (CEM) system is used, recording all the emissions of specific gasses, not only CO_2.

To select the Tier used for GHG inventory, the *IPCC Guidelines* provide a decision tree based on the information at hand. *(See* Figure 6.2: Decision Tree for Tier Selection*)*

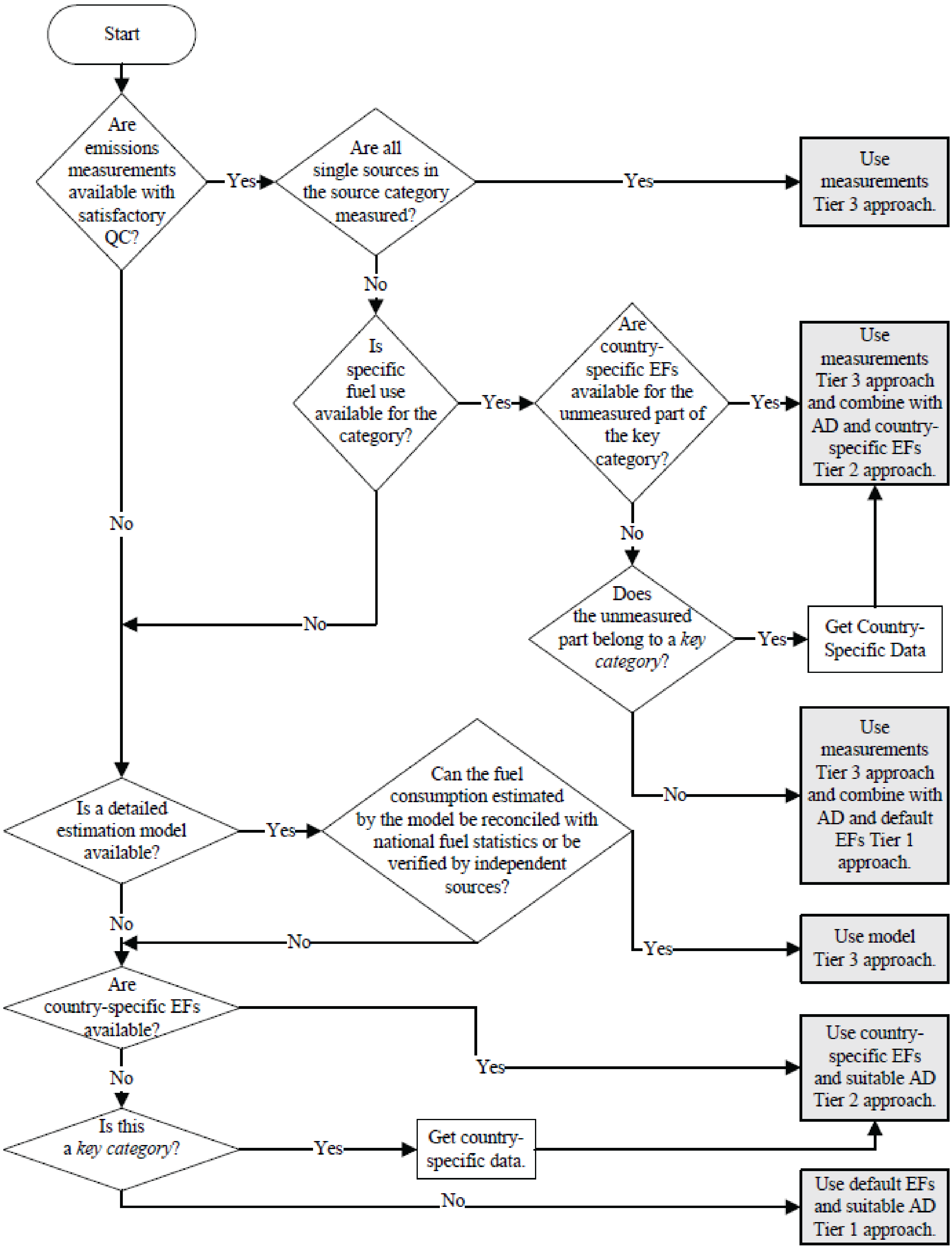


Figure 6.2: Decision Tree for Tier Selection
Source: *(IGES, 2006)*

For the purpose of this investigation a Tier 1 approach will be used to estimate the CO_2 emissions generated from the combustion of fossil fuels in the electricity generation sector in Nicaragua. The two fossil fuels used in Nicaragua for electricity generation are diesel and fuel oil no. 6, but also the combustion of sugar cane bagasse is used for this purpose. The definitions of fuel types used by the IPCC Guidelines are those of the International Energy Agency (IEA)

> ***Gas/diesel oil (distillate fuel oil):*** *Gas/diesel oil is primarily a medium distillate distilling between 180° C and 380° C. Several grades are available depending on uses: diesel oil for diesel compression ignition (cars, trucks, marine, etc.), light heating oil for industrial and commercial uses, and other gas oil including heavy gas oils which distil between 380° C and 540° C and are used as petrochemical feedstocks.*
>
> ***Fuel Oil:*** *This heading defines oils that make up the distillation residue. It comprises all residual fuel oils, including those obtained by blending. Its kinematic viscosity is above 0.1 cm^2 (10 cSt) at 80ºC. The flash point is always above 50ºC and the density is always more than 0.90 kg/l.*
>
> ***Wood, wood wastes, other solid wastes:*** *Covers purpose-grown energy crops (poplar, willow, etc.), a multitude of woody materials generated by an industrial process (wood/paper industry in particular) or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, black liquor, etc.) as well as wastes such as straw, rice husks, nut shells, poultry litter, crushed grape dregs, etc. Combustion is the preferred technology for these solid wastes. The quantity of fuel used should be reported on a net calorific value basis.*
>
> (IEA, 2005)

In order to estimate the CO_2 emissions the *Net Calorific Values* (NCV) are required by the *IPCC Guidelines*. The NCV differs from the *Gross Calorific Values* (GCV), because GCV includes the latent heat produced in the combustion from the vaporization of water (IPCC, 2007a); it is basically the calorific value under laboratory conditions (WCI, 2007). According to the IEA parameters used by the IPCC, the liquid fuel oil's NCV is considered to be 95% of their corresponding GCV. (IEA, 2005) The table below contains the default NCV values of the fuels used for electricity production in Nicaragua.

Fuel type	NCV (TJ/Gg)	Lower	Upper
Gas/Diesel Oil	43.0	41.4	43.3
Residual Fuel Oil	40.4	39.8	41.7
Other Primary Solid Biomass	11.6	5.9	23.0

Table 6: Default NCV Values with their Lower and Upper Confidence Intervals (95%)
Source: (IGES, 2006)

The following equation is used to calculate the emissions of a specific GHG due to stationary combustion:

$$Emissions_{GHG,fuel} = Fuel\ Consumption_{fuel}\ x\ Emission\ Factor_{GHG,fuel}$$

Equation 13: Emmisions by Fuel Type

Emissions $_{GHG, fuel}$: Emissions of a specific GHG by fuel type; result given in kilograms
Fuel Consumption $_{fuel}$: Amount of fuel combusted (TJ)
Emission Factor $_{GHG, fuel}$: Default emission factor of the GHG by fuel type (kg gas/TJ)
**For CO2 an oxidation factor of 1 (100%) is assumed.*

To obtain the total emissions of a specific GHG for a *source category*, the total emissions per fuel type combusted (Emissions $_{GHG, fuel}$) should be simply added using the following equation:

$$Emissions_{GHG} = \sum_{fuels} Emissions_{GHG,fuel}$$

Equation 14: Source Category Emissions.

For the purpose of GHG inventories the IPCC has break down the use of fossil fuels into specific sections or *source categories*. For the purpose of this investigation the GHG emissions of the *source category* “Electricity Generation” (1 A 1 a i) will be estimated. Each character of the code represents a category and subcategory for the source. The characters in the code **1.A.1.a.i** represent:

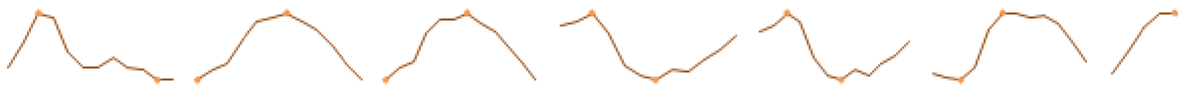
1: Energy
A: Fuel Combustion Activities
1: Energy Industries
a: Main Activity Electricity and Heat Production
i: Electricity Generation

The source category *Electricity Generation* is defined by the IPCC as “emissions from all fuel use for electricity generation from main activity producers except those from combined heat and power plants.” An extract of the official worksheets provided by the IPCC have been used to calculate the source category emissions for the fuels used in *Electricity Generation* in Nicaragua.

To view the carbon content values of fuels and other figures used for the Tier 1 CO_2 calculations, please refer to *Appendice 5: Meteorological Data*

The tables, data, and trendlines displayed in this sections are own elaboration of synthesized information from data collected by the meteorological station VADSTAT-UCA compiled in (Lopez de la Fuente, 2010).

Solar Data: Monthly Averages (1983-2004)

Month	Global Radiation	Horizontal Diffuse Radiation	Diffuse Radiation	Direct Normal Irradiance (DNI)	Sunshine (120 Wh/m2)	Cloud Cover (Nubosity)	Hori Rad
January	5142.55	1549.00	1925.45	5611.27	8.151691	2.9465818	8
February	5751.50	1724.32	2121.64	5846.32	8.527727	2.7821909	9
March	6478.05	1826.27	2225.59	6305.82	9.295355	2.6231591	10
April	6370.73	2254.82	2667.82	5264.82	8.829436	3.2752591	10
May	5513.45	2555.86	2883.00	3663.32	6.734500	5.1474636	10
June	5134.36	2622.09	2909.09	3095.45	5.640595	5.9378136	10
July	5137.23	2714.14	3006.86	2914.77	5.416159	5.9081000	10
August	5368.86	2541.55	2845.55	3455.59	6.021014	5.6568682	10
September	5142.68	2426.00	2707.18	3345.95	5.703186	5.7728091	10
October	5070.64	2132.05	2466.27	3930.91	6.325595	5.4407864	9
November	4836.55	1841.41	2215.91	4402.64	6.806582	4.5423955	8
December	4848.27	1562.95	1944.59	5196.41	7.654777	3.5098045	8
Average	***5399.57***	***2148.14***	***2493.25***	***4419.44***	***7.092218***	***4.4619360***	***9***
Trendline							

Solar Data: Yearly Averages (1983-2004)

Year	Global Radiation	Horizontal Diffuse Radiation	Diffuse Radiation	Direct Normal Irradiance (DNI)	Sunshine (120 Wh/m2)	Cloud Cover (Nubosity)	ET Horizo Radiati
1983	5523.33	2331.17	2739.92	4209.75	7.3198333	4.9366917	982
1984	5408.75	2163.67	2520.42	4393.50	7.1205667	5.1245500	982
1985	5456.08	2117.92	2475.50	4568.50	7.1877667	5.2162167	982
1986	5356.92	2085.08	2405.83	4526.17	7.3222000	4.9737917	982
1987	5515.25	2102.83	2455.83	4663.50	7.5242667	5.3831750	982
1988	5195.33	2142.83	2458.00	4142.42	7.2939000	5.5078667	982
1989	5460.33	2016.67	2350.58	4764.83	7.3572667	4.1907750	982
1990	5264.67	2124.83	2456.50	4218.33	6.7536750	4.5355667	982
1991	5454.33	2294.75	2676.67	4242.42	7.2368750	3.7407833	982
1992	5497.08	2337.08	2741.50	4203.25	7.2692167	3.3339667	982
1993	5258.58	2165.08	2488.58	4277.17	6.9204167	3.6781000	982
1994	5492.75	2219.00	2592.08	4536.50	7.2212667	4.2197250	982
1995	5205.67	2113.25	2423.08	4258.17	6.6275167	4.2673333	982
1996	5346.83	2045.67	2361.33	4569.92	6.9894083	3.7223417	982
1997	5345.83	2123.42	2462.50	4440.25	6.9855500	3.7750917	982
1998	5246.83	2231.73	2488.17	4112.67	6.8455917	4.0291750	979
1999	5370.42	2156.50	2504.33	4329.75	6.8059417	4.2579667	982
2000	5441.58	2111.00	2458.17	4500.00	7.0417917	4.2902417	982
2001	5520.42	2095.50	2453.25	4575.17	7.1546667	4.5482917	982
2002	5389.58	2087.83	2424.25	4502.08	6.7251364	4.7572500	982
2003	5549.58	2150.17	2519.33	4540.83	7.2354333	4.7234083	982
2004	5490.42	2050.08	2395.58	4652.50	7.1016083	4.7721917	982
Average	***5399.57***	***2148.14***	***2493.25***	***4419.44***	***7.0941202***	***4.4538409***	***982***
Trendline							

Appendice 6: CO2 Emission Calculation Worksheets. The values used in these calculations are only those of the fuels used for combustion for electricity generation, they have been provided by the *Nicaraguan Energy Institute* (INE); the IPCC dictates that *"Fuel statistics collected by an officially recognized national body are usually the most appropriate and accessible activity data."* (IGES, 2006)

Chapter 7: Case Study: Managua, Nicaragua

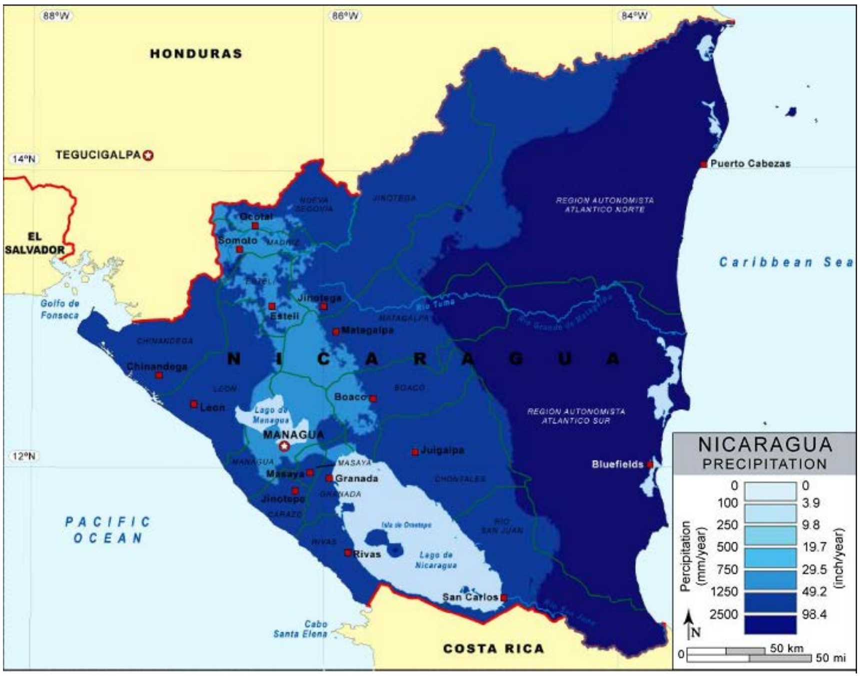
To be able to formulate a suitable solution that applies to the specific situation in Managua, Nicaragua it is necessary to have basic knowledge of data related to the study field concerning the specific location. This chapter provides the information regarding the location's general characteristics: climate, sunlight, geography, political division, population, and economy. It also contains information concerning fossil fuel usage, the electricity sector, and meteorological data; all of which are directly related to the study field of this research investigation.

7.1 General Characteristics

A country's location, boundaries, surface, climate and other general characteristics are of extreme importance when referring to energy. It gives us an introduction of the situation in the country and a general overview of the available energy sources and their consistency; such as: hours of sunlight during the winter and summer, biodiversity, average temperatures, natural resources available, among many other relevant characteristics.

7.1.1 Climate

Climate and weather are two different things, but highly interrelated, the mere difference has to do with its time dimension. According to NASA, the *National Aeronautics and Space Administration* of the United States: "*Weather is what conditions of the atmosphere are over a short period of time, and climate is how the atmosphere "behaves" over relatively long periods of time.*" (NASA, 2011b) These two atmosphere-related conditions (weather and climate) have changed throughout the years and have shown an even more drastic change over the last few years.



Map 2: Average Precipitation
Source: *(World Trade Press, 2007)*

Taking into consideration historical data of population, precipitation, vegetation and temperature, Nicaragua's climate is segmented into 3 different regions: Its Pacific lowlands are of high volcanic occurrence, containing ALL the volcanoes of the country. This region is also the most populated and exploited region, and by far the one with highest temperatures. The Northern-central highlands are those with the lowest temperatures and precipitation and are mainly used for agriculture. While the

Atlantic lowlands are the less populated areas, with medium temperatures, high rainfall and most of its surface is formed by natural reserves protected by the government. The Atlantic region has the largest intact rainforest north of the Amazon, Brazil (Camilo, 2006), with almost 2 million acres (1,872,066 acres), a surface equivalent to 18,720.66 km^2 (MARENA, 2011); occupying 15.6 % of the total land surface of the country.

7.1.2 Volcanoes

Nicaragua is surrounded by two tectonic plates, the Caribbean and Cocos, which is why it has so many volcanoes; forming part of the Central American Volcanic Arc (CAVA) that extends 1,500 km, from Guatemala to the Costa Rican-Panamanian border. It's the country that has the most volcanoes from the arc; 7 active and 21 inactive volcanoes, which include crater lagoons and high geothermal activity sites. (INETER, 2010) The CAVA is mainly formed by the subduction of the oceanic plate (Cocos tectonic plate) under the continental plate. The subduction region occurs a few kilometers from the coastal line of Nicaragua. (Quintero, 2007)

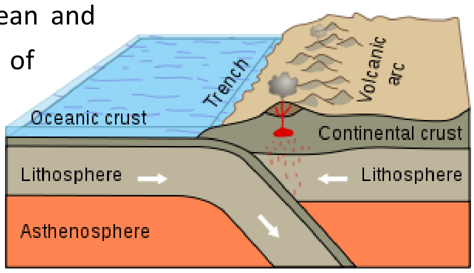


Figure 7.1: Tectonic plate subduction.
Source: *(Platetectonics.com, 2010)*

7.1.3 Political Division

Nicaragua is divided into 15 departments and 2 autonomous regions; the Autonomous Region of the Atlantic North and South. These 15 departments and 2 autonomous regions are subdivided into 153 municipalities. (INEC, 2006) This study will focus on the municipality of Managua (capital city), in the department with the same name, Managua. It is typical that the head city or municipality of each department is called with the same as the department. For further reference the department of Managua will be referred as Managua (D) and the municipality as Managua (M).

7.1.4 Geographic Location and Surface Area

Map 3: Map of Nicaragua
Design: *Author;* ***Source:*** *(Map Library, 2011)*

Nicaragua is the biggest country in Central America with a surface of 130,373.47 km^2 (INETER, 2010), located between the equator and the tropic of cancer (23^o 27 N). Nicaragua's furthest point above the equator is 15.023^o North and the closest point is 10.692^o North (GoogleMaps, 2011). Its close proximity to the equator gives the country an almost constant sunlight exposure throughout the year. The capital city, Managua, is located at 12^o North and may be considered as a latitudinal middle point for the country where the sunlight variation throughout the year can be observed.

Nicaragua's east and west boundaries are defined by two coastal lines, having access to both, the Pacific and Atlantic Oceans. To the north, it shares borders with Honduras and to the south with Costa Rica. The biggest body of water in Nicaragua is Lake Cocibolca, also known as Lake Nicaragua; with a surface area of 8,150 km^2 is the second largest lake in Latin America, just after Lake Titicaca in Peru and Bolivia. (World Lakes Network, 2011) The surface of all the country's fresh bodies of water is estimated around 10,380 km^2; almost 8 % of the total area of the country. (CIA, 2011)

The department of Managua is located between 11°45' – 12°40' N and 85°50' – 86°35' W, at an elevation of 82.97 meters above sea level. It is divided into 9 municipalities and has a total surface of 3,465.1 km^2. The municipality of Managua, capital city of Nicaragua, has a surface of 267.17 km^2. (INIDE, 2007a)

7.1.5 Sunlight

There are two solstice days per year; the summer solstice that indicates the longest day in the year and the winter solstice, which is the shortest day in a year. The summer solstice varies between June 20th and June 22nd in our calendar system, the Gregorian Calendar System. The variation is mainly because a calendar year is 365 or 366 days, but the real period (*sidereal period*) for the earth to complete the orbit around the sun takes exactly 365.256 days; that is why there is a leap year every four years, to reduce the change and have a more or less precise date from year to year according to the sun's position. (Swinburne University of Technology, 2011)

According to Managua's specific coordinates the average length of a day during the summer solstice is approximately 12h 50m 13s, with sunrise at 05:22 and sunset at 18:12; while for the winter solstice the day is approximately 11h 25m 00s, with sunrise at 06:01 and sunset at 17:26. (TimeDate, 2011) It is important to take into consideration this information when evaluating the possibility of using solar energy as an alternative energy source, since it relies solely on solar radiation to obtain its energy.

7.1.6 Population

The total population in Nicaragua, according to the *2005 National Census Report*, was of 5,142,098 people in 2005; with a population density of 42.7 inhabitants per km^2. (INEC, 2006) In the year 2007, INIDE, the institution currently responsible for statistics in the country, published a report which specifies the approximate population for the following years, up to year 2050. According to this publication the population of Nicaragua to the 30th of June, 2011 is of 5,888,945, with an estimated growth of 1.3 % per year. (INIDE, 2007b) The most populated areas in the country are in the Pacific Region; the cities of Managua, Matagalpa, Leon and Chinandega. On the hand, the area of the Atlantic is basically uninhabited, Together, the Autonomous Region of the Atlantic North and South have a total surface of 60,366 km^2, occupying 50.16 % of the country's total landmass (INIDE, 2008), but with only a population of 778,138, equivalent to 13.2 % of the total population. (INIDE, 2007b)

Map 4: Population Density.
Source: (World Trade Press, 2007)

According to the last census in 2005, Managua (D) has the biggest population in the country with 1,262,978 inhabitants, which is 24.6 % of Nicaragua's total population. The population density for Managua (D) is of 364.5 inhabitants per km^2. Furthermore, Managua (M) has 74.2 % of the population of Managua (M) with 937,489 inhabitants and a population density of 3,509 inhabitants per km^2. Managua (M) can be further divided in urban and rural area, from which 908,892 people (96.9 %) live in the urban area. (INIDE, 2007a)

7.1.7 Economy

According to the International Monetary Fund (IMF), when referring to GDP per capita, Nicaragua is considered to be the second poorest country in Latin America, just after Haiti. (IMF, 2011) Nicaragua's gross domestic product (GDP) for 2010 was 6,551.5 million U$ dollars, which translates into a GDP per capita of U$ 1,126.5, the lowest in Central America. In 2010 Nicaragua had a GDP growth of 4.5 % in relation to 2009; which was an easy task since 2009 had a negative GDP growth of – 1.5 % compared to 2008. Nicaragua also has the highest unemployment rate in the Region, with 7.8 % and the highest inflation rate in Central America, with 9.2 %. (BCN, 2010)

The national currency in Nicaragua is called *Córdoba Oro*, but it is also referred to as *"peso"*. On the 30th of June the official exchange rate for 1 U$ = C$ 22.4184 (BCN, 2011) and 1 € = C$ 32.44426 (Exchange-Rates.org, 2011). The Nicaraguan Córdoba is directly linked to the American dollars; the exchange rate with U$ has only gone up since Córdobas Oro were first established in 1991, with an exchange rate of 1 U$ = C$ 5.0. (Country Studies, 1998)

7.1.8 Nicaragua Fact Sheets

Nicaragua 2010	
Geographical Location	
Latitude	10°N - 15°45' N
Longitude	79°30'W - 88° W
Surface and Population	
Surface	130,373.40 km^2
Population	5,815,526
Growth Rate	1.20%
Utilities	
Water Consumption (10^3 m^3)	146,799.9 m^3
Electricity Consumption	2,339.60 MWh
Economic Figures	
Exchange Rate with U$	C$ 22.4184
Gross Domestic Product (million U$)	U$ 6,551.50
Real GDP Growth	4.50%
GDP per Capital	U$ 1,126.50
Unemployment rate	7.80%
Inflation rate	9.20%
External public debt (as % GDP)	59.20%
Loan Interest Rates (~)	10%

Table 7: General Figures, Nicaragua
Design: *Author;* ***Source:*** *(BCN, 2010)*

Description	Nicaragua	Managua (D)		Managua (M)		Managua (U)	
Surface (km^2)	130,370.00	3,465.10	*2.7%*	267.17	*7.7%*		
Population (2011)	5,888,945	1,417,387	*24.1%*	1,021,679	*72.1%*		
- 2009	5,742,308	1,383,474	*24.1%*	1,005,705	*72.7%*	985,143	*98.0%*
- 2008	5,668,866	1,365,315	*24.1%*	994,560	*72.8%*	971,747	*97.7%*
- Population Density (2011)	45.17	409.05		3,824.08			
Economically Active Population	3,895,447	1,000,996	*25.7%*	750,250			
Gross Annual Salary Income (thousand U$)	30,754,625	19,765,847	*64.3%*				
Households Water & Electricity							
- Private Households (2005)	978,335	243,047	*24.8%*	179,127	*73.7%*	173,044	*96.6%*
- Inhabitants per House	5.2	5.2		5.2			
- Water inside household	40.5%	63.9%		73.1%			
- Water in property	20.3%	25.3%		21.3%			
- Connection to Electricity Grid	68.4%	94.7%		97.0%			

Table 8: Quick Facts and Shares corresponding to Managua
Design: *Author;* ***Source:*** *(INIDE, 2008) & (INIDE, 2007a)*

7.2 Fossil Fuels

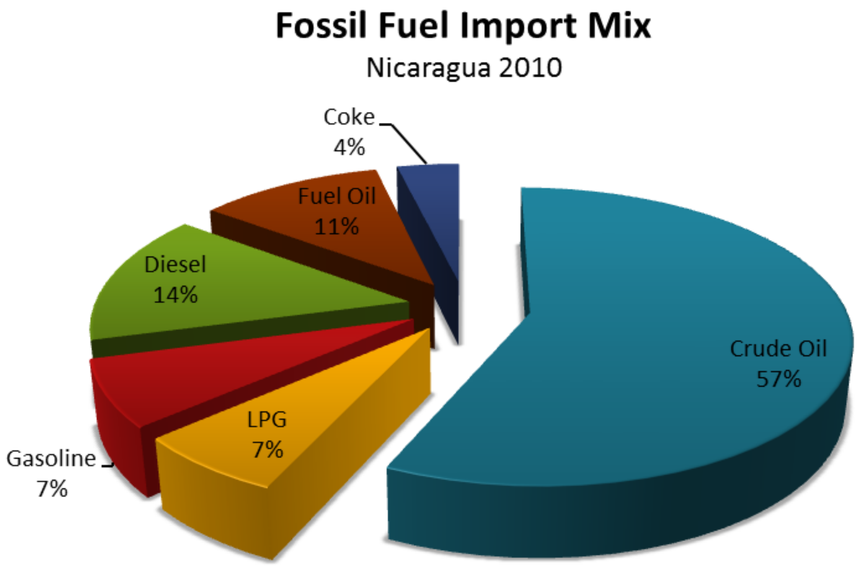
Nicaragua does not extract or produce any kind of fossil fuel that may be used as a main energy source (like: oil, coal or natural gas) and even though the country doesn't produce any of these, it is highly dependent on them for energy; especially oil and its derivatives.

Coal and natural gas are not used in any kind of energy transformation, but Liquefied Petroleum Gas (LPG) is produced in refineries from the transformation of crude oil to its different final products. LPG is mainly used in households as an energy source for cooking; and heating is not required due to the country's location and high temperature profile.

Fuel Type	Primary Use	Secondary Use
AVGAS	Aviation	
LPG	Domestic (cooking)	Industry
Gasoline	Transportation	
Diesel	Transportation, Heavy Machinery	Electricity Production
Fuel Oil	Electricity Production	
Crude Oil	Producing fossil fuel derivatives	

Table 9: Fuel Use Matrix.

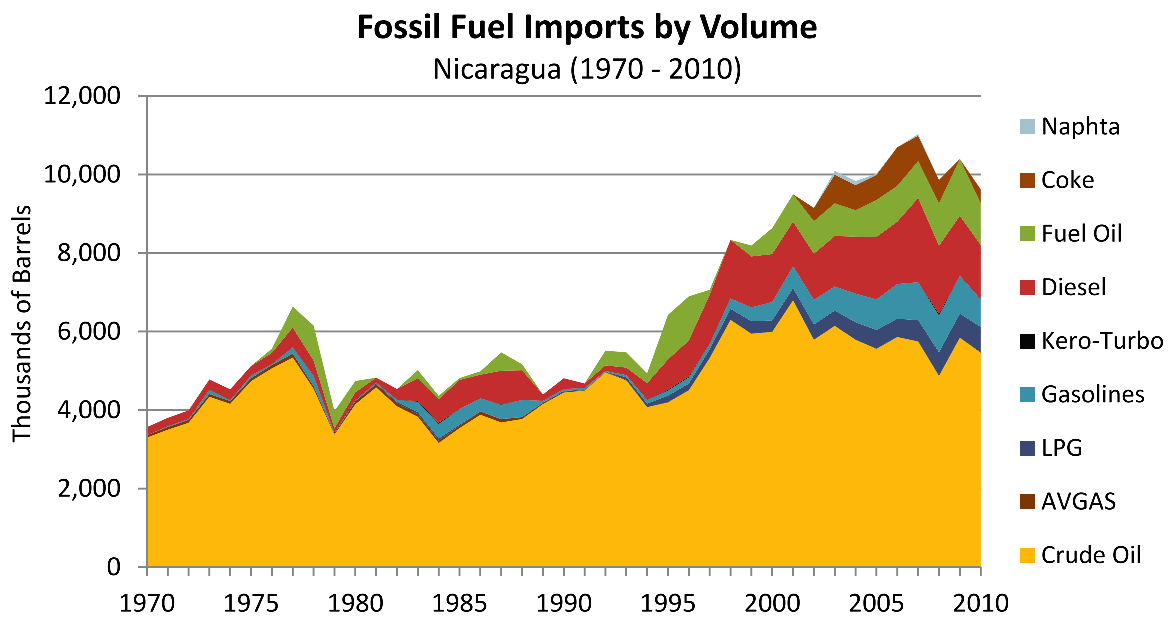
7.2.1 Imports



**Excluding products with a share less than 1%: AVGAS, Kero/Turbo, Asphalts and Solvents.*

Graph 7.1: Share of fossil fuel imports in 2010
***Design:** Author; **Data Source:** (MEM, 2011a)*

In 2010 Nicaragua imported a total of 9,655,153.81 barrels of fossil fuels (asphalts, solvents, LPG, AVGAS, gasoline, diesel, fuel oil, coke, crude oil and several derivatives) with a total value of U$ 742,209,826.81; including U$ 21,635,804.97 for transportation and U$ 1,583,338.08 for insurance. Crude oil formed more than 50 % of total fossil fuels imports; with a volume of 5,459,308.00 bbl. and a total cost of U$ 419,797,640.52 (including transportation and insurance); which makes U$ 76.90 the average cost per barrel of crude oil in 2010, meaning a 37.76 % increase in comparison to 2009, that a cost of U$ 55.82 per barrel. (MEM, 2011a)



Graph 7.2: Fossil fuel import trend (1970-2010)
Design: Author; Data Source: (MEM, 2011a)

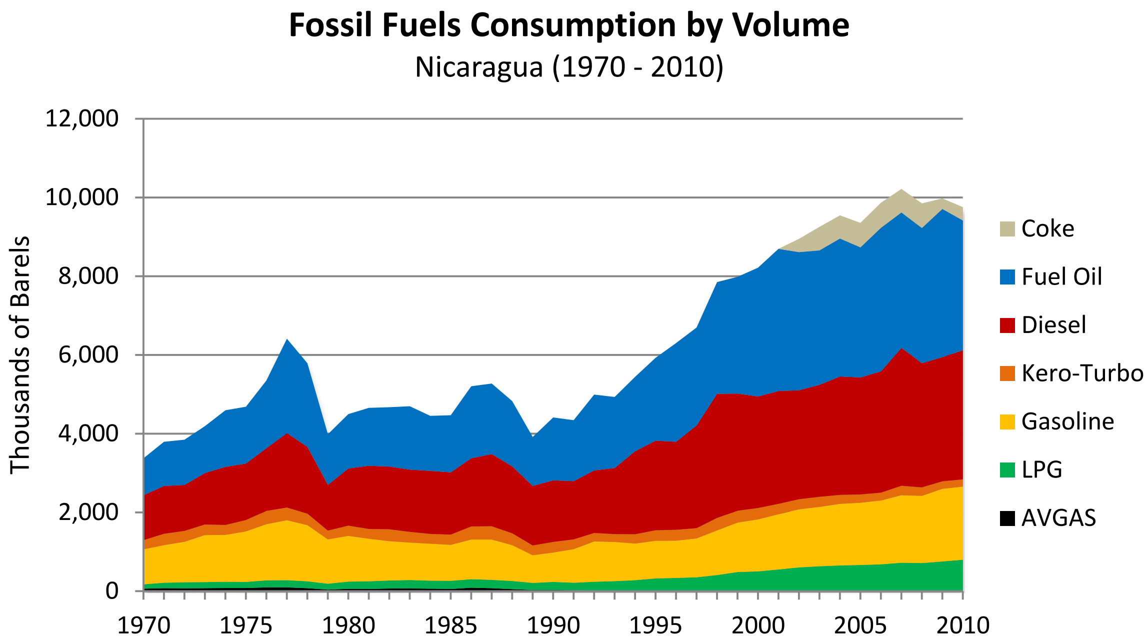
The variation on the crude oil imports from 2009 to 2010, clearly show a reduction in the acquisition capacity of the country in relation to the cost; in 2010 Nicaragua imported 6.5 % less crude oil than in 2009, but with a greater cost, 21.0 % more than 2009. (MEM, 2011a) The quantity of money spent and how it is spent is a factor of great importance in a country as poor as Nicaragua. Since Nicaragua isn't an oil producer the country's dependency on oil is a big weakness and even more with rising oil prices. If the country pursued other forms of alternative energy and more efficient uses of oil, they could save millions of dollars and disconnect from their big dependency on oil; an energy source that continues to show a steady increase on its price.

7.2.2 Exploration

According to the Special Law for Exploration and Exploitation of Hydrocarbons published in 1998, the Ministry of Energy and Mines (MEM) has been attributed the task of promoting hydrocarbon exploration and exploitation; defining a 102,004 km^2 total available area for exploration for possible exploitation sites. On the Pacific shore a total area of 33,515 km^2 has been established for exploration and an area of 68,489 km^2 on the Caribbean shore. Each segment has been divided into blocks of 10 km x 10 km. So far three companies have been granted permissions for exploration: Indoklanicsa, Infinity Energy Resources, and Noble Energy. (MEM, 2011b)

7.2.3 Consumption

With the pass of each year, the population continues to grow, the energy demand per capita becomes greater and the overall demand of fossil fuels increases rapidly; quickly creating a country hungry for energy, but this hunger for energy doesn't necessarily have to be satisfied only by fossil fuels. Certain energy demands can be shifted from fossil fuels to renewable energies to decrease the dependency of this already expensive resource.

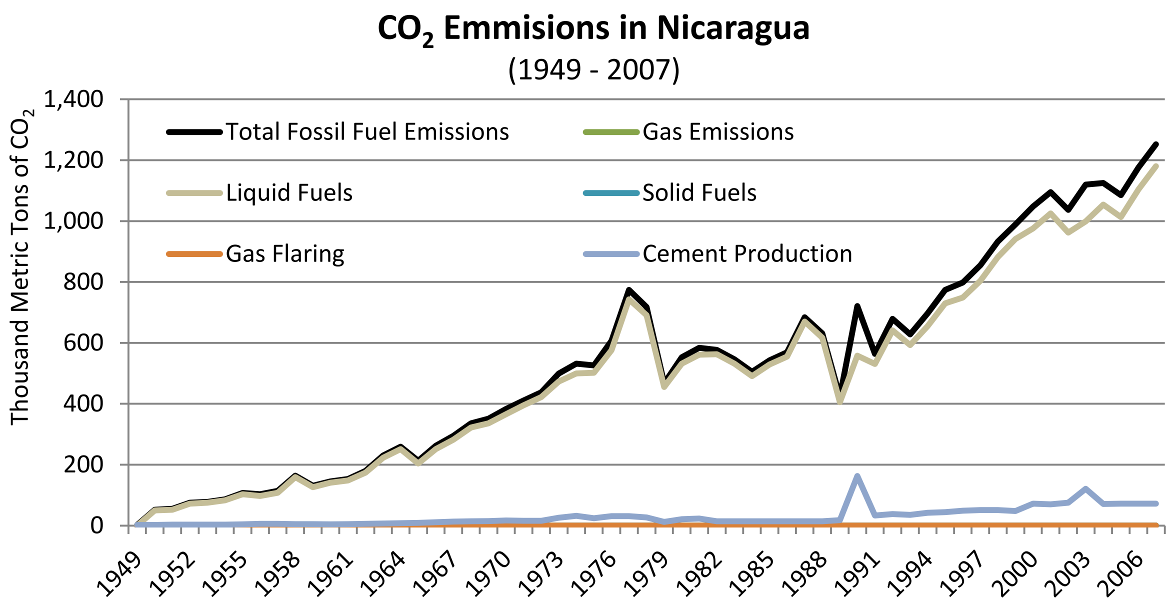


Graph 7.3: Fossil Fuels Consumption Trend (1970-2010).
Design: *Author;* ***Data Source:*** *(MEM, 2011a)*

The graph above shows the consumption of fossil fuels per year in Nicaragua from 1970 to 2010; including the crude oil derivatives produced in Nicaragua. It is interesting to notice that the total consumption in 1970 of 3,413.60 thousand barrels took 27 years to double, until 1997 with 6,893.50 thousand barrels. Now when we observe 1993, Nicaragua had a consumption of 4,984.40 barrels and in 2006 it nearly doubled to 9,864.99 thousand barrels, this time only taking 13 years to double its consumption. (MEM, 2010a) When is Nicaragua going to double their current consumption? In 7 years? Of course several factors influence this, not only consumption pattern, but also maturity of renewable energy technologies, price of fossil fuels, scarcity, environmental consciousness, country's foreign investment, progress and development, population, energy consumption patterns, among many other factors; but it is certainly something to think about.

7.2.4 CO_2 Emissions from Fossil Fuels

The CO_2 emissions in Nicaragua are mainly caused by the combustion of liquid fossil fuels, and the other part is from cement production. Graph 7.4 shows the total CO_2 emissions in Nicaragua by source. It is important to notice that there is no visible line representing gas flaring, gas emissions, or solid fuels. This is mainly due to the fact that these emissions are 0 or close to close to 0, since the country does not produce or import any natural gas or any type of solid fuel.



Graph 7.4: CO_2 Emissions by Source (1949-2007)
Design: *Author;* ***Data Source:*** *(CDIAC, 2010)*

7.3 Electricity Sector

7.3.1 Infrastructure

In Nicaragua there are a total of 68.4% of households supplied electricity by the grid, either the national grid or a smaller isolated network. In the department of Managua 94.7% of the households have grid coverage, while the municipality of Managua has the highest network coverage in the country with 97%. (INIDE, 2007a)

Nicaragua's main electricity grid is called *Sistema Interconectado Nacional* (SIN); its infrastructure consists of 1,923.63 kilometers of 69, 138 and 230 KV government owned lines. There are 334.55 kilometers of 230 KV lines that are basically used to interconnect Nicaragua with its neighboring countries, Honduras in the north and Costa Rica in the south; located in the pacific region of the country and connect with the rest of the system by 138 KV lines through transformers. The 230 KV lines were installed in 1976 and 1983, with several additions and adjustments in 2000, 2001 and 2003. (ENATREL, 2011)

The 138 KV lines consist of 922.47 kilometers that form 2 rings; 1 ring interconnects the capital city of Managua, which has an equivalent demand of 54.4% of the country's total electrical demand. The second ring interconnects the northeast part of the country with an equivalent demand of 6.4%. Most of these lines were installed in the 60's and 70's, connecting through 21 power substations with the 69 KV lines, which branch out in a radial formation to supply energy to end users. (ENATREL, 2011)

The 69 KV lines consist of a web of 666.62 kilometers; these lines are the ones responsible to transport electricity to specific places and end users; they are the oldest lines in the system. Most of the 69 KV lines were installed in the late 50's and early 70's, making them the oldest in the system, some of which still use wood poles. (ENATREL, 2011)

For an easier interpretation of the general aspects of Nicaragua's electrical infrastructure you may view the following map.

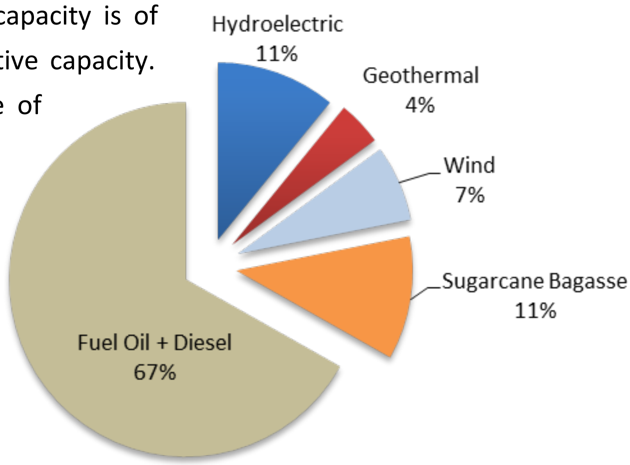
Map 5: Nicaragua's national electricity grid
Source: (ENATREL, 2011)

If you wish to view a detailed map of interconnections, generation sites, substations, and transformers you may consult the following documents on the web:

- *http://www.enatrel.gob.ni/images/enatrel/transmision/sistema-interconectado-nacional-2008.pdf*
- *http://www.enatrel.gob.ni/images/enatrel/transmision/mapa-sistema-interconectado-nacional-2008.pdf*

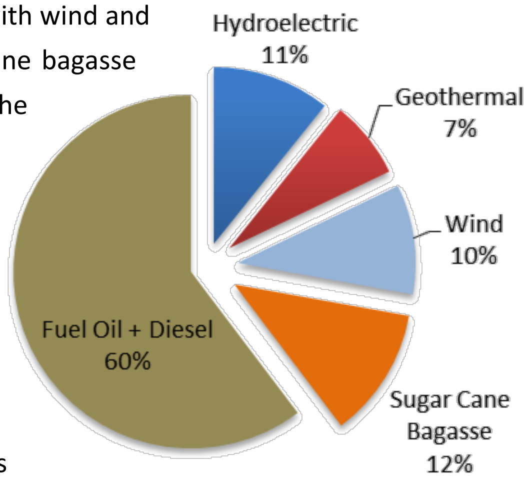
7.3.2 Production

Nicaragua has a wide variety of electricity production, its installed capacity includes sources such as: geothermal, hydropower, wind, biomass (sugar cane & rice husks), and of course, fossil fuels; mainly diesel and fuel oil. As of March 2011 its installed capacity is of 1,058.59 MW (nominal capacity); 907.03 MW effective capacity. The share of fossil fuels overcomes any other type of generation with an outstanding 67%, followed by sugar cane bagasse and hydropower, each with 11%, and then by wind with 7% and geothermal with 4%. (INE, 2011b) It's unbelievable to see such a small share of geothermal capacity when the country forms part of "ring of fire" and has so many active sites. It is also important to notice that there is absolutely no solar energy being exploited for electricity production.



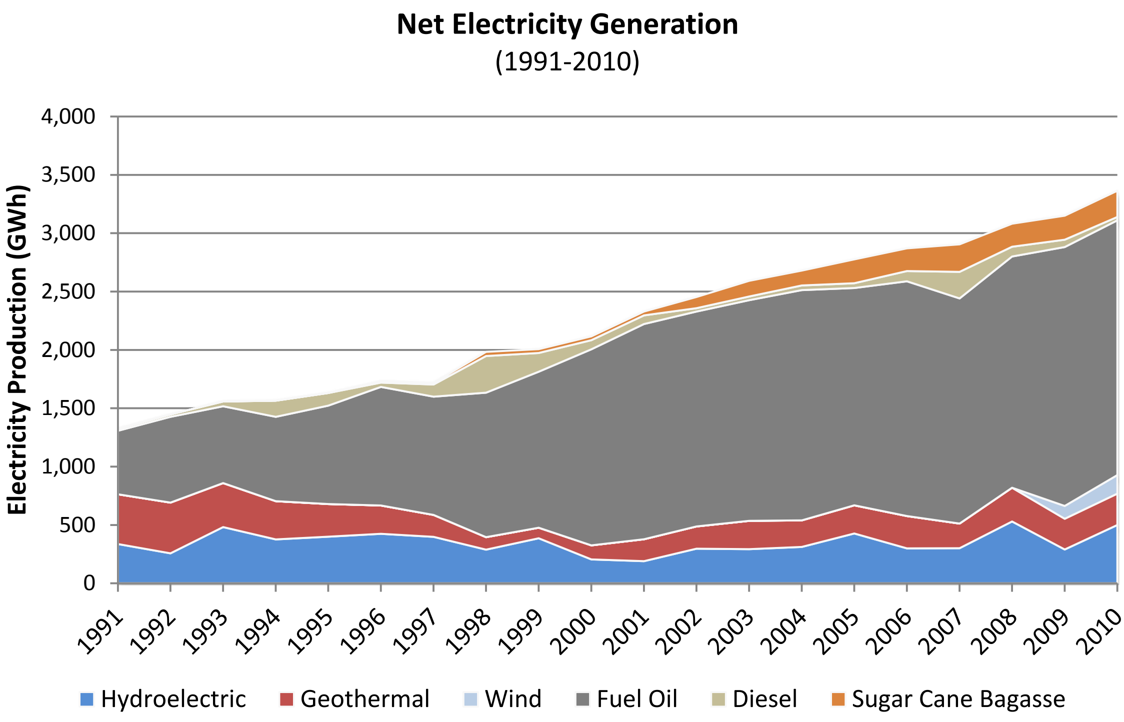
Graph 7.5: Effective Installed Capacity, March 2011.
Design: *Author;* ***Data Source:*** *(INE, 2011b)*

In 1991, the net electricity generation was 1,324.00 GWh. 19 years later it has nearly tripled to a total of 3,364.03 GWh in 2010; an increment of 154%. (INE, 2011a) The generation by fuel type from January to March 2011, shares a similarity to the installed capacity graph, but this time fossil fuels instead consisting of 67% it forms a share of 60%, with wind and geothermal assuming each 3% of its share, and sugarcane bagasse with an additional 1%, while hydropower remained the same with 11%. (INE, 2011b) It is important to notice that in graphs of this type it is necessary to take into account a full year for all the variations throughout the year can be considered. For example seasonal variations: hydroelectric power is used more frequently and freely during the wet season than the dry season, wind varies depending on the season and time of the day and the sugarcane bagasse generation is mainly during harvesting.



Graph 7.6: Net Generation (Jan – Mar 2011).
Design: *Author;* ***Data Source:*** *(INE, 2011b)*

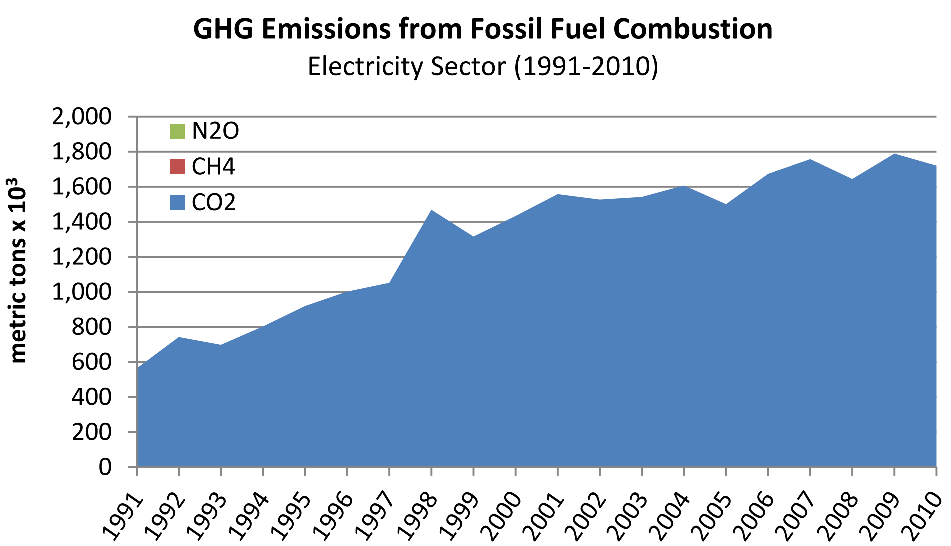
In 2010, 3,454,510 barrels (145,089,230 gallons) of fuel oil were used to produce 2,182.79 GWh, from this figures we can deduce an estimate of 15.04 kWh per gallon. The respective figures for diesel are: 86,330 barrels (3,625,710 gallons) used to produce 28.88 GWh, a 7.97 kWh/gal. (INE, 2011c) Concerning these estimates of kWh/gallon, they can be considered a bad practice and should not be taking lightly, since there are other factors that should be taking into account. For example, when generating electricity size does matter: engine efficiency tends to increase with the size and normally diesel engines are smaller than specialized fuel oil generators; also diesel generator are more commonly used in isolated systems that may have a reduced efficiency due to a lack of a rigorous maintenance plan and long exploitation periods.



Graph 7.7: Net Electricity Generation (1991-2010)
Design: *Author;* ***Data Source:*** *(INE, 2011a)*

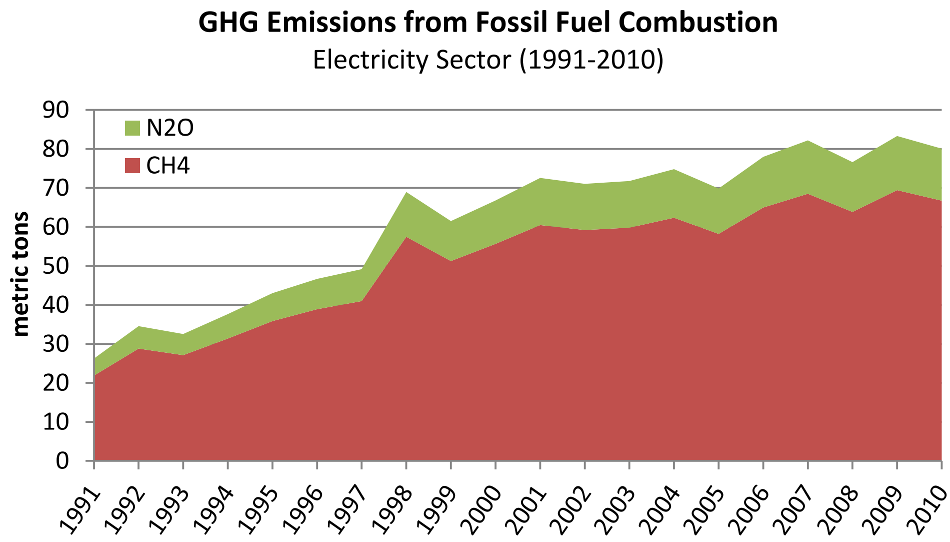
7.3.3 Greenhouse Gas Emissions

The GHG emission calculations were done using the Tier 1 methodology. The following graph represents the CO_2 emissions from the combustion of fossil fuels in the electricity sector, fuel oil no.6 and diesel; it does not include the emissions due to sugar cane bagasse and wood. The emissions of N_2O and CH_4 are not visible in the graph since they are too small in comparison to CO_2. The GWP for CO_2 is the same as the emissions since it is based on the same CO_2e.



Graph 7.8: GHG Emissions from Fossil Fuel Combustions in the Electricity Sector
Design: *Author;* ***Calculations:*** *Author*

In order to appreciate the N_2O and CH_4 emissions it is necessary to graph them separately from CO_2. The following graph shows the emissions for these gasses from the same fuel combustion as CO_2.

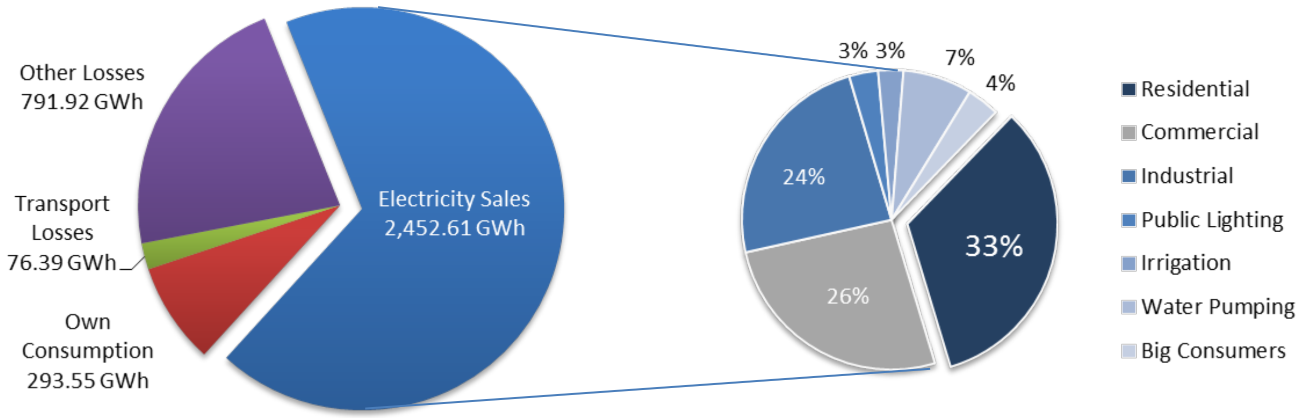


Graph 7.9: CH4 and N2O Emissions in the Electricity Sector from Fossil Fuel Combustions
Design: *Author;* ***Calculations:*** *Author*

7.3.4 Consumption

Production, consumption and sales, are three completely different concepts. Production is the total generation from the power supplier; from that generation (*gross production*) a part is used in the same facility and the rest is injected to the grid, this is known at *net production*. Then, from this net production some of it is lost in transmission, distribution and transformation, so only a part of it reaches the end users (*consumption*). One would believe that consumption forms a 100% of the sales, but regretfully this is not true, and certainly not in a country as poor as Nicaragua. A portion of the electricity that reaches the end users is not accounted for, due to illegal connections and alteration of the electricity meters; two factors that are very common in Nicaragua and are not yet legally pursued. At the end only a fragment of the gross production is registered as electricity sales by consumers.

Since the primary focus of this research is centered on the electricity consumption in Managua (M), Nicaragua, the consumption of the isolated systems will not be taken into account, focusing just on the electricity production and consumption of the national grid infrastructure (SIN); which supplies electricity to the location of the study. In 2010, the gross production of the suppliers connected to the SIN was of 3,614.47 GWh, from which 293.55 GWh were consumed by the same suppliers, totaling a net production of 3,320.92 GWh, which were injected to the grid. The *Centro Nacional de Despacho de Carga* (CNDC) or National Load Dispatch Center, recorded 76.386 GWh in losses due to transportation. At the end, only 2,452.61 GWh from the net production were registered as sales, with 800.89 GWh correspond ding to the residential sector; *see* Graph 7.10: Electricity Consumption, 2010. (INE, 2011c)



Graph 7.10: Electricity Consumption, 2010.
Design: *Author;* ***Data Source:*** *(INE, 2011c) & (CNDC, 2011)*

7.3.5 Load Curve and Demand

In 2010, the maximum load of 538.90 MW was recorded on the 14th of April at 19:00, and the lowest load was of 185.10 MW was registered on the 27th of April at 06:00; probably due to a problem in the network, since the rest of the year a minimum load between 240 and 250 MW can be observed to typically occur at 03:00. (INE, 2011a) The following figure represents the load curve for 15th of August 2011; this load curve retains a similar behavior for a typical labor day throughout the year. Each color in each bar represents the power generated by the different producers. The numbers on the top of the columns specify the total cost for electricity production in that particular hour. A live view of the current electricity load of the SIN is available at:

http://www.cndc.org.ni/InfoTiempoReal/CurvaDemanda/index.php

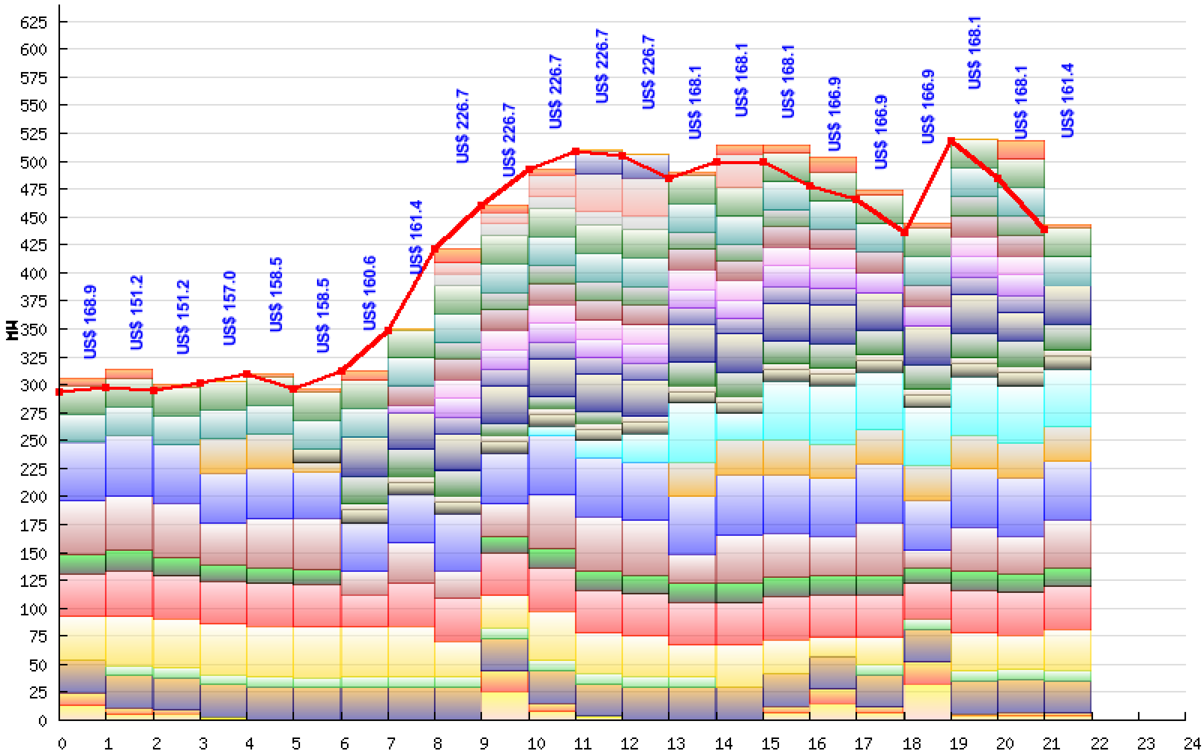
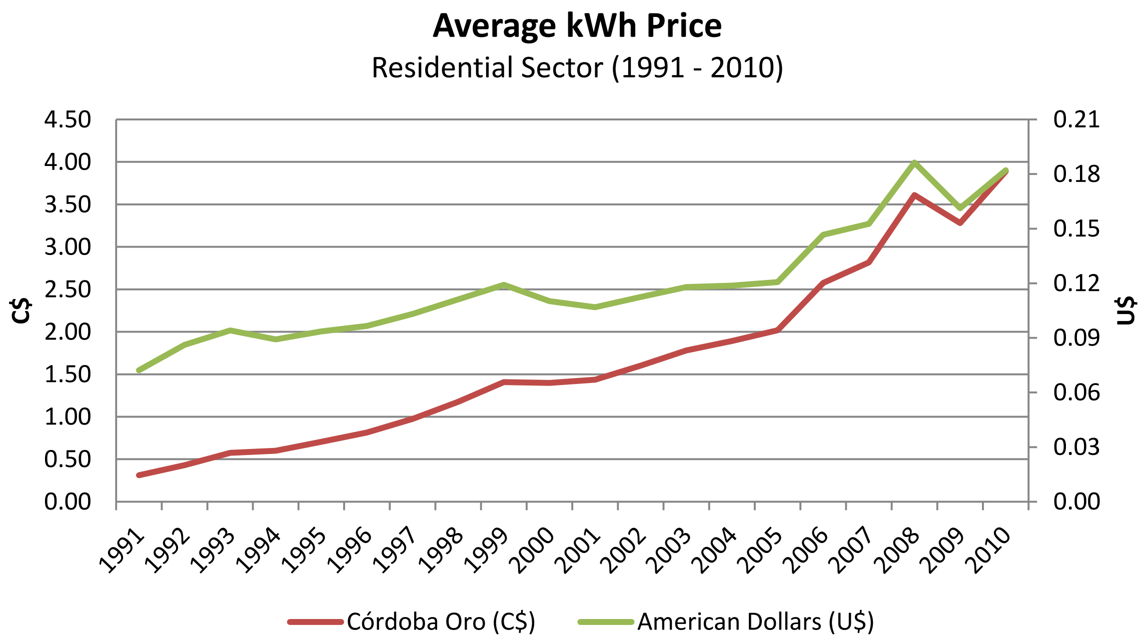


Figure 7.2: Nicaragua's National Grid Load Curve (15/08/2011)
Source: *(CNDC, 2011)*

7.3.6 Price

The electricity price in Nicaragua relies greatly in 3 factors: price of oil, U$ dollar exchange rate with Nicaraguan C$, and government subsidies. Since fuel oil is the biggest fuel source used for electricity generation, the costs for electricity are directly linked to the price of fuel oil no.6; which cost per barrel was of U$ 69.11 at the end of 2010, indicating a 23.5% rise in comparison to 2009. The electricity price trend for the residential sector can be observed on the graph below; the costs given in C$ were converted into U$ using the average exchange year for each particular year.



Graph 7.11: Residential Electricity Price Trend (1991-2010)
Design: *Author;* ***Source:*** *(INE, 2011c)*

Although the price of fuel oil increased 23.5%, the electricity price augmented only by 6.62%. In order to keep the electricity price stable the President of Nicaragua, Daniel Ortega, borrowed U$ 20 million dollars from ALBA in 2009; loan, which according to the declarations will be paid in fully when the electricity sector begins to exploit its natural resource, and price drops below the current one. In July 2011, the same thing occurred, but this time the loan was of U$ 107 million dollars. And that is not all, the electricity price is doubly subsidized since not only it uses a loan to maintain the electricity costs from the rising oil prices, but all users according to Law 271 of April 2005: all users that consume less than 150 kWh per month receive a discount, making their monthly bills virtually cero. (INE, 2011f)

7.3.7 Actors

Figure 7.3 shows the actors involved in the electricity sector, their tasks, and relation with other actors. Most of these actors have been mentioned before, except for CRIE, EOR, and MER; which have to do with the regional electricity sector. CRIE is the Regional Commission for Electricity Interconnection *(Comisión Regional de Interconexión Eléctrica)*; it is responsible for regulating the electricity transactions for the region (Central America). EOR is the Regional Operating Entity, which supervises all the operations in the region between one country and another. MER controls the short-term commercial electricity transactions. And finally, one actor that is not show in this figure is the regular consumers: residential, industrial, commercial, and others. This actor would be place directly under the distributor, since the only to the electricity market is through this entity.

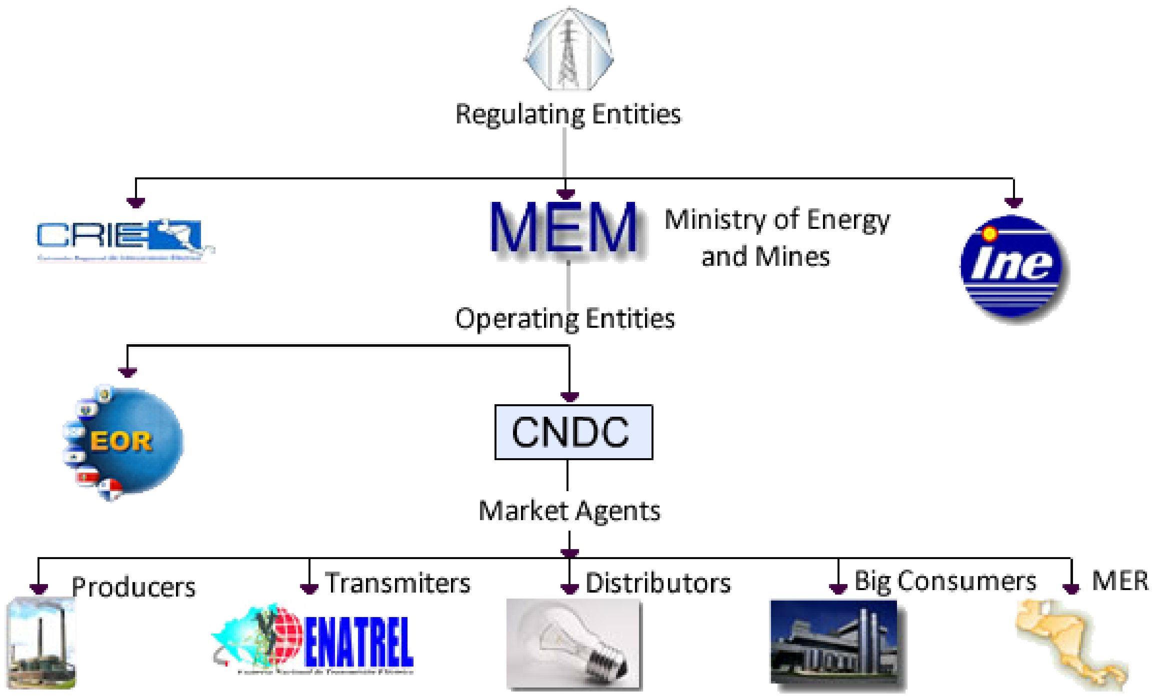


Figure 7.3: Actors in the Electricity Sector
Source: *(CNDC, 2011)*

7.4 Meteorological Data

The information provided by NASA is based on worldwide satellite estimation with a resolution of 1 degree latitude/longitude, which in terms of length in kilometers at latitude of 12° it is equivalent to ~ 110.622 km. The calculations by NASA also present other uncertainties, for example when dealing with any type of solar radiation the methods used by the instruments on the satellite are unable to calculate these values when there is a clearness level below 0.3 or above 0.8. For this reason it is better to have on-site measurements, but it also important to keep in mind that these measurements can also have errors, due to a lack of maintenance, equipment malfunction, or simply not good record keeping habits. Therefore it is best to use a combination of satellite data with one or two on-site meteorological stations.

The meteorological data obtained for Managua, Nicaragua is from 3 different sources:

- **National Aeronautics and Space Administration (NASA):** Satellite data; compilation of 23 years of data (1983-2005); average values for 1°: 86-87 W, 12-13 N; Elevation: 208 m.
- **Nicaraguan Institute of Territorial Studies (INETER):** On-site measurements. Data from the meteorological station at the international airport of Managua

  Coordinates: 12° 08' 36" N, 86° 09' 49" W; Elevation: 56 meters above sea level
- **Universidad Centroamericana (UCA):** On-site measurements. VADSTENA-UCA

  Coordinates: 12.12° N, 86.27° W

The following meteorological data is from a compilation of 22 years (1983 to 2004) recorded by the meteorological station VADSTENA-UCA. The table contains average monthly values divided into two cycles of 132 months each (11 years):

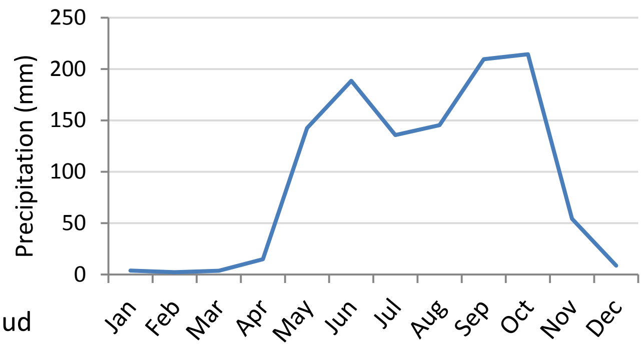
Average Monthly Values	1983-1993	1994-2004	Difference
Global Radiation (kWh/m^2 per day)	5.399	5.400	1.59×10^{-4}
Direct Normal Irradiance (DNI) (kWh/m^2/day)	4.383	4.456	1.65×10^{-2}
Global Horizontal Irradiance (GHI) (kWh/m^2/day)	2.869	2.913	1.52×10^{-2}
Diffuse Radiation (kWh/m^2/day)	2.531	2.487	-1.79×10^{-2}
Atmospheric Clarity (Global/Extraterrestrial)	0.55113	0.551437	5.57×10^{-4}
Sunshine (120 W/m^2 hours/day)	7.20963	6.99479	-3.07×10^{-2}
Nubosity (Octs/day)	4.68195	4.31145	-8.59×10^{-2}

Table 10: Monthly Average Meteorological Data (1983-2004)
Design: *Author;* ***Data Source:*** *(Lopez de la Fuente, 2010)*

Global and diffuse radiations were measured with a Kipp & Zonen CM11 piranometer with an error of ≤ 5%. The direct normal radiation was measured with a pirheliometer (Eppley NIP) with a solar tracker, and has an error of ≤ 2%.

7.4.1 Precipitation

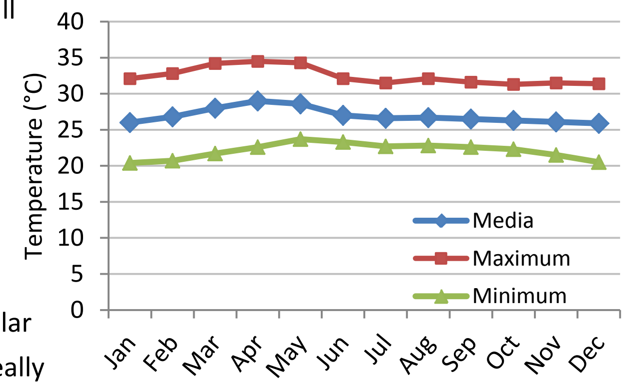
Precipitation is not directly related to solar applications, but the cloud coverage and drop in temperature DOES affect the operation of solar systems. Therefore, it is important to be aware which months correspond to the dry season and which ones to the rainy season. During the rainy season it is most likely to have heavy cloud coverage, reducing the amount of solar radiation reaching the solar system. In Nicaragua the rainy season is between May and October, and the dry season goes from November to April (Lopez de la Fuente, 2010); which can be clearly observed in the graph above.



Graph 7.12: Average Precipitation throughout the Year.
Design: *Author;* ***Data Source:*** *(INETER, 2011)*

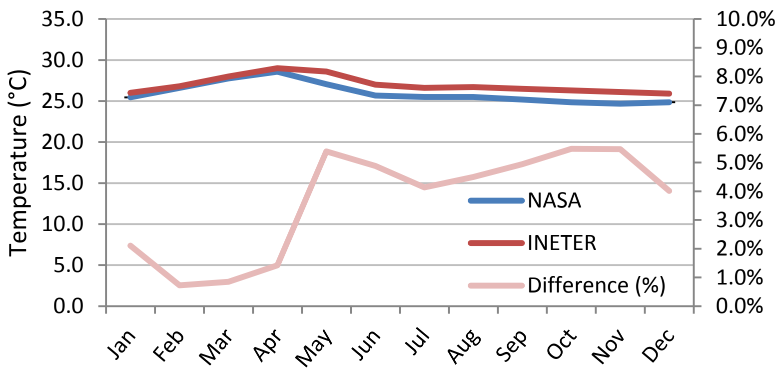
7.4.2 Temperature

Temperature is an important aspect for all devices, and most important to those devices that operate outdoor AND have a direct relation to ambient temperatures. The operating temperature of a photovoltaic system directly influences its performance and energy output. The ambient temperature also affects the heat exchange rate of the solar thermal water heater. For that reason it is really important to review the temperature profile of a location before installing any of these devices. Graph 7.13 presents the average temperature changes throughout the year; along with its maximum and minimum values for each month.



Graph 7.13: Temperature Profile: Nicaragua
Design: *Author;* ***Data Source:*** *(INETER, 2011)*

The difference of data from the 2 sources (NASA & INETER) that provided monthly averages is not relevant, since the difference is minor; the greatest difference is of 6%. *(See graph below)*



Graph 7.14: Monthly average comparison: NASA and INETER
Design: *Author;* ***Data Source:*** *(INETER, 2011) & (NASA, 2011a)*

Another important factor to observe when storing hot water is the temperature change from day to night. The temperatures during the day (06:00 – 19:00) will give us the ambient temperature when the solar collectors are absorbing solar radiation, while the temperatures during the night (19:00 – 06:00) will indicate the temperatures with which the thermal storage tank will deal, putting its heat storage efficiency to the test. In other latitudes it is also important to observe the freeze point, since water can expand and burst the pipes of the solar collector; but in Nicaragua this is not a relevant factor, since temperature has not dropped under 18 °C in the last 30 years. (INETER, 2011)

	Average	Absolute Minimum	Absolute Maximum
Day	32.64 °C	27.50 °C	38.77 °C
Night	28.63 °C	23.85 °C	34.51 °C
24 Hours	30.97 °C	26.13 °C	36.99 °C
Day-Night Difference	4.02 °C	2.15 °C	5.76 °C

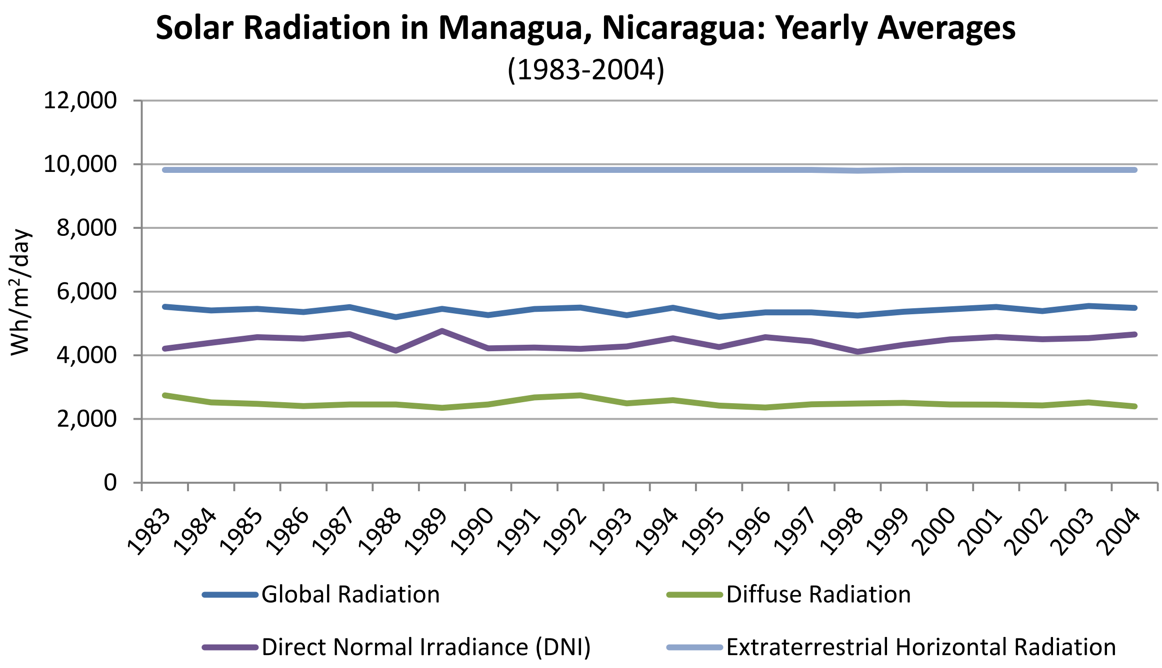
Table 11: Day-Night Temperatures.
Design & Calculations: *Author;* ***Data Source:*** *(Lopez de la Fuente, 2010)*

7.4.3 Solar Radiation

It is common for meteorological stations to record several types of radiation, these includes: sunshine, direct radiation, diffuse radiation, and direct normal irradiance.

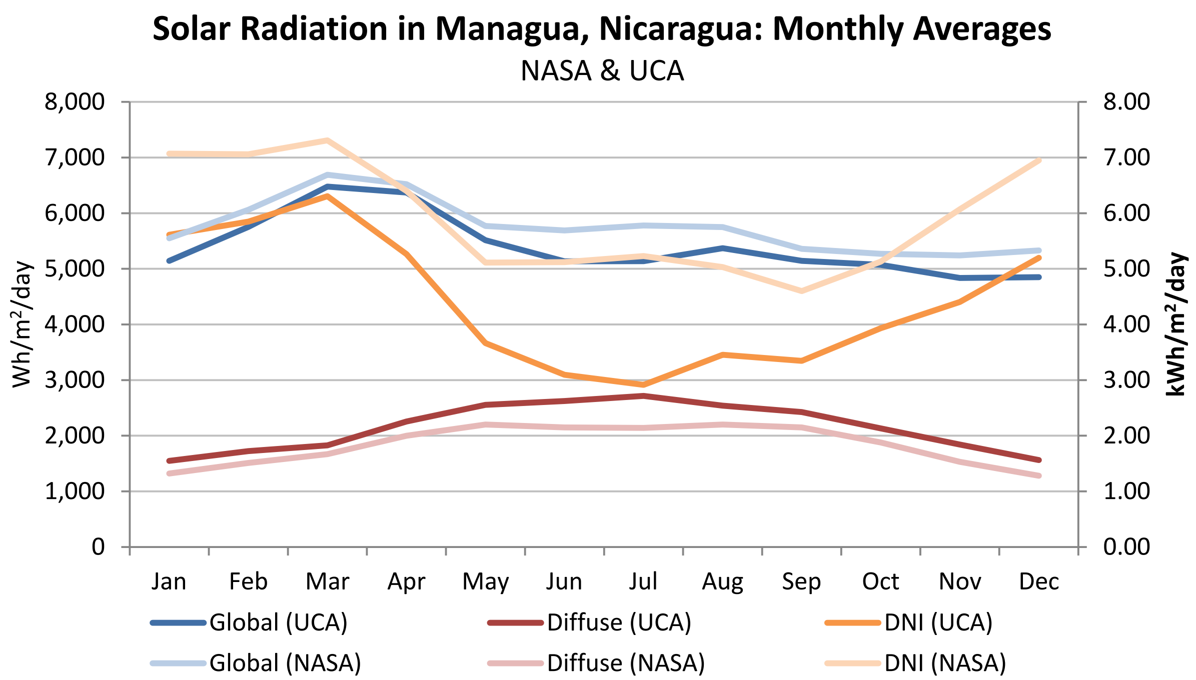
- **Sunshine:** is commonly measure in hours per day of solar irradiance above a specific yield, typically 120W/m^2.
- **Direct radiation:** solar radiation that has not been scattered, it reaches the source via the shortest distance formed by parallel rays.
- **Diffuse radiation:** scattered solar radiation coming from all directions due to object obstruction or particles in the atmosphere.
- **Direct normal irradiance (DNI):** amount of solar radiation incident over a surface normal to the solar beam
- **Extraterrestrial radiation:** is not measured by a meteorological station. It is the radiation incident above the atmosphere, at AM=0. This type of radiation is commonly called the *solar constant*, because changes in the atmosphere do not affect its intensity ~1,360 W/m2. The only variations in extraterrestrial radiation are due to the elliptical orbit of Earth around the Sun, and its inclination. The extraterrestrial radiation recorded for a particular location over the period of 4 years (considering leap year), should be equal for the next 4 years of the same location.

Graph 7.15 shows the yearly averages of solar radiation recorded by the VADSTENA-UCA meteorological station between 1983 and 2004. As it can be observed in the graph extraterrestrial radiation has maintained constant throughout the years, while diffuse and direct normal irradiance have slightly changed from year to year due to atmospheric changes. Although DNI and diffuse radiation have changed slightly its yearly values keep usually are in the same range; diffuse radiation: 2,000 – 2,300 W/m^2; direct normal irradiance: 4,200 – 4,600 W/m^2.



Graph 7.15: Solar radiation: Yearly averages in Managua, Nicaragua (1983-2004)
Design: *Author;* ***Data Source:*** *(Lopez de la Fuente, 2010)*

Solar measurements from two sources can be seen in the following graph: monthly averages from UCA based on 22 years (1983-2004), and monthly averages from NASA also based on 22 years (1983-2005). A small difference can be observed between the 2 data sets. This is mainly due to the fact that NASA's data is the average for an area of ~12,100 km based on estimations from satellite data, while the data recorded by UCA are on-site measurements of one specific point.

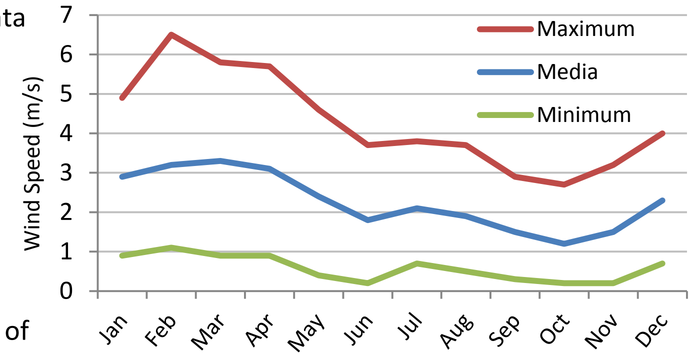


Graph 7.16: Solar radiation: Monthly averages in Managua, Nicaragua
Source: *(Lopez de la Fuente, 2010) & (NASA, 2011a)*

7.4.4 Wind

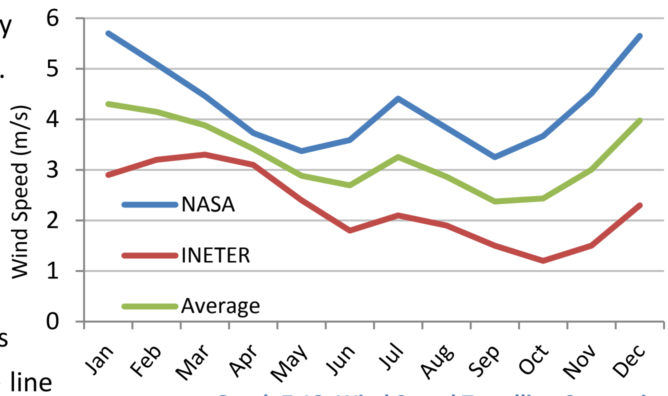
In some cases, like wind farm feasibility studies, wind speed, direction, and consistency is required at different heights, along with a description of the surrounding "roughness" or obstacles that influence wind paths. In the case of solar thermal collectors and PV systems, just a general knowledge of the wind variations throughout the year and peak wind speeds is required for the location. In the situation of Managua, the solar systems will most likely be placed on one-story rooftops; therefore the wind speed data at a height of 10 m will be used for these applications. The systems should also be able to withstand the highest wind speeds ever recorded and even more, otherwise the wind may rip the solar system from the roof or even take the roof with it.

Graph 7.17 shows the wind speeds recorded at a height of 10 m by the meteorological station of the international airport of Managua; the data was provided by INETER, the Nicaraguan Institute of Territorial Studies. The graph reflects the wind speed behavior throughout the year; taken from the monthly averages of the last 52 years (1958-2010). It also contains trend lines of the minimum and maximum averages of each month.



Graph 7.17: Wind Speed Behavior throughout the year
Design: *Author;* ***Data Source:*** *(INETER, 2011)*

Wind speeds may vary greatly from one location to another (even at short distances), but the wind data recorded from an on-site station may have greater variations with satellite data. Graph 7.18 compares the different trendlines; one from 52 years of data from an on-site meteorological station and the other from 10 years of data compiled by NASA; the third line is simply a construct that takes into considerations both data sources by displaying an average line of both data.



Graph 7.18: Wind Speed Trendline Comparison
Design: *Author;* ***Data Source:*** *(INETER, 2011) & (NASA,*

It is important to notice that these lines are based on monthly averages and do not represent the highest or lowest wind speeds. The absolute maximum wind speed registered by the on-site station of the international airport was of a wind speed of 9.6 m/s, therefore the solar systems should at least be able to withstand that maximum (INETER, 2010). However, extra precautions should be taken since Nicaragua is susceptible to hurricanes; although Managua is on the Pacific side it has suffered strong winds from hurricanes in a couple of occasions.

Chapter 8: Results

8.1 Objective I: Current Situation

Identify the current electricity production scheme, electricity consumption, and hot water production in households.

The goal of this objective is to better understand the current situation in Managua in order to be able to select a SWH and PV system that applies to the real needs of the population, and to figures that can be used to create more precise estimations according to the specific situation.

8.1.1 The Residential Electricity Sector

The information displayed in this section will be of great use when creating the scenarios.

- **Electricity tariffs:** can be used to calculate the economical savings due to the electricity savings from using the solar system at a household level. The economical savings will then be used to calculate the amount of money that can be redirected to make monthly payments of the solar system.
- **Fuel efficiency:** This data will be used to calculate the amount of fossil fuel reduction due to electricity savings.
- **Managua's share** of electricity consumption and load will help pin point how much of the total consumption and load can actually be affected by the use of SWH and PV systems. Since this research is only focused on Managua, the remaining consumption and load will remain unchanged.
- **Residential share:** will be used to narrow down even more the amount of consumption and load that is going to be affected by the utilization of a solar system.
- **Residential connections** will
- **Variable costs:** This can be used to estimate the economical savings due to the electricity savings at a municipal level.

8.1.1.1 Electricity Tariffs

The electricity pricing for Low Tension (110V, 220V, 440V) divides into 5 categories:

- **Residential (T0):** Exclusive for households in the urban or rural.
- **Residential (TA):** Urban and rural households in neighborhoods that are in development or spontaneous.
- **General Minor (TB):** For commercial use in neighborhoods in development or spontaneous.
- **Industry Minor (TC):** For industrial use, factories, workshops, or other industrial applications.
- **Retiree (TJ):** For senior citizens that are receiving a work pension.

(INE, 2011d)

The residential T0 tariff has a differential pricing depending on the consumption. The table to the right shows the electricity purchase price for the *Residential T0 Tariff* on August 2011.

Description	C$	U$
First 25 kWh	1.7928	0.07947
Next 25 kWh	3.8623	0.17120
Next 50 kWh	4.0451	0.17931
Next 50 kWh	5.3461	0.23698
Next 350 kWh	4.9863	0.22103
Next 500 kWh	7.9199	0.35106
Over 1,000 kWh	8.8772	0.39350

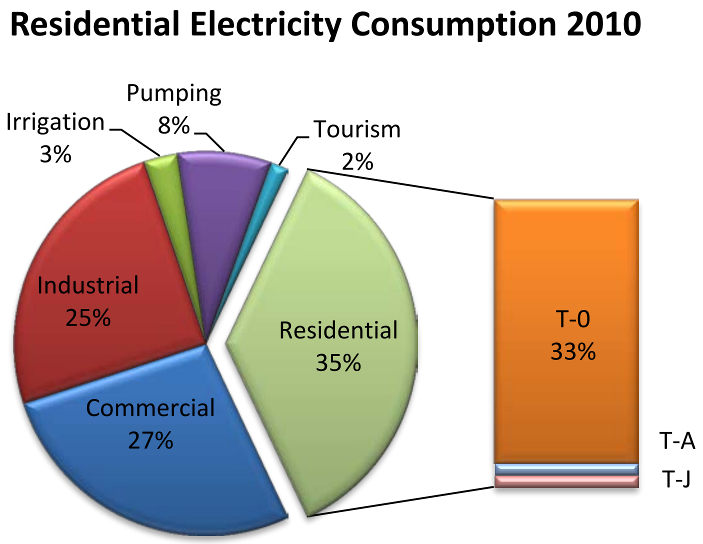
Table 12: T0 Residential Electricity Tariff (August 2011)
Source: *(INE, 2011d)*

8.1.1.2 Number of Electricity Connections to the National Grid

On March 2011, the number of connections to the national grid added up to 837,816, from which 753,621 were residential connections (90%). (INE, 2011d) As of May 2011, Managua (D) has a total of 280,254 residential users, from which 212,275 (75%) are in Managua (M). From the users in Managua (M) 131,706 (62%) receive an electricity subsidy from the government for consuming less than 151 kWh per month. (INE, 2011e) The number of users NOT subsidized by the government can be used as the upper limit for the application of SWH and PV systems.

8.1.1.3 Electricity Consumption

According to electricity sales of 2010, the residential sector consumes the greatest portion of electricity in the national grid (SIN). In 2010, the residential sector consumed 800.89 GWh from the total sales of 2,452.61 GWh, which is equivalent to almost 34%. This sector includes all the sales of the T0, TA, and TJ tariffs. The electricity sales recorded for the T0 tariff form the greatest share of residential sales, 754,922,348 kWh, 92% of the residential sector consumption. *See Graph 8.1*. (INE, 2011d)



Graph 8.1: Residential Electricity Consumption 2010
Source: *(INE, 2011d)*

8.1.1.4 Fossil Fuel Use and its Production Efficiency

In 2010 a total of 3,320.92 GWh was injected into the grid (net generation); 2154.61 GWh (64.88%) was produced by fuel oil generators and 13.96 GWh (0.42%) from diesel generators; this and other figures can be observed in the following table. The fuel efficiency was obtained from the electricity statistics of March 2011; it was impossible to calculate from past figures since fuel oil generators use a combination of fuel oil + diesel, and some generators are specified as diesel generators, but apparently they use fuel oil, since the diesel consumption reported is too low to produce the amount of electricity injected by these generators. *(See* Table 13*)*

2010	S.I.N.	Fuel Oil		Diesel	
		Total	Share (%)	Total	Share (%)
Net Generation (GWh)	3,320.92	2,154.61	64.88%	13.96	0.42%
Fuel Consumption (10^3 Gal)	145,300.72	143,140.86	98.51%	2,159.86	1.48%
Fuel Efficiency (kWh/Gal)		15.25		13.82	

Table 13: Fossil Fuel Use and its Production Efficiency
Source: *(INE, 2011c) & (INE, 2011d)*

8.1.1.5 The Share of Electricity Demand and Consumption in Managua

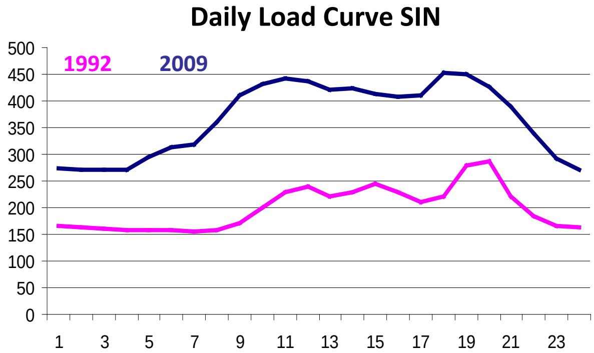
According to a study performed by MEM in 2009, Managua had 18.5% of the users connected to the SIN, 60.5% of the electricity supplied by SIN is consumed in Managua (D), also responsible for 39.5% of the load during the evening peak at 20:00. (MEM, 2010b)

	Nicaragua	Managua	Share (%)
Users (thousands)	666.5	123.8	18.5
Annual Consumption (GWh)	2,106.4	1,280.0	60.5
Maximum Demand (MW)	445	176	39.5

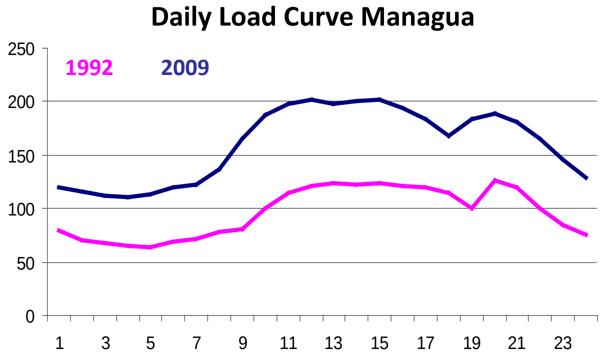
Table 14: Demand and Consumption Share of Managua
Source: (MEM, 2010b)

8.1.1.6 The Load Curve in Managua

The daily load curve in Nicaragua has maintained the same pattern during the last 20 years. Two peaks can be observed on the daily load curve of SIN, one at mid-day and another during the early evening. The daily load curve of Managua also shows the same behavior with two peaks, but the peak demand during mid-day is maintained for a longer period of time. The following graphs demonstrate the load curves corresponding to SIN during 1992 and 2009 *(*Graph 8.3*)*, and the load share of Managua *(*Graph 8.3*)*.

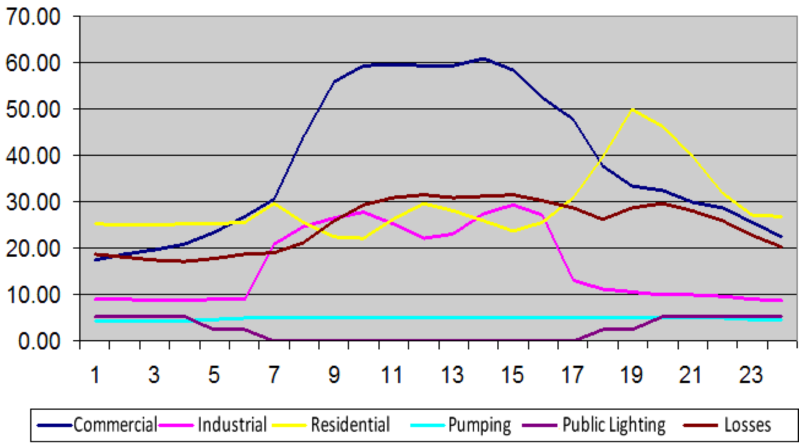


Graph 8.3: Daily Load Curve, SIN (1992, 2009)
Source: *(MEM, 2010b)*



Graph 8.3: Daily Load Curve, Managua (1992, 2009)
Source: *(MEM, 2010b)*

The load curve is composed by the demand of various consumer types: commercial, industrial, residential, water pumping, public lighting, and an adjustment due to losses. Each of these types of consumers has a different demand behavior throughout the day, and the sum of these demands creates the general load curve shown in the previous graphs. Graph 8.4, shows the different daily load curves for each type of consumer in Managua. In the graph it is evident that the mid-day peak load is due to the demand of the commercial sector, while the evening peak load is mainly due to the demand of the residential sector.



Graph 8.4: Managua's Load Curve from the Different Consumer Sectors
Source: *(MEM, 2010b)*

The following table presents the precise participation of each consumer sector on each of the peak loads presented throughout the day.

Peak Load Breakdown Analysis				
2009	Day Peak		Evening Peak	
	Share (%)	MW	Share (%)	MW
Time of the day - Load	**14:00 – 15:00**	**203.70**	**19:00 – 20:00**	**175.99**
LT Residential	16.9	34.49	38.2	67.18
LT Commercial and Services	20.2	41.22	18.4	32.41
LT Industrial	8.0	16.27	0.4	0.71
LT Water Pumping	3.4	6.94	4.0	6.99
Low Tension Total	**48.6**	**98.92**	**64.9**	**114.22**
MT Lighting	0	0	3.9	6.93
MT Commercial	18.03	36.73	5.4	9.54
MT Industrial	23.58	48.02	15.1	26.49
MT Water Pumping	1.41	2.87	1.6	2.90
Medium Tension Total	**43.81**	**89.25**	**22.1**	**38.93**
Losses / Adjustment	8.42	17.15	9.0	15.90

Table 15: Day and Evening Peak Load Breakdown by Consumption Sector
Source: *(MEM, 2010b)*

The residential sector can be further segment by user type depending on the amount of electricity consumed *(see* Table 16*)*. These figures are useful to the investigation to make a better estimation of which users are more likely to acquire a solar system. Users that consume more than 250 kWh per month are more likely to have the financial capability for acquiring a SWH or PV system. And although they consume almost 50% of the total consumption of the residential sector, the amount of connections (users) are less than 20% of all residential users; which makes it easy to greatly affect the consumption pattern with fewer solar systems. These users also are a better fit for the solar systems, since it most likely that the energy produce is consumed on site and there will not be any surplus energy wasted, so there is less need to negotiate a feed-in tariff or net-metering with the distributor. Table 8.5 displays the consumption of the residential users in Managua, according to their consumer level. It also displays their demand during the evening peak.

Residential Demand by Consumer Layers	Demand (MW)	Share (%)	Consumption (MWh)	Share (%)
Less than 50 kWh/month	4.52	6.5%	34.52	3.6%
51 - 100 kWh/month	9.88	14.1%	123.21	12.5%
101 - 150 kWh/month	14.01	20.1%	213.98	21.8%
151 - 250 kWh/month	10.31	14.8%	162.62	16.5%
251 - 500 kWh/month	14.28	20.5%	215.19	21.9%
Greater than 500 kWh/month	16.68	24.0%	232.47	23.7%
TOTAL	**69.62**	**100%**	**981.99**	**100%**

Table 16: Residential Consumption and Evening Peak Demand by Consumer Level
Source: *(MEM, 2010b)*

8.1.1.7 Peak Demand Production

The electricity production in Nicaragua is according to the lower production cost concept. The CNDC is responsible for programming which generators go online, at what time, and for how long. They make a weekly production programme and revise it the day prior to the schedule and on the same day, to make any modifications due to generator unavailability or other issues that may compromise the programme.

Renewable energies have priority over any other type of generation at any time. This is done in order to reduce the CO_2 emissions of electricity production, and also to take advantage of the energy produced by non-constant, unpredictable source. For example geothermal, biomass, and hydro: are sources that normally can begin production on demand; while solar and wind are unpredictable sources that are highly dependent on the weather.

The generators that have the lowest production costs have priority over those with higher costs. Table 17 displays the variable costs in August 2011 for each generator connected to the national grid. The CNDC programme is made according to these costs and the generators availability. The ones highlighted with red have the highest production costs and are more likely to be used only during peak hours. The economical part of the electricity savings due to the use of the proposed solar systems can be calculated according to the costs displayed in this table.

Generator	U$/kWh
CENSA	U$ 0.1697
Tipitapa	U$ 0.1502
Corinto	U$ 0.1580
NSL	U$ 0.0698
PENSA	U$ 0.0627
Hugo Chavez # 1	U$ 0.2425
Hugo Chavez # 2	U$ 0.2425
Che Guevara # 1	U$ 0.1773
Che Guevara # 2	U$ 0.1773
Che Guevara # 3	U$ 0.1770
Che Guevara # 4	U$ 0.1783
Che Guevara # 5	U$ 0.1794
Che Guevara # 6	U$ 0.1689
Che Guevara # 7	U$ 0.1703
Che Guevara # 8	U$ 0.1731
Che Guevara # 9	U$ 0.1684
Gesarsa	U$ 0.1811
EEC - 20	U$ 0.1623
Monte Rosa	U$ 0.0270
Nicaragua U # 1	U$ 0.2036
Nicaragua U # 2	U$ 0.2063
Las Brisas U # 1	U$ 0.3513
Las Brisas U # 2	U$ 0.2666
Momotombo	U$ 0.0619
Managua U # 3	U$ 0.2325
Managua U # 4	U$ 0.1724
Managua U # 5	U$ 0.1709
Santa Barbara	U$ 0.1502
Centro America	U$ 0.1623

Table 17: Generator Variable Costs August 2011
Source: *(CNDC, 2011)*

8.1.2 Water Heaters in Households and their Current Applications

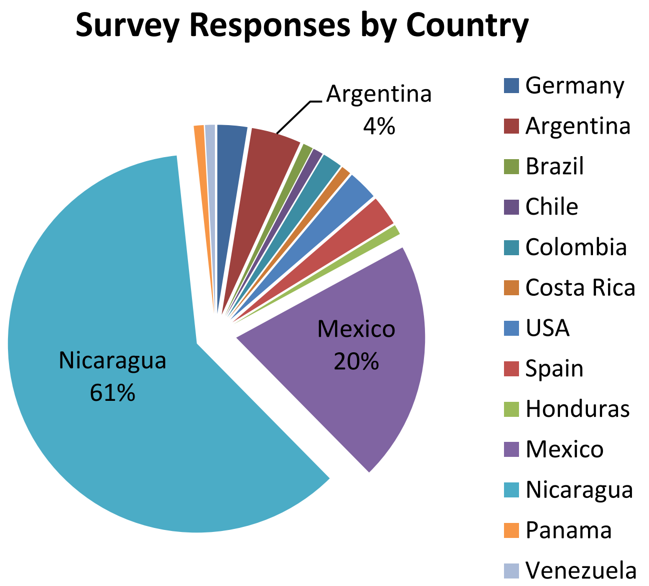
A small online survey was conducted in order to get an overview of the water heater devices used by the people that live in Managua and their operation time. The survey also aided the research to get a general impression of the types of water heaters currently used in households, time in the shower people spent, whether they shower twice a day or not, the time of the day at which they take a shower, and how often they take two showers in a week.

The online survey was first published on May 21st 2011 at http://www.yu-ju.net; the last response was recorded on the 13th of July 2011. It was designed using HTML, and the user response was saved directly to a MySQL database on the server with the use of PHP commands. Since it was oriented to the population of Managua it was in Spanish, the official language of Nicaragua. The survey was promoted through the social network *Facebook.*

127 responses were recorded during the survey runtime, 71 of these responses corresponded to situations in Nicaragua, from which 1 corresponded to the city of Granada and the 70 remaining corresponded to Managua. A summary of the results can be observed in the following tables and graphs:

Start Date:	05/28/2011
End Date:	07/13/2011
Total Records:	127
Blank Records:	7
Duplicate Records:	3

Country	
Argentina	5
Brazil	1
Chile	1
Colombia	2
Costa Rica	1
Germany	3
Honduras	1
Mexico	24
Nicaragua	71
Panama	1
Spain	3
USA	3
Venezuela	1
TOTAL	**117**



Graph 8.5: Survey Responses by Country

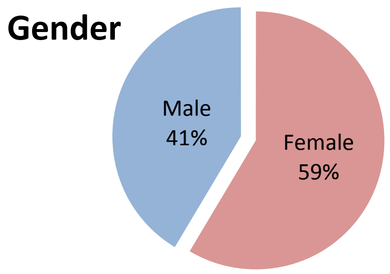
The following results are only from those responses corresponding to Managua, Nicaragua.

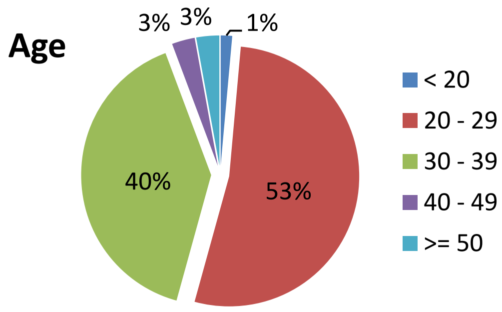
Gender	
Female	41
Male	29

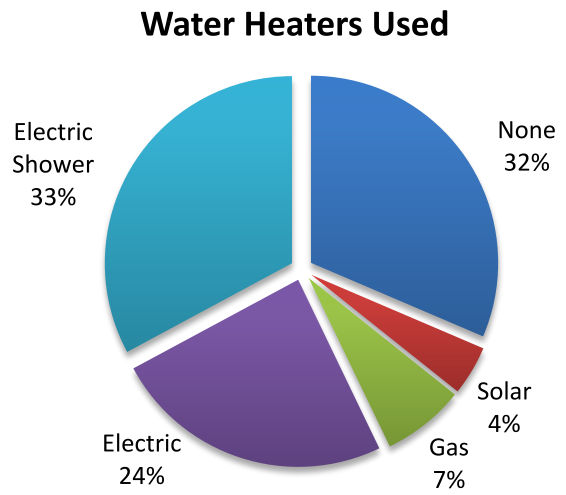
Age	
Less than 20	1
Between 20 & 29	37
Between 30 & 39	28
Between 40 & 49	2
Greater than 50	2

Water Heaters Used	
None	22
Solar	3
Gas	5
Electric	17
Electric Shower	23

Other Information	
Avg. People in Household	4.07
Average Shower Duration	14.5 min
Shower Twice	50 (71%)
Interested in SWH	58 (83%)
Most Frequent Shower Times in the Evening	7:00 PM 9:00 PM







Graphs 8.6: Survey Results

The responses obtained through the survey give a pretty good impression of the uses of hot water of the people that live in Managua, Nicaragua:

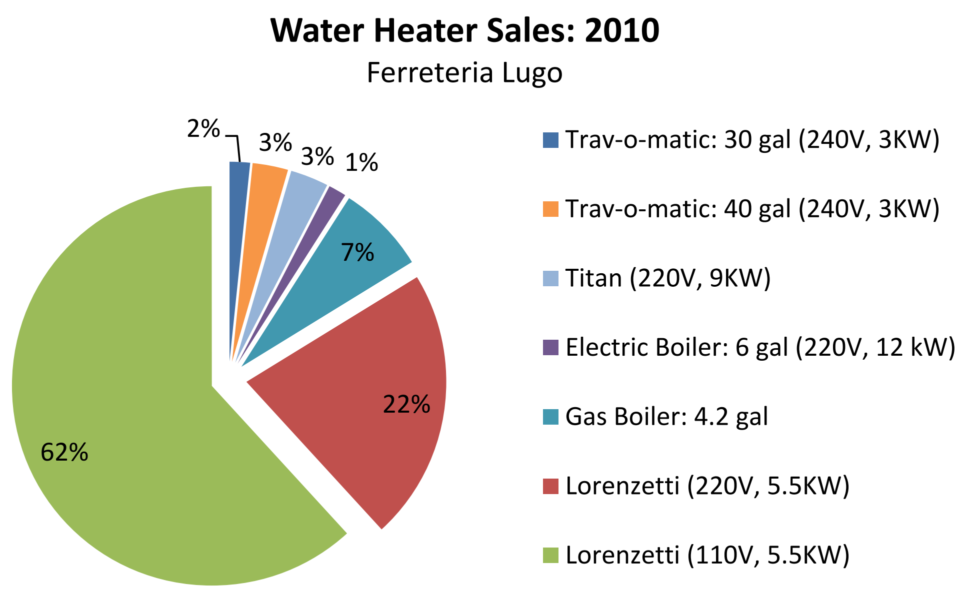
- Average shower time can be used to calculate the energy used per person.
- Average number of people can be used to obtain the total energy requirements per household and to select a SWH solution according to the specific hot water needs.
- The shower time in the evening coincides with the evening peak load time.
- The amount of people interested in SWH gives a glance if this type of solution would be accepted by the people in Managua, Nicaragua.
- The survey results also demonstrates that one third of the people that responded do not shower with hot water, instead of the previously assumed 100%.
- From the people that DO shower with hot water, 83% use an electric water heater.

8.1.3 Water Heating Solutions Available in Managua

Two of the most popular and biggest hardware stores in Managua were visited in order to get a general overview of the water heating solutions offered and their popularity. The hardware stores chosen were selected due to their popularity, centric location, and mainly because of their computer based sale system, which would make it easier to provide sale volumes of specific products. *Ferretería Lugo* and *Sinsa Radial* were the two hardware stores that were kind enough to provide sales figures of year 2010. The data obtained is NOT a statistical representation of the share of water heaters sold in Managua; it is simply data to get a general overview of the water heater's market.

There is a wide selection of water heaters offered in Managua; they can be categorized in two types: continuous flow or boiler with storage tank. Each of these types can be further classified by the type of fuel used to obtain the thermal energy: electricity or gas (LPG). None of the hardware stores offer a solar water heating solution. In order to acquire solar water heaters one has to visit a company specialized in solar solutions; *the next section will further discuss the solar devices offered in Managua.*

Table 18: Ferretería Lugo: Water Heater Sales 2010 displays the units sold of the different water heaters offered by Ferretería Lugo. It is evident that electric heaters are the most popular type of heaters, with the electric shower heads leading the market sales Lorenzetti puts a big gap in sales between them and the rest of water heaters. The most popular device is the Lorenzetti 110V shower head with 301 units sold in 2010, followed by the Lorenzetti 220V with 107 units. The sales of both Lorenzetti products form 84% of the total units sold in 2010. According to the person that provided the information, the Lorenzetti shower heads have been the most popular water heater sold for a long time; her own words were: *"for as long as I can remember"*.



Graph 8.7: Ferretería Lugo: Water Heater Sales 2010
Source: *(Ferretería Lugo, 2011)*

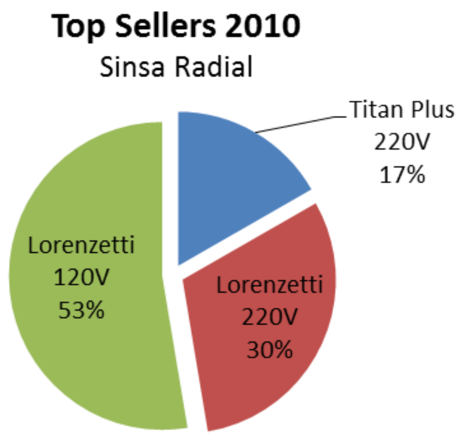
Water Heaters Sales: 2010

Ferretería Lugo

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Trav-o-matic: 30 gal (240V, 3kW)	2	0	0	0	0	2	1	1	0	1	0	1	**8**
Trav-o-matic: 40 gal (240V, 3kW)	1	0	1	1	1	0	1	0	5	0	0	4	**14**
Titan (220V, 9kW)	0	1	6	0	0	0	0	3	0	1	0	4	**15**
Electric Boiler: 6 gal (220V, 12 kW)	0	0	0	0	3	0	0	0	3	1	0	0	**7**
Gas Boiler: 4.2 gal	4	0	7	2	3	2	2	0	4	4	5	2	**35**
Lorenzetti (220V, 5.5kW)	17	15	7	5	8	7	8	6	3	11	10	10	**107**
Lorenzetti (110V, 5.5kW)	0	0	0	10	47	49	35	38	36	38	41	7	**301**

Table 18: Ferretería Lugo: Water Heater Sales 2010
Source: *(Ferretería Lugo, 2011)*

Sinsa Radial only provided information about their most sold products: Lorenzetti 110V, Lorenzetti 220V, and Titan Plus, a continuous flow electric water heater. The sale count had to be performed manually from each invoice (bill) due to limitations of the system design, which is why they could only provide information of just a few products. Table 8.2 contains the sale data obtained; here we can observe that the pattern repeats itself, the Lorenzetti 120 V is the product most sold, followed by the Lorenzetti 220V. Once more the sales of both Lorenzetti products form about 80% of the total water heater sales.



Graph 8.8: Sinsa: Top Selling Water Heaters 2010
Source: *(Sinsa Radial, 2011)*

Water Heaters: Top Sellers 2010

Sinsa Radial

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Titan Plus: 220V, 12kW	19	15	2	23	13	13	11	21	25	21	26	14	**203**
Lorenzetti: 220V, 5.5kW	43	19	22	20	24	29	33	38	41	36	38	28	**371**
Lorenzetti: 120V, 5.5kW	70	40	48	27	31	73	65	81	62	47	36	58	**638**

Table 19: Sinsa Radial: Top Selling Water Heater Sales in 2010
Source: *(Sinsa Radial, 2011)*

8.1.4 Solar Companies

There are currently 6 companies in Managua that offer solar systems: Altertec, ECAMI, Era Solar, Nica Solar, SuniSolar, and TecnoSol. Some of these companies offer a wide range of renewable energy solutions including wind, micro hydro, and solar, but their main focus is on rural areas that are not covered by the electricity grid; bringing electricity to those that previously did not have the possibility. Era solar is the only company that is exclusively focused on rural electrification and do NOT offer SWH or big PV systems, instead they only offer solar refrigeration equipment and small PV systems from 55W to 85 W. Leaving only 5 companies to promote SWH and bigger PV systems. So far only a few systems have been installed on grid connected locations. It is most probable that the population that has electricity from the grid is not interested in making a big investment, since there currently is NO feed in tariff regulation for small producers, and financing options for these relatively "new" type of devices is not as easy to obtain.

8.1.4.1 Solar Water Heaters

Only two companies provided prices for solar water heaters: ECAMI and Tecnosol. Table 8.9 displays the prices of the different systems for households with a max of 4 or 5 inhabitants. The prices shown on the table are basically turn-key prices; they include the solar collector, thermal tank, installation materials, installation service, and taxes. The warranty of the solar devices varies between 1 to 3 years, depending on the brand, and the warranty of the installation service is usually 1-3 months.

Company	Type of Collector	Electrical Element	Capacity (L)	Absorber Area (m^2)	Price (U$)
ECAMI	Flat Plate Collector	2.5 kW	200	2.60	2,047.00
ECAMI	Flat Plate Collector	2.5 kW	200	2.60	1,529.50
TecnoSol	Flat Plate Collector	3 kW	200	1.86	1,480.50
ECAMI	Evacuated Tubes	2.5 kW	200	-	1,242.00
TecnoSol	Evacuated Tubes	3 kW	180	-	1,536.50

Table 20: SWH prices for Households with a Maximum of 5 people.
Source: *ECAMI & TecnoSol (May 2011)*

These systems may be financed through a bank as a home improvement. Several banks offer similar interests rates: between 12 and 17%, with a payback period up to 7 – 10 years. In order to obtain this type of loan several requisites must be fulfilled and something of a greater value needs to be put as collateral. The home improvement loans require taking out a mortgage on the house as collateral.

ECAMI is the only solar company to offer an easy financing option for their systems. On May 2011, they promoted a SWH campaign in Managua offering a finance option with 0% interests in alliance with Credomatic, the biggest credit card issuer in Nicaragua. Each credit card holder has a pre-approved amount for a loan based on the credit card's limit, getting the financing is as easy as any other credit card transaction *(extra financiamento)*. The only inconvenience is the small loan payback periods: 6, 12, 18, 24, or 36 months. The amount of the loan does not affect the maximum credit limit of the credit card, but instead it is an additional credit to the credit card holder.

8.1.4.2 Photovoltaic Systems

None of the companies provided an estimate of the costs of a PV system. In order to estimate the investment costs of such systems we will use the reference costs provided by SolarBuzz (www.solarbuzz.com). SolarBuzz is a solar market research and analysis company that keeps track of thousands of online retail prices of the primary components in a solar system: PV module, inverter, and charge controllers. The tables to the right provide the estimates for PV modules and inverters for the month of July 2011.

Module Pricing Trends per Watt peak		
United States	$2.84	-6%
Europe	€2.51	-1%
Number of Prices <$3.00 or €2.10/Wp	443 (42% of survey)	-9%
Lowest Mono-cSi Module Price	$1.48 €1.04	-15% -15%
Lowest Multi-cSi Module Price	$1.52 €1.06	-8% -9%
Lowest Thin Film Module Price	$1.40 €0.98	2% 2%

Inverter Pricing Trends per Continuous Watt		
United States	$0.714	0%
Europe	€0.500	0%

Table 21: PV module and Inverter Costs
Source: *(SolarBuzz, 2011)*

National Incentives for Renewable Energies

The government of Nicaragua ratified law 532 on the 13th of April 2005, under which it establishes incentives for investment on renewable energy projects. Law 532 dictates the following incentives under its Article 7:

- **Exoneration of import taxes (DAI)** on all the material required for the generation of electricity with renewable sources, including transmission lines and other materials required to connect the generator with the national electricity grid (SIN).
- **Exoneration of sales tax (IVA)** of all the equipment required for renewable energies and their connection to the grid.
- **Exoneration of income tax (IR)** for a period of up to 7 years, beginning on the date the generator starts operating.
- **Exoneration of municipal taxes** for a period of up to 10 years, beginning on the date the generator starts operating. 75% the first 3 years, 50% the next 5 years, and 25% the last 2 years.
- **Exoneration of all use of renewable resource taxes** that might come to exist for a period of 5 years, beginning on the date the generator starts operating.
- **Exoneration of all revenue taxes** due to the construction, operation or expansion of the renewable energy project; for a period of up to 10 years since the date it begins operating.

(Asamble Nacional, 2005)

The law also establishes priority for electricity produced from renewable energies. The electricity from these types of sources should be prioritized during the tenders with the electricity distributor. The contracts with the distributor should be for a minimum of 10 years, and the price should be no less than 5.5 cents and no more than 6.5 cents (U$ dollar). (Asamble Nacional, 2005)

8.2 Objective II: Solar Thermal Water Heater Potential

Determine the potential electricity savings from the use of a solar thermal water heater system in a household according to solar radiation in Managua.

In order to achieve this objective the T*SOL Expert 4.5 Simulation software was used. The following parameters were introduced for water hot water consumption:

- Average Daily Consumption: 160 L
- Desired Temperature of Hot Water: 45° C
- Inlet Temperature in February: 18° C
- Inlet Temperature in August: 16° C
- Load Profile: Detached house with a maximum use during the morning

In order to select the best option for a SWH, three variants were established with different systems, and a simulation was executed comparing each system type while using the same parameters:

- Tilt angle: 13°
- Azimuth angle: 0° (South)
- Absorber area: 2.0 m^2
- External Heating Element: 9 kW, modulating continuous flow electrical heater

The systems compared were: (No Brand) Flat plate collector, (No Brand) Evacuated Tubes, Solahart 151kf flat plate collector. The simulation was carried out with official values obtained from the WMO for Managua, Nicaragua; recorded the meteorological station of the international airport *Augusto Cesar Sandino*, with coordinates 12.15° N, 86.15° W. The simulation was executed for a period of 1 year, providing the following results:

Variant Reference	Solahart 151kf	Evacuated Tubes	Flat Plate Collector
Irradiation onto Collector Surface	1,871.44 kWh/m²	1,871.44 kWh/m²	1,871.44 kWh/m²
Energy Produced by Collector Loop	1,917.26 kWh	2,082.89 kWh	1,774.43 kWh
DHW Heating Energy Supply	1,768.61 kWh	1,969.12 kWh	1,768.61 kWh
Solar Contribution to DHW	1,917.26 kWh	1,794.26 kWh	1,774.43 kWh
Energy from Auxiliary Heating:	241.81 kWh	174.85 kWh	354.63 kWh
DHW Solar Fraction	88.80%	91.10%	83.30%
Total Solar Fraction:	88.80%	91.10%	83.30%
System Efficiency	55.08%	47.94%	47.41%
Fuel Savings	2,458.0 kWh	2,110.9 kWh	2,274.9 kWh
CO_2 Emissions Avoided	1,637.0 kg	1,405.9 kg	1,515.1 kg

Table 22: Variant Comparison
Source: *T*SOL*

8.2.1 Water Heating Energy Requirements in a Household

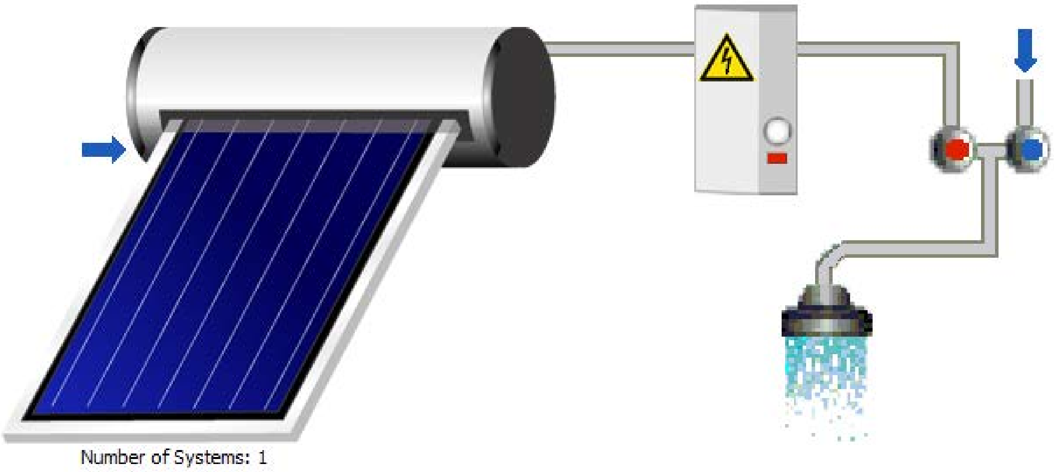
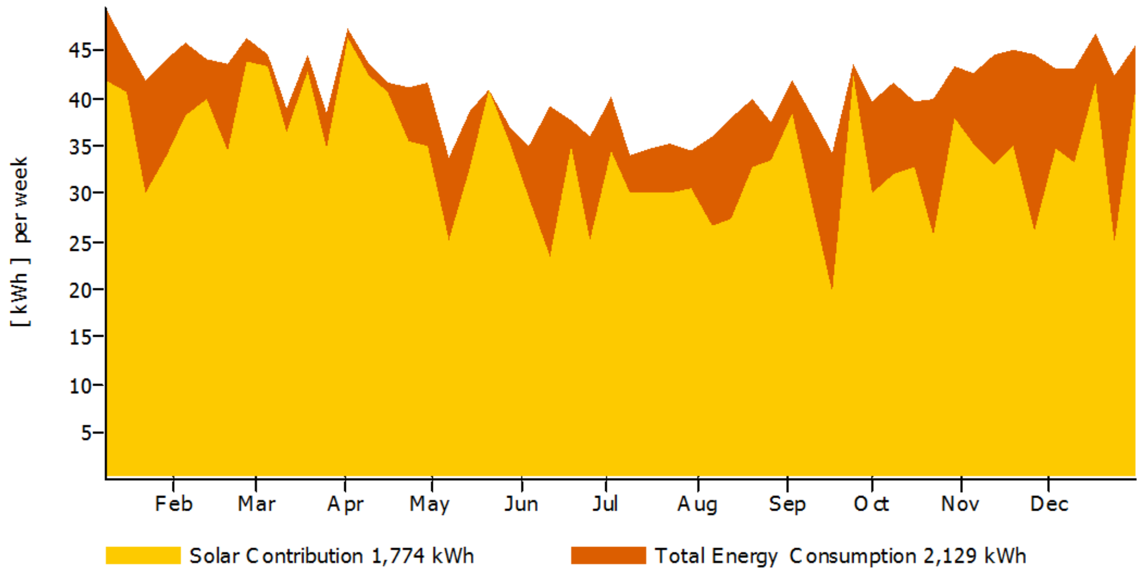


Figure 8.1: Flat Plate Collector Configuration Diagram
Source: *T*SOL 4.5*



Graph 8.9: Energy Consumption and Solar Contribution
Source: *T*SOL 4.5*

Graph 8.9 displays the total energy consumption in 1 year as 2,129 kWh due to domestic hot water needs. The solar contribution to this energy requirement would be of 1,774 kWh, leaving only a difference of 354.63 kWh to be supplied by the electrical water heater. A more precise estimate of the electricity savings can be created by using the values obtained in objective 1. The electricity consumption from hot water use in households in Managua can be estimated by assuming the following values:

- People per Household: 4 or 5 inhabitants; *4.5 will be used for this variable*
- Average Shower Time: 15 minutes
- People that take Evening Shower: 2 people
- Heating Device: Lorenzetti Shower Head (5.5 kW) or Titan Plus Continuous Flow (9; 12 kW)

In the case of an electrical shower and the continuous flow heating device the energy required per day is relatively easy to calculate using the formula below. The water flow, water use, and water temperature are not relevant in this situation, since the device is a 2-stage heater that runs at full power whenever the shower is on. When using an electrical shower the temperature of the water can be regulated by reducing the water flow to allow it to come into contact with the heating element for a longer period of time. The Lorenzetti shower head also has 3 settings: off, summer, and winter. For the purpose of calculating the electricity consumption it will be assumed that the shower head is always used in the summer setting, using a total power of 3 kW.

$$\boldsymbol{Energy\ Required\ per\ Day}_{(\boldsymbol{Heating\ Device})} = \frac{(Inhabitants + People\ Evening\ Shower)x\ Shower\ Time}{60\ minutes} XPower\ of\ Electrical\ Device$$

$$\boldsymbol{Energy\ Required\ per\ Day}_{(\boldsymbol{Lorenzetti\ 5.5\ KW})} = \frac{(4.5+2)x\ 15\ min}{60\ min} x\ 3\ KW = 4.88\ kWh/day$$

$$\boldsymbol{Energy\ Required\ per\ Year}_{(\boldsymbol{Heating\ Device})} = Energy\ Required\ per\ Day_{(Heating\ Device)}\ x\ 365\ days$$

$$\boldsymbol{Energy\ Requirement}: \boldsymbol{Monthly\ Average}_{(\boldsymbol{Heating\ Device})} = \frac{Energy\ Required\ per\ Year_{(Heating\ Device)}}{12\ months}$$

$$\boldsymbol{Monthly\ Electricity\ Costs}_{(\boldsymbol{Heating\ Device})} = Monthly\ Average_{(Heating\ Device)}\ x\ Cost\ per\ kWh$$

Equations 15: Energy Requirements in Household with Continuous Flow Water Heaters

Using the previous equations it is possible to calculate the energy requirements per household for the 3 most popular water heating devices in Managua, Nicaragua *(see Table below)*.

	Lorenzetti 5.5 kW	Titan 9 kW	Titan Plus 12 kW
Average Inhabitants (people)	4.5	4.5	4.5
Shower Time	15 min	15 min	15 min
Evening Shower (people)	2	2	2
Electric Heater Power	3 kW	9 kW	12 kW
Electricity Consumed			
- Per Day	4.88 kWh	14.63 kWh	19.50 kWh
- Per Year	1,779.38 kWh	5,338.13 kWh	7,117.50 kWh
- Monthly Average	148.28 kWh	444.84 kWh	593.13 kWh
Cost per kWh (U$)	U$ 0.22	U$ 0.22	U$ 0.22
Monthly Electricity Cost (U$)	U$ 32.62	U$ 97.87	U$ 130.49

Table 23: Energy Consumption of Electric Heaters
Source: *Author*

8.2.2 Economic Analysis

According to the previous calculations the Lorenzetti electric shower consumes the least energy, with a monthly average of 148.28 kWh equivalent to U$ 32.62 of electricity costs. The cost per kWh was taken from the T0 Residential tariff assuming that the household continues to consume more than 150 kWh, but less than 500 kWh per month. If the household consumes more than 500 kWh then the tariff that should be used is U$ 0.35 / kWh. In other words, the greater electricity consumption the household currently has, the greater the economic benefit when using a same size SWH; although the energy savings are the same, the electricity costs per kWh are higher.

Taking into account the option of a loan for 7 years with 12% annual interest, we can obtain the monthly payments from the loan amount, depending on the total investment cost and down payment required. If we select a mid-cost SWH like the flat plate collector offered by ECAMI with a net cost of U$ 1,529.50 and an initial payment of 15%, then the monthly payments would be of U$ 22.95. If the solar contribution for the energy requirements is of 80%, it would mean 118.63 kWh that are not purchased from the grid, which is equivalent to a saving U$ 26.10. Now, by subtracting the monthly payment from this saving amount, there is a remaining U$ 3.15 per month. These calculations are being conservative, by using the least energy consuming heating device and a constant electricity cost, when normally the electricity tariff has demonstrated an increase throughout the years; the higher the electricity increases the greater theoretical savings from the use of a SWH.

Economic Analysis	
Payback Period (years)	7
Annual Interest Rate (%)	12%
Down payment (%)	15%
Solar Investment	
- Flat Plate Collector Cost	U$ 1,529.50
- 10% Down payment (U$)	U$ 229.42
- Monthly Payments (U$)	U$ -22.95
Solar Contribution (80%)	
- Electricity Savings (kWh)	118.63
- Monetary Savings (U$)	26.10
Total Monthly Saving (U$)	**3.15**

Table 24: Economic Analysis of Flat Plate Collector

8.2.3 CO_2 Emission Reduction

It is possible to estimate the CO_2 savings per household using the electricity savings previously calculated, the values of fuel efficiency given in ***objective i*** results, and the CO_2 emission factors by fuel type from EPA.

Fossil Fuel and CO_2 Reduction	
Fuel Efficiency	
- Fuel Oil No. 6 (kWh/gal)	15.25
- Diesel (kWh/gal)	13.82
Fuel Savings	
- Fuel Oil No. 6 (gal)	93.34
- Diesel (gal)	103.00
CO_2 Emission Factors$_1$	
- Fuel Oil No. 6 (kg CO_2/gal)	11.80
- Diesel (kg CO_2/gal)	10.15
CO_2 Reduction	
- Fuel Oil No. 6 (kg CO_2)	1101.46
- Diesel (kg CO_2)	1045.48

1: EPA CO_2 Emission Factors for Stationary Combustion

Table 25: Fossil Fuel and CO_2 Reduction

8.3 Objective III: Photovoltaic System Potential

Determine the electricity production potential of a one-sized photovoltaic system in a household according to solar radiation in Managua.

The purpose of this objective is to obtain the annual electricity production of a 1 sized PV system. This production means electricity savings for the household, which also signifies a monetary saving in the monthly energy bill, potential fossil fuel savings, and CO_2 emission reduction of the electricity that is no longer consumed.

The size selected for the application of PV systems in Managua is a small system of 1 kWp. The reason for this size selection is because of the low electricity selling tariff from renewable energies, and the high residential electricity purchase tariff. The current feed-in tariff for renewable energy sources is U$ 0.055 per kWh, and the lowest price for electricity purchases from the grid is U$ 0.07947 per kWh for the first 25 kWh consumed, then it starts going up from there: U$ 0.1712 for the next 25 kWh, and so on, up to $ 0.3935 when the household consumes more than 2,000 kWh per month. *(For the complete purchase price scheme of the Residential T0 tariff please refer to* Table 12 *on page 76)* Therefore it is more rentable NOT to over dimension the PV system, but instead select a small system that does not produce any surplus energy, to enable the consumption of most of the electricity produced and avoid selling electricity at a price that is not suitable for the money invested per Wp.

Since no prices for PV systems were obtained from the local solar companies, the average costs from SolarBuzz for the month of July 2011 were used to estimate the approximate costs of a 1 kWp PV system. *(To see the costs of PV components provided by SolarBuzz please refer to* Table 21 *in page 85)*

- *Estimated cost per component = Average cost per unit X units desired*
- **PV Modules:** U$ 2.840 per Wp x 1,000 Wp = U$ 2,840.00
- **Inverter:** U$ 0.714 per continuous W x 1,000 W = U$ 714.00
- **Approximate PV system cost: U$ 2,840.00 + U$ 714.00 = U$ 3,554.00**

In order to corroborate the results of electricity generation for a 1 kWp system several simulations were executed by the following software: PV*SOL 4.0, Homer 2.81, Insel 8, and the online calculator from ENREL, PVWATTS version 1 *(*http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/*)*. All simulations were executed for 1 year with tilted PV modules at 12.1°, with a South orientation.

8.3.1 Simulation with Insel

Insel is a very flexible software that allows the user to create precise simulations according to his needs. In order to be able to simulate any data output it is necessary to generate a diagram using the building blocks provided; the user must select and interconnect all the building blocks needed to produce the desired results. The software also contains pre-loaded meteorological data of more than 2,000 locations worldwide.

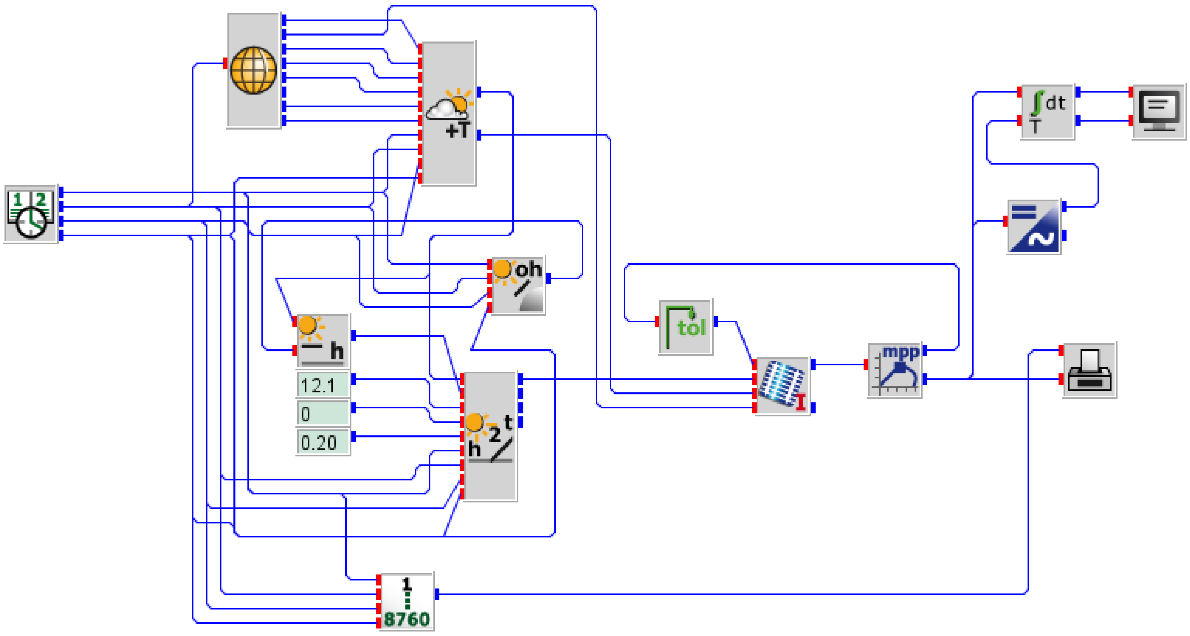
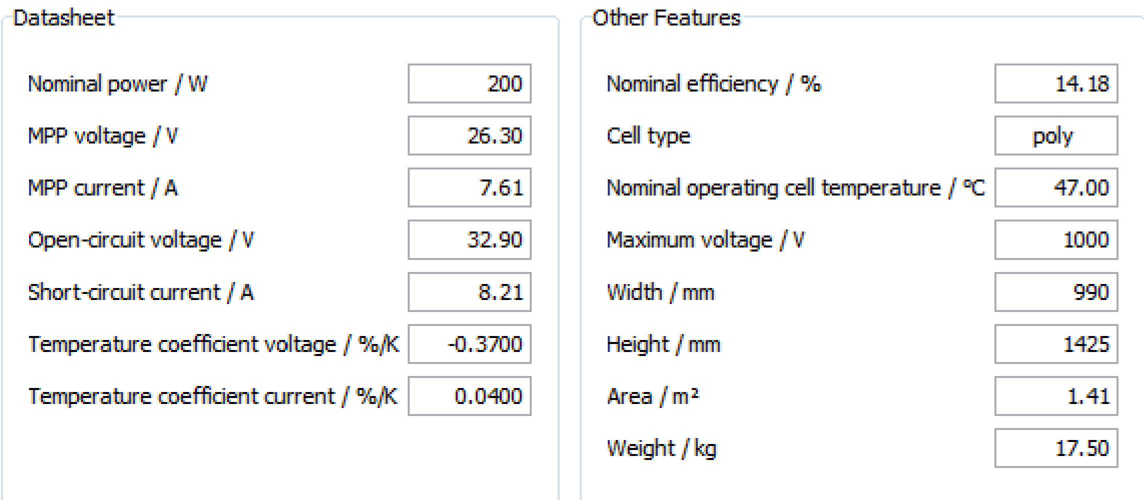


Figure 8.2: Insel PV System Diagram
Source: Insel 8

The figure above displays the diagram built in order to simulate the energy output of a 1 kWp PV array and its inverter with a MPP tracking system. The clock block was configured to run a simulation for a period of 1 year (1.1.2011 – 1.1.2012) with hourly intervals. The meteorological block connected to the clock block, provided the rest of the building blocks with meteorological data for Managua, while all the other blocks that contain a Sun figure interpreted this data and converted it to horizontal radiation, radiation on a tilted plane, extraterrestrial radiation, and diffuse radiation. All these blocks were required to produce the data needed by the PV module: irradiance on a tilted surface, wind speed, temperature, and current. The diagram was programmed to provide the annual energy output of the PV array with 5 Kyocera KC200GH-2P PV modules with the following characteristics:



Datasheet

Nominal power / W	200
MPP voltage / V	26.30
MPP current / A	7.61
Open-circuit voltage / V	32.90
Short-circuit current / A	8.21
Temperature coefficient voltage / %/K	-0.3700
Temperature coefficient current / %/K	0.0400

Other Features

Nominal efficiency / %	14.18
Cell type	poly
Nominal operating cell temperature / °C	47.00
Maximum voltage / V	1000
Width / mm	990
Height / mm	1425
Area / m²	1.41
Weight / kg	17.50

Figure 8.3: Kyocera KC200GH-2P PV Module Characteristics
Source: Insel 8

The simulation gave the following results:

- **PV energy output:** 1,815 kWh
- **Inverter output:** 1,664 kWh

It is normal that the energy output of the inverter is lower than the energy input from the PV array, since the inverter consumes part of this energy for its own uses, and there are also some losses in transformation. Normally an inverter has an efficiency of around 85-90%. The simulation also plotted a graph of the PV output throughout the year, but another graphical representation will be provided in the following sections by another software.

8.3.2 Simulation with Homer

Homer provides several economic and environmental information that cannot be easily calculated by using Insel: CO_2 emissions avoided, electricity sales to the grid, cash flow analysis, and many others. The figure to the right shows the diagram configuration for this software, it can be interpreted as DC generated by the PV array, which is later converted to AC that is connected to the grid and also has a specified load.

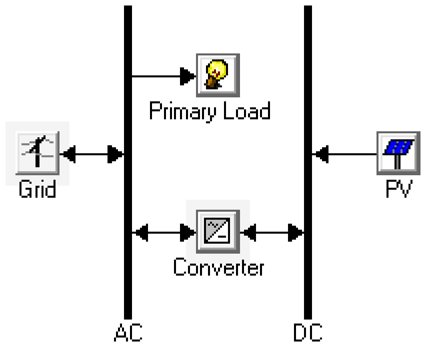


Figure 8.4: Homer PV System Diagram
Source: *Homer 2.81*

The software was also inputted with the costs of the PV components previously mentioned, along with their life expectancy, and an electricity tariff of U$ 0.22. The simulation was configured for a period of 40 years in order to obtain a precise cash flow analysis for operation during this period of time. The figure below shows a graphical representation of the cash flow throughout the simulation. The negative cash flow of year 0 is the initial investment of the PV system (U$ 3,554.00), the positive cash flows of each year is the savings from electricity not purchased from the grid minus a fee of U$ 50 for annual maintenance of the system. The replacement value is an expense for the replacement of the inverter every 15 years and the PV modules every 20 years, which after 40 years only the inverter has a salvage value for the remaining years of its life expectancy.

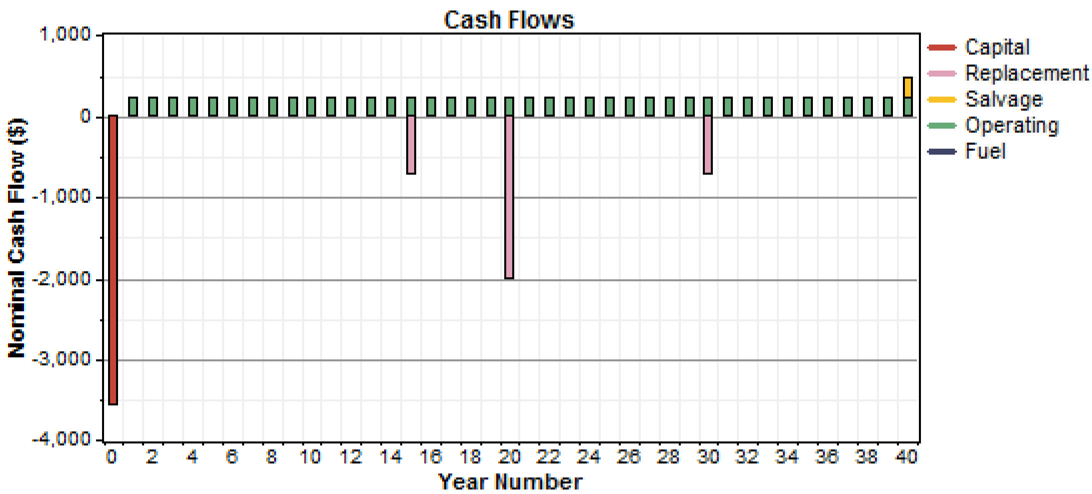


Figure 8.5: Cash Flows in a Period of 40 years
Source: *Homer 2.81*

Table 26 displays the cash flow summary for the period of 40 years. The replacement of the PV modules is lower than the initial investment due to savings in structure construction, installation labor, and a reduction in the PV module costs.

Component	Capital (U$)	Replacement (U$)	O&M (U$)	Salvage (U$)	Total
PV	2,840	2,000	0	0	4,840
Electricity Savings	0	0	-11,568	0	-11,568
Converter	714	1,428	0	-238	1,904
Maintenance	0	0	2,000	0	2,000
System	3,554	3,428	-9,568	-238	-2,824

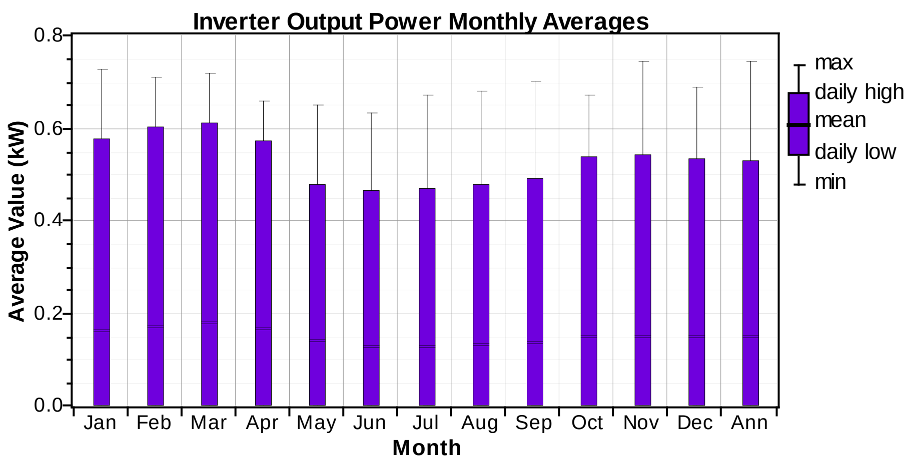
Table 26: Cash Flow Summary
Source: *Homer 2.81*

Among the many information acquired from the simulation, we also obtained the following:

- **PV energy output:** 1,461 kWh/year
- **Inverter output:** 1,315 kWh/year
- **CO_2 emissions avoided:** 831 kg/year
- **SO_2 emissions avoided:** 3.6 kg/year
- **NO_x emissions avoided:** 1.76 kg/year

The gas emissions were calculated based on the software's default emissions for grid electricity production: CO_2: 632 g/kWh, SO_2 2.74 g/kWh, NO_x: 1.34 g/kWh. These values depend on the electricity production mix of the generators connected to the grid and they can be manipulated in the software, but for now it is better no to change them since manual calculations will be made according to the emissions of Nicaragua's peak electricity production.

Another data that is important to this investigation is the maximum output power of the inverter, since we want to avoid surplus energy by NOT over sizing the PV system. The maximum inverter output power recorded is 0.74 kW and the average daily high is around 0.6 KW. As long as the electricity demand in the household is around 600 W during peak production, the surplus electricity will be minimal. The inverter output behavior throughout can be observed in the following graph:



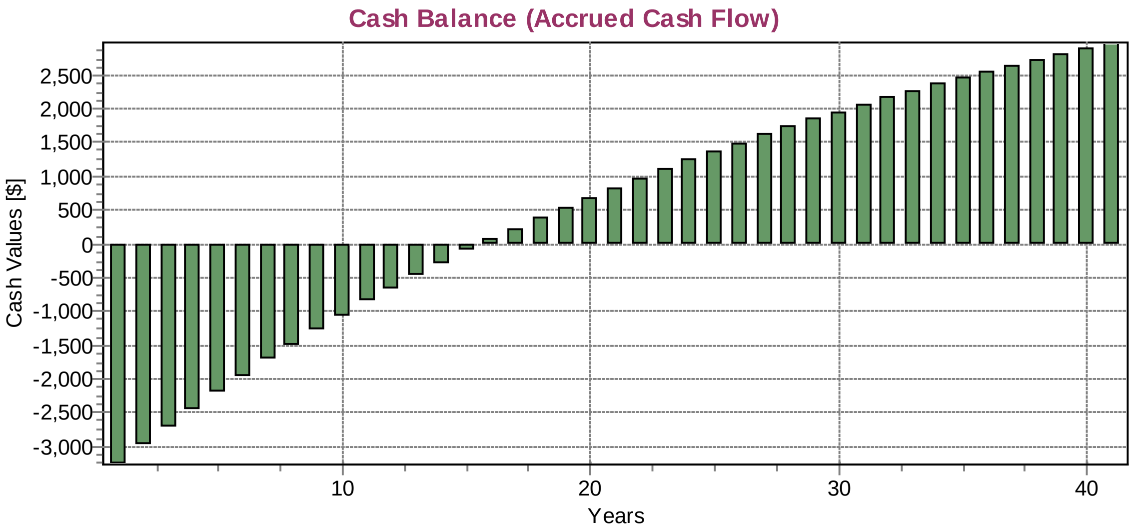
Graph 8.10: Inverter Output Power
Source: *Homer 2.81*

8.3.3 Simulation with PV*SOL

The simulation with PV*SOL Expert 4.0 (R9) has many benefits; among these benefits the main contributions brought to this investigation are the shade analysis, economic efficiency calculation with PV module degradation, and a visual representation of the PV system.

8.3.3.1 Economic Analysis

A self-financed PV system would have an amortization period of 15.6 years, considering the electricity savings at a tariff of U$ 0.22 and U$ 50 annual maintenance fee; the final capital value at the end of 40 years would be of U$ 2,979. The graph below shows the cash balance from investing on a U$ 3,554 PV system, but although this simulation considers degradation in production of 10% after a period of 10 years it does NOT consider re-investment due to a replacement of components. It can be introduced in the calculation, but only as annual costs as a percentage of the investment, U$ per kWp, or as a fixed expense in U$.



Graph 8.11: Cash Balance of Self-Financed PV System
Source: *PV*SOL 4.0*

8.3.3.2 Visual Representation

One of the main benefits of PV*SOL is the 3D modeling module used to create a visual representation of where the PV system is been installed and its surroundings. This enables the user to simulate an environment that is more likely to be suitable to their specific situation. The 3D module also allows the user to view a graphical representation of the shades projected by the objects around the PV system and calculates the shade distribution frequency over the PV array.

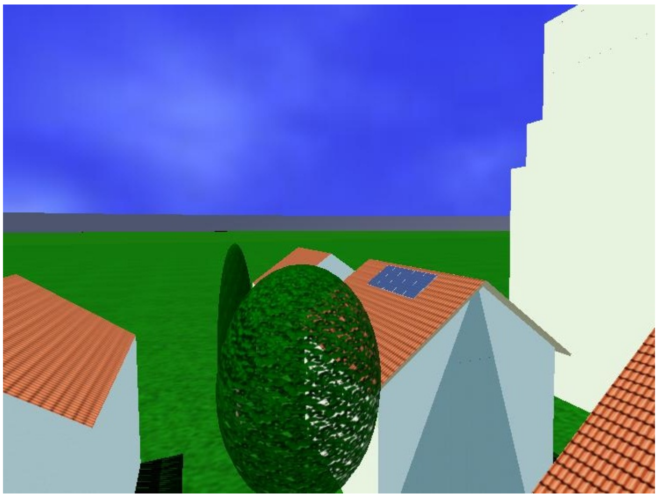


Figure 8.6: 3D Model of PV Layout
Source: *PV*SOL 4.0*

8.3.3.3 Shade Analysis

In conjunction with the 3D module the shade analysis allows to calculate and view actual representations of the shades projected by the objects in the surrounding at any giving time or day in the year according to the specific coordinates of the location. The shade analysis then calculates all the shadows casted over the PV array and then interprets how these affect the overall performance of the PV module string. The figures below show the visual shadow projections (left) and the shade analysis of the rooftop (right).

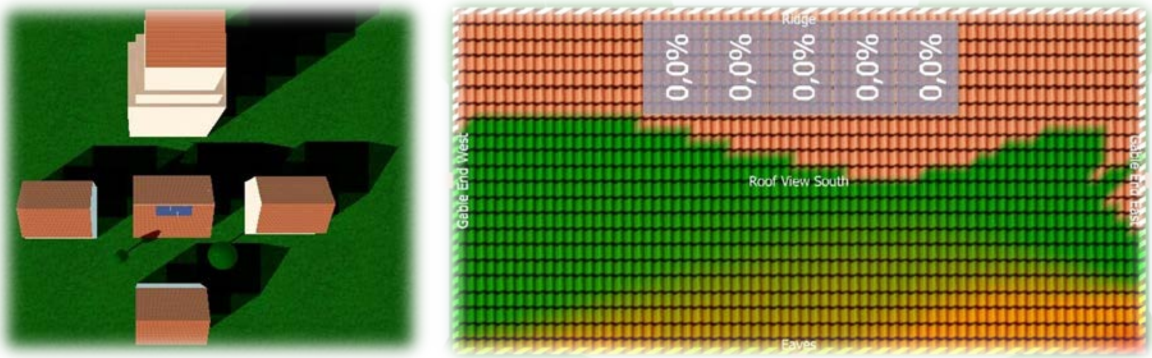
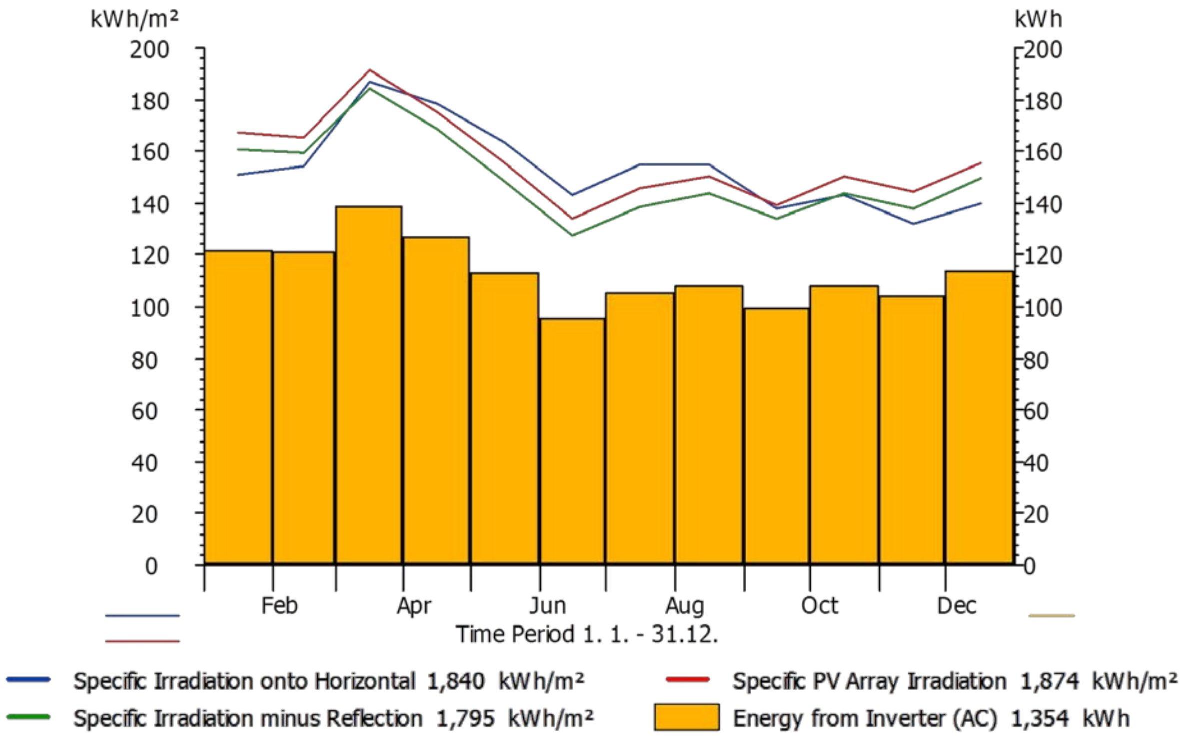


Figure 8.7: Shade Analysis
Source: *PV*SOL 4.0*

8.3.3.4 PV Production and Emission Reduction

In this particular situation the data was calculated based on a 1.05 kWp, since it was not possible to find the same Kyocera 200 W PV modules, therefore Kyocera 210 W panels were used. The graph below displays the displays the irradiations affecting the PV system, including the reflected irradiation and the corresponding monthly energy output of the inverter.



Graph 8.12: Specific Radiation over PV Array and AC Energy Output
Source: *PV*SOL 4.0*

The final results yielded by the simulation of 1 year are the following:

- **PV Energy Output:** 1,510 kWh
- **Inverter Output:** 1,354 kWh
- **PV System Own Use:** 2.8 kWh
- **CO_2 Emissions Avoided:** 1,197.62 kg
- **SO_2 Emissions Avoided:** 0.59 kg
- **NO_x Emissions Avoided:** 0.53 kg

8.3.4 Simulation with PVWATTS

PVWATTS is a simple web based PV calculation software that only requires the user to select the location, introduce the energy costs and define the size of the PV system. The software then uses the meteorological information on its database to calculate monthly irradiation on the PV array, the energy output and its monetary equivalent. According to PVWATTS a 1 kWp PV system in Managua, Nicaragua produces 1,336 kWh per year.

8.3.5 PV Simulation Results Comparison and Analysis

	Insel	Homer	PV*SOL	PVWATTS
PV Array Output (DC)	1,815 kWh	1,461 kWh	1,510 kWh	---
Inverter Output (AC)	1,664 kWh	1,315 kWh	1,354 kWh	1,336 kWh
CO_2 Emissions Avoided	---	831 kg	1,197.6 kg	---

Table 27: Summarized Simulation Results

All simulations generated similar inverter output results except for Insel. Going back to the software we discovered that the meteorological database for Managua, Nicaragua does not contain wind speed, precipitation, or atmospheric clarity indexes. We assume that is the reason for a higher energy output compared to the other results, therefore we have put this values a side and have calculated the average AC energy output from the other results: **1,335 kWh per year**. In any case it is always good to plan according to the lowest values or worst case scenario.

Now using the average energy output and the emission factors according to the fuel efficiency of peak load generators it is possible to calculate the CO_2 emissions avoided by reducing peak load electricity consumption *(See Table to the right)*. The CO_2 emission factor per kWh was calculated with the following equation:

$$kg\ CO_2/kWh = \frac{CO_2\ Emission\ Factor}{Fuel\ Efficiency}$$

If we average the simulations CO_2 emissions avoided (1,014.31 kg) and compare them to the average CO_2 calculated per fuel for peak load (1006.73 kg), there is only a difference of 7.58 kg equivalent to 0.75%, a fairly accurate estimate between simulations and manual estimations!

Peak Load CO_2 Emission Reduction	
Electricity Savings	**1,335 kWh/year**
Fuel Efficiency	
Fuel Oil No. 6 (kWh/gal)	15.25
Diesel (kWh/gal)	13.82
CO_2 Emission Factors	
Fuel Oil No. 6 (kg CO_2/gal)	11.80
Diesel (kg CO_2/gal)	10.15
Calculated CO_2 Factors	
Fuel Oil No. 6 (kg CO_2/kWh)	0.773770
Diesel (kg CO_2/kWh)	0.734443
Potential CO_2 Reduction per Year	
Fuel Oil No. 6 (kg CO_2)	1,032.98 kg
Diesel (kg CO_2)	980.48 kg

Table 28: Peak Load CO_2 Reductions from 1 kWp PV

8.4 Objective IV: Scenarios and Projections

Create scenarios of the new load profile and determine the electricity production-consumption savings, decrease of fossil fuels use, and the reduction of carbon dioxide emissions.

Initially the LEAP scenario modeling software was going to be used to create the scenarios by inputting the data obtained in the previous objectives, but once the initial scenario projections were made with LEAP it did not provide detailed data of particular characteristics; for example load curve variation due to the introduction of a specified number of SWH and PV systems per year using a particular capacity, with the meteorological information of the location. For that reason, in order to obtain the data desired, the scenarios had to be manually created.

Several scenarios were created by changing many variables and modifying the key assumptions, but for the purpose of this objective only two scenarios will be presented: Business as Usual and Solar Applications in Households. The Business as Usual Scenario simply projects current growth, production, and consumption patterns into a near future using historical growth rates and share percentages. The Solar Application Scenario projects the same growth, production, and consumption patterns, but in this scenario a reduction or saving due to the use of solar water heaters AND photovoltaic systems in households.

8.4.1 Scenario Creation

In order to create the projections for the subsequent variables the following steps were taken:

Population & Household: Population estimates were taken from the values of the 1995 census, 2005 census, and the estimates and projections established by the INIDE. In some occasions the values were given annually, while in others they were in periods of 5 years. The following formula was used to calculate the average annual growth rate when given two values with gap in between:

$$i = \left(\frac{Future\ Value}{Present\ Value}\right)^{1/n} - 1$$

i: Represents the estimated growth rate per period
n: is the number of periods between the Future Value and Present Value

Equation 16: Growth Rate from Future and Present Values

The population and households in Managua where estimated according to average share percentages obtained from known values (1990-2020). The full data sets for population and households can be found in Appendice 7: Projections and Estimations.

Electricity Sector: The generation, consumption, fossil fuel use, number of connections, and other data regarding the electricity sector where estimated from average growth rates obtained from the historical data (1991-2010).

- The number of residential electricity connections to the national grid is known for 3 different layers: Nicaragua, Managua (D), and Managua (M). From the connections of Managua (M) we know how many users receive subsidies for consuming less than 150 kWh

(May 2011). From this data we obtain the share percentages for each layer and project them for future years according to the growth rate of overall connections.

Load Curve: The average load curve for a regular labor day was extrapolated by obtaining the growth rate using equation 15, from the data of 2006 and 2010. The load curved used for 2011 is from real value for a regular week day in August 2011.

CO_2, CH_4, N_2O: The emissions for these gasses were calculated from real fossil fuel consumption in the electricity sector (1991-2010), and projected values (2011-2050), using the methodology specified in the IPCC GHG Inventory Guidelines.

8.4.2 Key Assumptions

Several assumptions are taken in order to create the projections for the use of SWH and PV systems in households.

General Assumptions

- Only the users that consume above 150 kWh per month, which DO NOT receive subsidies are more likely to use water heaters, have the financial means for acquiring a solar system, and are more probable to benefit from such a system without producing any surplus energy.
- According to data from the survey a total of 32% of users DO NOT use hot water, from which 57% use electric water heaters, and 7% use gas boilers. To define the upper limit for possible users that are able, and willing to acquire a solar system we take the users in Managua that DO NOT receive subsidies for each year, and obtain its 30%; considering that they have the financial means, adequate consumption, and use hot water.
    - **Potential market for solar systems (SWH & PV):**
        - Users that consume above 150 kWh per month x 30%
- The average electricity saving from each solar system installed is assumed to be:
    - **Solar Water Heaters:** 1,779 kWh per year
    - **PV Systems:** 1,335 kWh per year

Fossil Fuels

- To be conservative the fossil fuel reductions are calculated from the use of fuel oil, which is the least expensive fossil fuel used in the electricity generation (in comparison to diesel), it has a greater efficiency (15.24 kWh/ gal in comparison to 13.76 kWh per gallon of diesel), and is the fuel most used for this application.
    - $Fossil\ Fuel\ Reduction = \frac{Electricity\ Savings}{Fuel\ Oil\ Efficiency}$
- With regard to oil price an average increase of 1.5% per year is assumed.
    - $Economical\ savings = Fuel\ Oil\ Reduction\ x\ Projected\ Fuel\ Oil\ Price$
- It is also assumed that new fossil fuels generators will no longer be acquired by the electricity sector, but in order to project an increase of fossil fuels and how the solar systems will contribute in the reduction of this fuel, an annual growth rate of 1% was used.

Solar Water Heater Operation

- It is installed in a household with 5 inhabitants, which are probably 2 adults and 3 young people.
- All inhabitants shower in the morning (5) between 06:00 and 08:00. Two of the people that live in the household shower once again at night between 19:00 and 21:00.

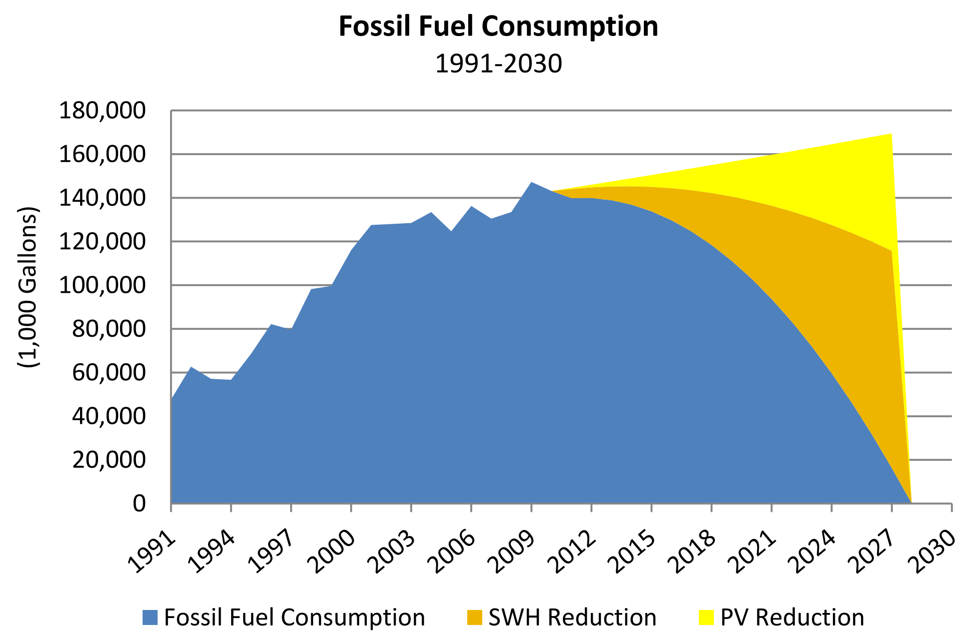
Market penetration, Solar System Sales

- SWH sales begin with 3 devices per month the first year, and increase their sales volume by 1 unit every 2 months (6 per year).
- PV sales begin with 1 device every 2 months the first year, and increase their sales volume by 1 unit every 3 months (4 per year).

8.4.3 Scenario Results

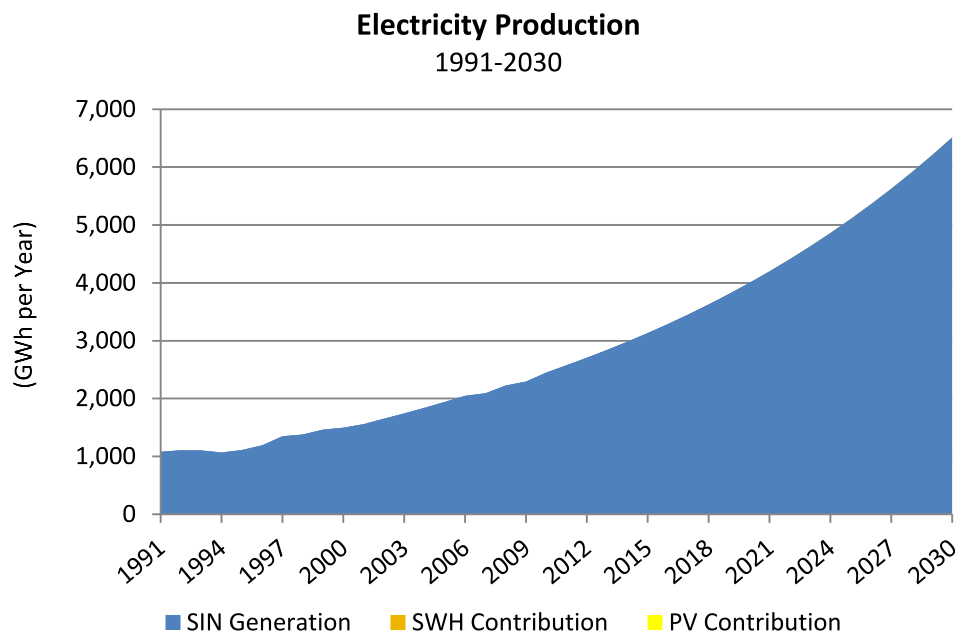
The period for the scenarios was initially established from 2011-2050, including the last 19 years of data (1991-2010), but once the first scenarios were created it became obvious that such a distant future is difficult to estimate, and realized that for the purpose of this research a scenario construction up to 2030 was enough.

Using the previously established assumptions it was discovered that the fossil fuel consumption was completely eliminated by year 2028; for this reason the scenario period was reduced to 2030. The graph below displays the fossil fuel consumption in the electricity sector and the equivalent reduction of fossil fuels due to the incorporation of SWH and PV in households. The business as usual scenario is simply the upper limit of the area in the graph, in other words, the fossil fuel consumption – SWH Reduction – PV Reduction.



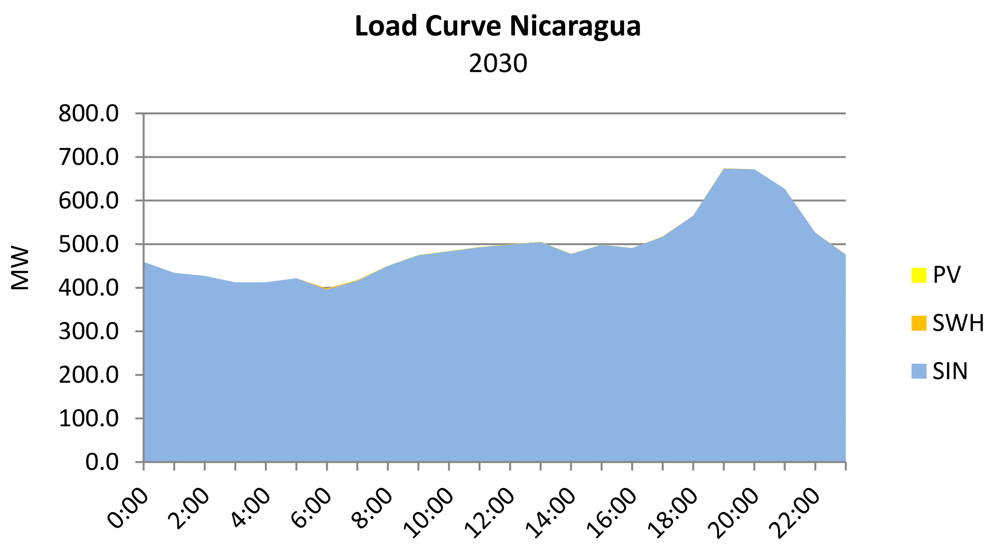
Graph 8.13: Scenario: Fossil Fuel Consumption (1991-2030)
Design: *Author*

The fact that the fossil fuel consumption was eliminated it does not mean that the generation of electricity was entirely substituted by the proposed solar systems, as a matter of fact it became evident that the total contribution of this systems did not form a big share of the electricity generation. Actually the production share of the solar systems according to the established market penetration is basically unperceivable in the total generation *(see* Graph 8.14*)*.



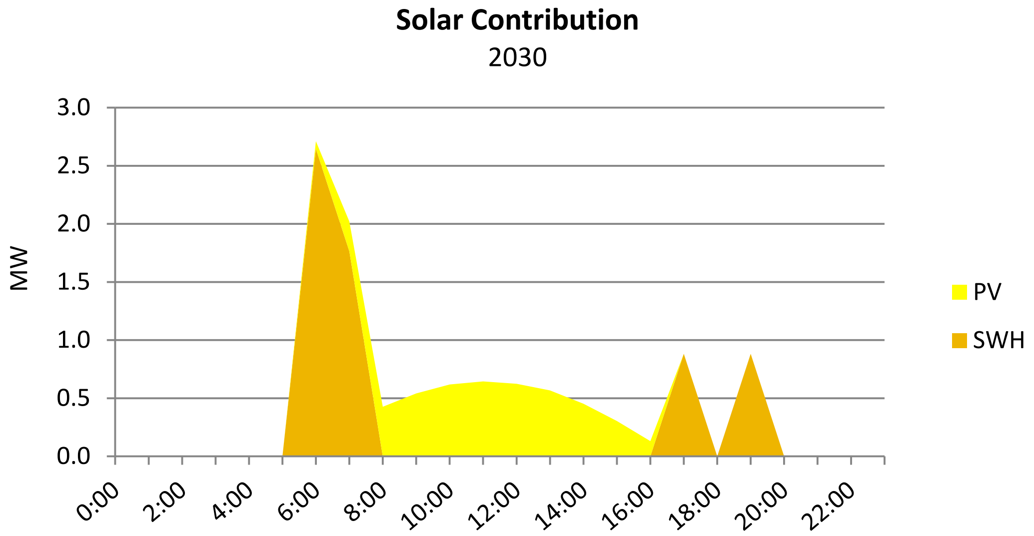
Graph 8.14: Scenario: Electricity Production (1991-2030)
Design: *Author*

The load curve for 2030 retains the same behavior as the past recent years. The solar contribution does not show a relevant change in the national grid load, in fact it is so low that it is not even perceivable in the graph below.



Graph 8.15: Scenario: Load Curve SIN (2030)
Design: *Author*

In order to view the load reduction due to the contribution from the solar systems it was necessary to graph it separately in a separate graph, *see* Graph 8.16. The orange peaks from SWH represent electricity that was previously consumed from the grid for water heating; these are the times of the day in which people take showers, but they do not consume electricity since they are using SWH in year 2030.



Graph 8.16: Scenario: Solar Contribution (2030)
Design: *Author*

**Please refer to Appendice 7 in order to view the estimated values used in the scenarios.*

Chapter 9: Conclusions and Recommendations

9.1 Household Analysis and Conclusions

Solar water heaters are more cost effective than photovoltaic systems for electricity savings at a household level. The investment and amortization period for SWH is less than a PV system, and without an established feed-in tariff to promote the use of domestic PV systems it is less likely that households in Nicaragua adopt this type of systems.

9.1.1 Electricity and Economical Savings

Although electric showers require a small initial investment it involves lifelong operating costs. By performing a life cycle analysis it is possible to view the costs involving the operation of an electric shower. The table below demonstrates the costs involving an electric shower, SWH, and PV systems, over a period of 10 years. The electric shower that was a cheap investment turned out to be the most expensive. After 10 years a total of U$ 5,159.80 have been spent in electricity consumed by the electric shower; on the other the total expenses of a SWH are U$ 1,729.50, and U$ 3,754.00 for a PV system. After doing the lifecycle cost analysis the expensive alternatives (SWH and PV), do not seem like such a bad idea.

Lifecycle Costs	Electric Shower	Solar Water Heater	Photovoltaic System
Annual Energy Consumed	1,779 kWh	0	0
Annual Energy Saved		1,779 kWh	1,335 kWh
Energy Cost per kWh	U$ 0.22		
Energy Inflation Rate	6%		
Installed Cost	U$ 30.00	U$ 1,529.50	U$ 3,554.00
Annual Maintenance Fee	U$ 0.00	U$ 20.00	U$ 20.00
Operating Costs (U$)			
Year 1	391.46	20.00	20.00
Year 2	414.95	20.00	20.00
Year 3	439.85	20.00	20.00
Year 4	466.24	20.00	20.00
Year 5	494.21	20.00	20.00
Year 6	523.87	20.00	20.00
Year 7	555.30	20.00	20.00
Year 8	588.62	20.00	20.00
Year 9	623.93	20.00	20.00
Year 10	661.37	20.00	20.00
Total Operating Cost	**U$ 5,159.80**	**U$ 200.00**	**U$ 200.00**
Life Cycle Cost After 10 years	U$ 5,189.80	U$ 1,729.50	U$ 3,754.00

Table 29: Life Cycle Cost Analysis of 3 Investments
Design: *Author*

Another type of interesting economic analysis to view how long it takes to recover the initial investment is a cash flow (balance) analysis. Table 9.2 displays the balance of the same three types of investments. In this case the first year includes the operating costs, maintenance fee, and initial investment. The subsequent years are the balance of the previous years plus the operating costs (maintenance and energy costs) minus the electricity savings. By performing this analysis we can observe that by the end of the fourth year the SWH represents U$ 102.64 in savings, while the PV system shows savings until the end of the tenth year, U$ 117.20. In the case of the electric shower balance will continue to be negative since there are no savings related to the use of this device.

Cash Flow (Balance)	Electric Shower	Solar Water Heater	Photovoltaic System
Annual Energy Consumed	1,779 kWh	0	0
Annual Energy Saved		1,779 kWh	1,335 kWh
Energy Cost per kWh	U$ 0.22		
Energy Inflation Rate	6%		
Installed Cost	U$ 30.00	U$ 1,529.50	U$ 3,554.00
Annual Maintenance Fee	U$ 0.00	U$ 20.00	U$ 20.00
Balance Sheet			
Year 1	-421.46	-1,158.12	-3,280.30
Year 2	-836.42	-763.26	-2,988.98
Year 3	-1,276.26	-343.50	-2,678.98
Year 4	-1,742.50	102.64	-2,349.18
Year 5	-2,236.72	576.75	-1,998.39
Year 6	-2,760.58	1,080.50	-1,625.35
Year 7	-3,315.88	1,615.68	-1,228.73
Year 8	-3,904.50	2,184.17	-807.11
Year 9	-4,528.43	2,787.97	-359.00
Year 10	-5,189.80	3,429.20	117.20

Table 30: Cash Flow (Balance) Analysis
Design: *Author*

9.1.2 Fuel and CO_2 savings

Each SWH and PV system saves electricity from being consumed in the household, and since 60% of Nicaragua's electricity is produced by fossil fuels this represents a decrease in the use of fossil fuel, which also mean a reduction of the CO_2 emissions due to the combustion of these fuels. Table 9.3 displays the annual fuel savings and CO_2 emissions avoided per system; separate values are given for fuel

Fuel and CO_2 Reduction	SWH	PV
Annual Electricity Savings (kWh)	1,779.38	1,335.00
Fuel Use Avoided		
Fuel Oil No. 6 (gal)	93.34	87.54
Diesel (gal)	103.00	96.60
CO2 Emissions Avoided		
Fuel Oil No. 6 (kg CO_2)	1,101.46	1,032.98
Diesel (kg CO_2)	1,045.48	980.48

Table 31: Annual Fuel and CO_2 savings per Solar System Installed
Design: *Author*

and CO_2 emissions reduction, in case fuel oil no.6 is used to generate the electricity OR diesel. Although there is a visible fuel and CO_2 savings, when dealing with households this is intangible and is not as relevant in the decision making process of acquiring a system; the asset that has a greater weight in the decision making process of a household is the economic analysis.

9.2 Scenario Analysis

In order to interpret the influence of the use of SWH and PV systems at a national level it is necessary to observe the data estimations obtained from the scenario creations.

9.2.1 Net Generation

Although the SWH and PV systems represent substantial electricity savings at a household level, this does NOT represent a big change in the total electricity savings at a national level. As the solar systems are introduced the energy requirements continue to grow and the solar contribution is not able to do a significant change at the established penetration levels. In 2010 the net electricity generation is 3,320.92 GWh and at the end of the projected period (2030) it is 8,811.39 GWh, demonstrating an annual growth rate of 5%; while the electricity savings in 2030 are 3,216.17 MWh, only 0.037% of the net generation projected for that year.

9.2.2 Load Curve

The expected change in the behavior of the load curve to reduce peak loads did NOT occur with the current projections. This is mainly due to the low share of electricity demand the solar systems represent. Even though there is was no modification of the peaks the solar systems still represent avoiding the use of fossil fuel to produce peak load electricity.

9.2.3 CO_2 Emissions Avoided

Even though the solar systems do not represent a big share of the total electricity generation, they are a significant way to avoid CO_2 emissions. By year 2030 the projected solar systems installed represent avoiding the emission of 2,497.99 tons of CO_2 per year, which will continue to represent this amount for the lifetime of device as long as fossil fuels are used to generate electricity in the grid, which is most likely to still be used for peak loads. It is also important to mention that the PV systems CO_2 avoidance will decrease as the PV production decreases; it is estimated that the PV arrays decrease their efficiency by 10% after 10 years, and 20% after 20 years.

9.2.4 Capital Use

The electricity savings from SWH and PV systems represent a decrease in the need of fossil fuels required to produce this electricity. In terms of fuel oil a SWH avoids the use of 93.34 gallons of fuel, while the PV system represents 87.54 gallons. At the current fuel cost (U$ 2.56952/ gal) this means U$ 239.84 for SWH and U$ 224.94 for PV systems. If a firm decision was to be taken to re orient this capital, and use it as an incentive discount for the solar systems it would mean that more people would venture in acquiring such systems, CO_2 emissions would be avoided, electricity prices would not be so dependent of fossil fuel prices, and a one-time incentive would mean savings for the electricity sector for all the subsequent years the system is operational; which actually mean greater savings in the following years since oil prices tend to increase. The problem is that this is not of the interest of the producers, transporters, or distributors, since giving that kind of power to the end users would represent a decrease in their sales.

Another capital reorientation would be that of the government loans used to subsidize the electricity sector in order to maintain a low electricity tariff. In 2009 the President obtained a loan for 20 million dollars and another one of 107 million dollars in this year (2011), in order to keep the increasing oil prices from reflecting on the electricity tariffs. If these loans were used as an incentive to promote other technologies, like the acquisition of SWH, the electricity demand would decrease, the price link between oil and electricity would separate a little, the country would be less dependent of oil imports, and it may even boost the economy. A re orientation of the capital used for fossil fuels to other sectors would represent a big change in the economy, energy security, and greater independence of the nation regarding oil use. The loan money could also be used to establish the manufacture of SWH, making them cheaper for local consumers, creating job opportunities, and maybe even increment the GDP for the exportation of these products.

9.3 Barriers

There are many barriers for the introduction of renewable energies, but one of the main obstacles is the interests of the institutions involved in the decisions. Various institutions, governmental and private corporations, have many interests with fossil fuel consumption. Institutions that should approve or promote clean energies do not have an interest to do so, since they directly participate in electricity market they rather continue to depend on fossil fuels and simply raise the prices when oil price increase. The only interest in renewable energies is when they acquire them, so they do not relinquish their power, so the users continue to depend on them for electricity production; but such changes rarely occurs since they require significant amount of “unnecessary” money for investment, and they already have the generation equipment that still operates; it would mean putting their current asset (U$) out of service.

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Annexes

Appendice 1: GHGs Global Warming Potential and Radiative Efficiency

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]1.4x10^{-5}	1	1	1	1
Methane[c]	CH_4	12[c]	3.7x10^{-4}	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03x10^{-3}	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990
Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	CH_3CClF_2	17.9	0.2	1,800	5,490	2,310	705
HCFC-225ca	$CHCl_2CF_2CF_3$	1.9	0.2		429	122	37
HCFC-225cb	$CHClFCF_2CClF_2$	5.8	0.32		2,030	595	181
Hydrofluorocarbons							
HFC-23	CHF_3	270	0.19	11,700	12,000	14,800	12,200
HFC-32	CH_2F_2	4.9	0.11	650	2,330	675	205
HFC-125	CHF_2CF_3	29	0.23	2,800	6,350	3,500	1,100
HFC-134a	CH_2FCF_3	14	0.16	1,300	3,830	1,430	435
HFC-143a	CH_3CF_3	52	0.13	3,800	5,890	4,470	1,590
HFC-152a	CH_3CHF_2	1.4	0.09	140	437	124	38
HFC-227ea	CF_3CHFCF_3	34.2	0.26	2,900	5,310	3,220	1,040
HFC-236fa	$CF_3CH_2CF_3$	240	0.28	6,300	8,100	9,810	7,660
HFC-245fa	$CHF_2CH_2CF_3$	7.6	0.28		3,380	1030	314
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	0.21		2,520	794	241
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	0.4	1,300	4,140	1,640	500
Perfluorinated compounds							
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	0.21		12,300	17,200	20,700
PFC-14	CF_4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C_2F_6	10,000	0.26	9,200	8,630	12,200	18,200

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon SAR‡ (100-yr)	20-yr	100-yr	500-yr
***Perfluorinated compounds** (continued)*							
PFC-218	C_3F_8	2,600	0.26	7,000	6,310	8,830	12,500
PFC-318	$c\text{-}C_4F_8$	3,200	0.32	8,700	7,310	10,300	14,700
PFC-3-1-10	C_4F_{10}	2,600	0.33	7,000	6,330	8,860	12,500
PFC-4-1-12	C_5F_{12}	4,100	0.41		6,510	9,160	13,300
PFC-5-1-14	C_6F_{14}	3,200	0.49	7,400	6,600	9,300	13,300
PFC-9-1-18	$C_{10}F_{18}$	>1,000[d]	0.56		>5,500	>7,500	>9,500
trifluoromethyl sulphur pentafluoride	SF_5CF_3	800	0.57		13,200	17,700	21,200
Fluorinated ethers							
HFE-125	CHF_2OCF_3	136	0.44		13,800	14,900	8,490
HFE-134	CHF_2OCHF_2	26	0.45		12,200	6,320	1,960
HFE-143a	CH_3OCF_3	4.3	0.27		2,630	756	230
HCFE-235da2	$CHF_2OCHClCF_3$	2.6	0.38		1,230	350	106
HFE-245cb2	$CH_3OCF_2CHF_2$	5.1	0.32		2,440	708	215
HFE-245fa2	$CHF_2OCH_2CF_3$	4.9	0.31		2,280	659	200
HFE-254cb2	$CH_3OCF_2CHF_2$	2.6	0.28		1,260	359	109
HFE-347mcc3	$CH_3OCF_2CF_2CF_3$	5.2	0.34		1,980	575	175
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	7.1	0.25		1,900	580	175
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	0.33	0.93		386	110	33
HFE-449sl (HFE-7100)	$C_4F_9OCH_3$	3.8	0.31		1,040	297	90
HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$	0.77	0.3		207	59	18
HFE-43-10pccc124 (H-Galden 1040x)	$CHF_2OCF_2OC_2F_4OCHF_2$	6.3	1.37		6,320	1,870	569
HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$	12.1	0.66		8,000	2,800	860
HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$	6.2	0.87		5,100	1,500	460
Perfluoropolyethers							
PFPMIE	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	800	0.65		7,620	10,300	12,400
Hydrocarbons and other compounds – Direct Effects							
Dimethylether	CH_3OCH_3	0.015	0.02		1	1	<<1
Methylene chloride	CH_2Cl_2	0.38	0.03		31	8.7	2.7
Methyl chloride	CH_3Cl	1.0	0.01		45	13	4

a: The CO_2 lifetime based on the revised version of the Bern Carbon cycle model

Extracted from:

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Appendice 2: Montreal Protocol Controlled Substances

Annex A: Controlled substances

Group	Substance	Ozone-Depleting Potential*
	Group I	
$CFCl_3$	(CFC-11)	1.0
CF_2Cl_2	(CFC-12)	1.0
$C_2F_3Cl_3$	(CFC-113)	0.8
$C_2F_4Cl_2$	(CFC-114)	1.0
C_2F_5Cl	(CFC-115)	0.6
	Group II	
CF_2BrCl	(halon-1211)	3.0
CF_3Br	(halon-1301)	10.0
$C_2F_4Br_2$	(halon-2402)	6.0

** These ozone depleting potentials are estimates based on existing knowledge and will be reviewed and revised periodically.*

Annex B: Controlled substances

Group	Substance	Ozone-Depleting Potential
	Group I	
CF_3Cl	(CFC-13)	1
C_2FCl_5	(CFC-111)	1
$C_2F_2Cl_4$	(CFC-112)	1
C_3FCl_7	(CFC-211)	1
$C_3F_2Cl_6$	(CFC-212)	1
$C_3F_3Cl_5$	(CFC-213)	1
$C_3F_4Cl_4$	(CFC-214)	1
$C_3F_5Cl_3$	(CFC-215)	1
$C_3F_6Cl_2$	(CFC-216)	1
C_3F_7Cl	(CFC-217)	1
CF_3Cl	(CFC-13)	1
C_2FCl_5	(CFC-111)	1
	Group II	
CCl_4	Carbon Tetrachloride	1.1
	Group III	
$C_2H_3Cl_3$*	1,1,1-trichloroethane* (methyl chloroform)	0.1

** This formula does not refer to 1,1,2-trichloroethane.*

Appendice 3: Ozone Depleting Substance's ODP and GWP

Class I Ozone Depleting Substances with a rated GWP

Chemical Name	Lifetime (Years)	ODP_4 (WMO 2006)	ODP_3 (MP)	GWP_2 (WMO 2006)	GWP_1 (TAR)
Group I (from section 602 of the CAA)					
CFC-11 (CCl_3F) Trichlorofluoromethane	45	1	1	4750	4600
CFC-12 (CCl_2F_2) Dichlorodifluoromethane	100	1	1	10890	10600
CFC-113 ($C_2F_3Cl_3$) 1,1,2-Trichlorotrifluoroethane	85	1	0.8	6130	6000
CFC-114 ($C_2F_4Cl_2$) Dichlorotetrafluoroethane	300	1	1	10040	9800
CFC-115 (C_2F_5Cl) Monochloropentafluoroethane	1700	0.44	0.6	7370	7200
Group II (from section 602 of the CAA)					
Halon 1211 (CF_2ClBr) Bromochlorodifluoromethane	16	7.1	3	1890	1300
Halon 1301 (CF_3Br) Bromotrifluoromethane	65	16	10	7140	6900
Halon 2402 ($C_2F_4Br_2$) Dibromotetrafluoroethane	20	11.5	6	1640	
Group III (from section 602 of the CAA)					
CFC-13 (CF_3Cl) Chlorotrifluoromethane	640		1	14420	14000
Group IV (from section 602 of the CAA)					
CCl_4 Carbon tetrachloride	26	0.73	1.1	1400	1800
Group V (from section 602 of the CAA)					
Methyl Chloroform ($C_2H_3Cl_3$) 1,1,1-trichloroethane	5	0.12	0.1	146	140
Group VI (listed in the Accelerated Phaseout Final Rule)					
Methyl Bromide (CH_3Br)	0.7	0.51	0.6	5	5

The substances displayed here are an extract from the United States of America's ***Environmental Protection Agency*** (EPA) and are organized according to EPA's classification. To view the complete listing please access the following URL: http://www.epa.gov/ozone/science/ods/classone.html

GWP_1: Values from the IPCC's *Third Assessment Report: Climate Change 2001*
GWP_2: Values from the WMO's *Scientific Assessment of Ozone Depletion: 2006*
ODP_3: Values from the *Montreal Protocol*
ODP_4: Values from the WMO's *Scientific Assessment of Ozone Depletion: 2006*

Class II Ozone Depleting Substances with a rated GWP

Chemical Name	Lifetime (Years)	ODP_4 (WMO 2006)	ODP_3 (Montreal)	GWP_2 (WMO 2006)	GWP_1 (TAR)
HCFC-21 ($CHFCl_2$) Dichlorofluoromethane	1.7		0.04	151	210
HCFC-22 (CHF_2Cl) Monochlorodifluoromethane	12	0.05	0.055	1810	1700
HCFC-123 ($C_2HF_3Cl_2$) Dichlorotrifluoroethane	1.3	0.02	0.02	77	120
HCFC-124 (C_2HF_4Cl) Monochlorotetrafluoroethane	5.8	0.022	0.022	609	620
HCFC-141b ($C_2H_3FCl_2$) Dichlorofluoroethane	9.3	0.12	0.11	725	700
HCFC-142b ($C_2H_3F_2Cl$) Monochlorodifluoroethane	17.9	0.07	0.065	2310	2400
HCFC-225ca ($C_3HF_5Cl_2$) Dichloropentafluoropropane	1.9	0.02	0.025	122	180
HCFC-225cb ($C_3HF_5Cl_2$) Dichloropentafluoropropane	5.8	0.03	0.033	595	620

The substances displayed here are an extract from the United States of America's ***Environmental Protection Agency*** (EPA) and are organized according to EPA's classification. To view the complete listing please access the following URL: http://www.epa.gov/ozone/science/ods/classtwo.html

GWP_1: Values from the IPCC's *Third Assessment Report: Climate Change 2001*
GWP_2: Values from the WMO's *Scientific Assessment of Ozone Depletion: 2006*
ODP_3: Values from the *Montreal Protocol*
ODP_4: Values from the WMO's *Scientific Assessment of Ozone Depletion: 2006*

Global Warming Potential of Ozone Depleting Substances Substitutes

Substance Name (Chemical Formula)	Atmospheric Lifetime (years)	GWP_1 GWP_2 GWP_3	Use
Sulfur hexafluoride (SF_6)	3.2 3.2 3.2	22.45 23.9 22.2	Cover gas in magnesium production, casting dielectric gas and insulator in electric power equipment fire suppression. Also used as a discharge agent in military systems and formerly an aerosol propellant.
HFC-23 (CHF_3)	270 264 260	12.24 11.7 12	Byproduct of HCFC-22 used in very-low temperature refrigeration blend and component in fire suppression. Also used for plasma etching and cleaning in semiconductor production.
HFC-32 (CH_2F_2)	4.9 5.6 5	543 650 550	Blend component of numerous refrigerants.
HFC-41 (CH_3F)	2.4 3.7 2.6	90 150 97	Not in use today.
HFC-43-10mee ($C_5H_2F_{10}$)	15.9 17.1 15	1.61 1.3 1.5	Cleaning solvent
HFC-125 (C_2HF_5)	29 32.6 29	3.45 2.8 3.4	Blend component of numerous refrigerants and a fire suppressant.
HFC-134 ($C_2H_2F_4$)	9.6 10.6 9.6	1.09 1 1.1	Not in use today.
HFC-134a (CH_2FCF_3)	14 14.6 13.8	1.32 1.3 1.3	One of the most widely used refrigerant blends, component of other refrigerants, foam blowing agent, fire suppressant and propellant in metered-dose inhalers and aerosols.
HFC-143 ($C_2H_3F_3$)	3.5 3.8 3.4	347 300 330	Not in use today.
HFC-143a ($C_2H_3F_3$)	52 48.3 52	4.4 3.8 4.3	Blend component of several refrigerant blends.
HFC-152a ($C_2H_4F_2$)	1.4 1.5 1.4	122 140 120	Blend component of several refrigerant blends and foam blowing agent. Also used as an aerosol propellant.
HFC-227ea (C_3HF_7)	34.2 36.5 33	3.66 2.9 3.5	Fire suppressant and propellant for metered-dose inhalers, and refrigerant.
HFC-236fa ($C_3H_2F_6$)	240 209 220	9.65 6.3 9.4	Refrigerant and fire suppressant.

Substance Name (Chemical Formula)	Atmospheric Lifetime (years)	GWP_1 GWP_2 GWP_3	Use
HFC-236ea ($C_3H_2F_6$)	10.7 -- 10	1.35 -- 1.2	Not in use today.
HFC-245ca ($C_3H_3F_5$)	6.2 6.6 5.9	682 560 640	Not in use today; possible refrigerant in the future.
HFC-245fa ($C_3H_3F_5$)	7.6 -- 7.2	1.02 -- 950	Foam blowing agent and possible refrigerant in the future.
HFC-365mfc ($C_4H_5F_5$)	8.6 -- 9.9	782 -- 950	Some use as a foam blowing agent; possible refrigerant in the future.
Perfluoromethane (CF_4)	50 50 50	5.82 6.5 5.7	Plasma etching and cleaning in semiconductor production and low temperature refrigerant.
Perfluoroethane (C_2F_6)	10 10 10	12.01 9.2 11.9	Plasma etching and cleaning in semiconductor production.
Perfluoropropane (C_3F_8)	2.6 2.6 2.6	8.69 7 8.6	Plasma etching and cleaning in semiconductor production, low temperature refrigerant and fire suppressant.
Perfluorobutane (C_4F_{10})	2.6 2.6 2.6	8.71 7 8.6	Fire suppressant and refrigerant where no other alternatives are technically feasible.
Perfluorocyclobutane (C_4F_8)	3.2 3.2 3.2	10.09 8.7 10	Not used much if any. Refrigerant where no other alternatives are technically feasible.
Perfluoropentane (C_5F_{12})	4.1 4.1 4.1	9.01 7.5 8.9	Not used much if any. Precision cleaning solvent-low use refrigerant where no other alternatives are technically feasible.
Perfluorohexane (C_6F_{14})	3.2 3.2 3.2	9.14 7.4 9	Precision cleaning solvent-low use, refrigerant and fire suppressant where no other alternatives are technically feasible.
Nitrogen trifluoride (NF_3)	740 -- --	10.97 -- --	Plasma etching and cleaning in semiconductor production.
HFE-7100 ($C_4F_9OCH_3$)	5 -- 5	397 -- 390	Cleaning solvent and heat transfer fluid.
HFE-7200 ($C_4F_9OC_2H_5$)	0.77 -- 0.77	56 -- 55	Cleaning solvent and heat transfer fluid.

Appendice 4: UNFCCC and the Kyoto Protocol

UNFCCC: Annex I Parties

Australia
Austria
Belarus*
Belgium
Bulgaria*
Canada
Croatia*
Czech Republic*
Denmark
European Economic Community
Estonia*
Finland
France
Germany
Greece
Hungary*
Iceland
Ireland
Italy
Japan
Latvia*
Liechtenstein
Lithuania*
Luxembourg
Monaco
Netherlands
New Zealand
Norway
Poland*
Portugal
Romania*
Russian Federation*
Slovakia*
Slovenia*
Spain
Sweden
Switzerland
Turkey
Ukraine*
United Kingdom of Great Britain and Northern Ireland
United States of America

* Countries that are undergoing the process of transition to a market economy

UNFCCC: Annex II Parties

Australia
Austria
Belgium
Canada
Denmark
European Economic Community
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Japan
Luxembourg
Netherlands
New Zealand
Norway
Portugal
Spain
Sweden
Switzerland
United Kingdom of Great Britain and Northern Ireland
United States of America

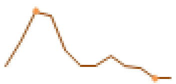
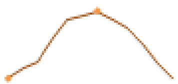
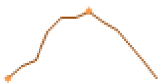
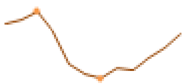
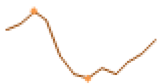
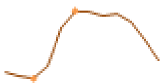
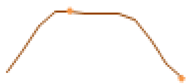
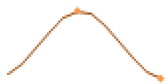
UNFCCC: Countries with Economies in Transition (EITs)

Belarus
Bulgaria
Croatia
Czech Republic
Estonia
Hungary
Latvia
Lithuania
Poland
Romania
Russian Federation
Slovakia
Slovenia
Ukraine

Appendice 5: Meteorological Data

The tables, data, and trendlines displayed in this sections are own elaboration of synthesized information from data collected by the meteorological station VADSTAT-UCA compiled in (Lopez de la Fuente, 2010).

Solar Data: Monthly Averages (1983-2004)

Month	Global Radiation	Horizontal Diffuse Radiation	Diffuse Radiation	Direct Normal Irradiance (DNI)	Sunshine (120 Wh/m^2)	Cloud Cover (Nubosity)	ET Horizontal Radiation	Daylight	Solar noon Horizontal Elevation
January	5142.55	1549.00	1925.45	5611.27	8.151691	2.9465818	8607.55	11.37587	0.83924
February	5751.50	1724.32	2121.64	5846.32	8.527727	2.7821909	9334.91	11.61208	0.90319
March	6478.05	1826.27	2225.59	6305.82	9.295355	2.6231591	10105.14	11.93137	0.96815
April	6370.73	2254.82	2667.82	5264.82	8.829436	3.2752591	10549.41	12.27295	0.99894
May	5513.45	2555.86	2883.00	3663.32	6.734500	5.1474636	10588.32	12.55739	0.99321
June	5134.36	2622.09	2909.09	3095.45	5.640595	5.9378136	10490.14	12.69750	0.98183
July	5137.23	2714.14	3006.86	2914.77	5.416159	5.9081000	10468.95	12.63301	0.98766
August	5368.86	2541.55	2845.55	3455.59	6.021014	5.6568682	10493.05	12.38671	0.99979
September	5142.68	2426.00	2707.18	3345.95	5.703186	5.7728091	10276.77	12.05632	0.98441
October	5070.64	2132.05	2466.27	3930.91	6.325595	5.4407864	9662.50	11.71587	0.92758
November	4836.55	1841.41	2215.91	4402.64	6.806582	4.5423955	8871.45	11.43492	0.85609
December	4848.27	1562.95	1944.59	5196.41	7.654777	3.5098045	8412.95	11.29978	0.81694
Average	***5399.57***	***2148.14***	***2493.25***	***4419.44***	***7.092218***	***4.4619360***	***9821.76***	***11.99782***	***0.93808***
Trendline									

Solar Data: Yearly Averages (1983-2004)

Year	Global Radiation	Horizontal Diffuse Radiation	Diffuse Radiation	Direct Normal Irradiance (DNI)	Sunshine (120 Wh/m^2)	Cloud Cover (Nubosity)	ET Horizontal Radiation	Daylight	Solar noon Horizontal Elevation
1983	5523.33	2331.17	2739.92	4209.75	7.3198333	4.9366917	9822.92	11.99781	0.981826
1984	5408.75	2163.67	2520.42	4393.50	7.1205667	5.1245500	9822.92	11.99781	0.981826
1985	5456.08	2117.92	2475.50	4568.50	7.1877667	5.2162167	9822.92	11.99781	0.981826
1986	5356.92	2085.08	2405.83	4526.17	7.3222000	4.9737917	9822.92	11.99781	0.981826
1987	5515.25	2102.83	2455.83	4663.50	7.5242667	5.3831750	9822.92	11.99781	0.981826
1988	5195.33	2142.83	2458.00	4142.42	7.2939000	5.5078667	9822.92	11.99781	0.981826
1989	5460.33	2016.67	2350.58	4764.83	7.3572667	4.1907750	9822.92	11.99781	0.981826
1990	5264.67	2124.83	2456.50	4218.33	6.7536750	4.5355667	9822.92	11.99781	0.981826
1991	5454.33	2294.75	2676.67	4242.42	7.2368750	3.7407833	9822.92	11.99781	0.981826
1992	5497.08	2337.08	2741.50	4203.25	7.2692167	3.3339667	9822.92	11.99781	0.981826
1993	5258.58	2165.08	2488.58	4277.17	6.9204167	3.6781000	9822.92	11.99781	0.981826
1994	5492.75	2219.00	2592.08	4536.50	7.2212667	4.2197250	9822.92	11.99781	0.981826
1995	5205.67	2113.25	2423.08	4258.17	6.6275167	4.2673333	9822.92	11.99781	0.981826
1996	5346.83	2045.67	2361.33	4569.92	6.9894083	3.7223417	9822.92	11.99781	0.981826
1997	5345.83	2123.42	2462.50	4440.25	6.9855500	3.7750917	9822.92	11.99781	0.981826
1998	5246.83	2231.73	2488.17	4112.67	6.8455917	4.0291750	9797.50	11.99781	0.981826
1999	5370.42	2156.50	2504.33	4329.75	6.8059417	4.2579667	9822.92	11.99781	0.981826
2000	5441.58	2111.00	2458.17	4500.00	7.0417917	4.2902417	9822.92	11.99781	0.981826
2001	5520.42	2095.50	2453.25	4575.17	7.1546667	4.5482917	9822.92	12.05435	0.981826
2002	5389.58	2087.83	2424.25	4502.08	6.7251364	4.7572500	9822.92	11.99781	0.981826
2003	5549.58	2150.17	2519.33	4540.83	7.2354333	4.7234083	9822.92	11.99781	0.981826
2004	5490.42	2050.08	2395.58	4652.50	7.1016083	4.7721917	9822.92	11.99784	0.981826
Average	***5399.57***	***2148.14***	***2493.25***	***4419.44***	***7.0941202***	***4.4538409***	***9821.76***	***12.00018***	***0.981826***
Trendline									

Appendice 6: CO_2 Emission Calculation Worksheets

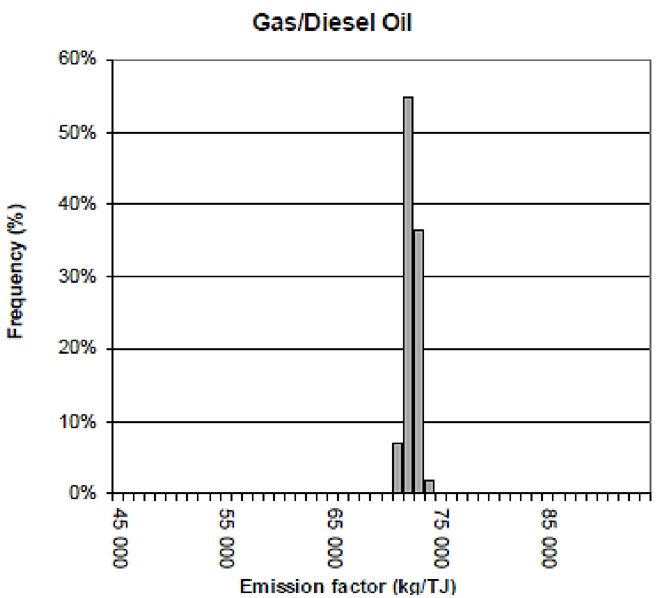
All the tables and figures displayed in this section are an extract from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy.*

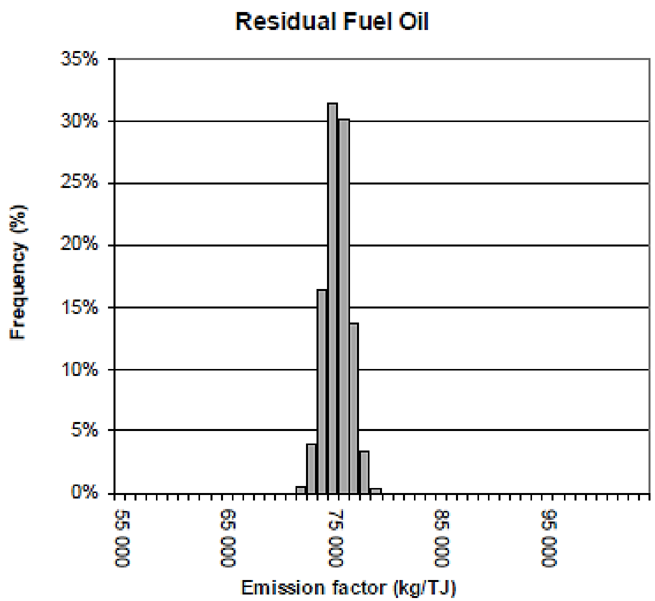
Carbon Content and Effective CO_2 Emission Factor by Fuel Type

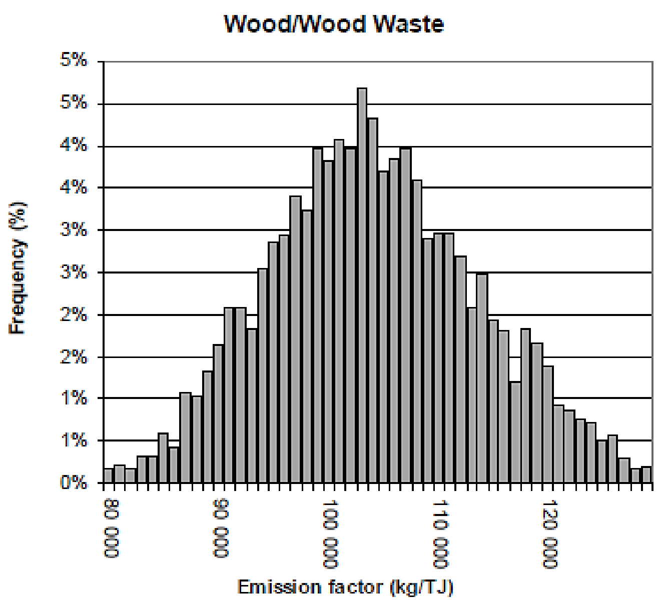
Fuel type	Default carbon content (kg/GJ)	Default carbon oxidation factor	Effective CO_2 emission factor (kg/TJ)		
			Default Value	95% confidence interval	
	A	B	C=A*B*44/12*1000	Lower	Upper
Gas/Diesel Oil	20.2	1	74 100	72 600	74 800
Residual Fuel Oil	21.1	1	77 400	75 500	78 800
Other Primary Solid Biomass	27.3	1	100 000	84 700	117 000

The values for other primary solid biomass are approximate according to expert assessment given in the IPCC GHG inventory guidelines.

Probability Distribution Functions (PDFs) per Fuel Type for CO2 Emissions from the Combustion







Default Emission Factors for Stationary Combustion in the Energy Industries

Fuel type	CO_2			CH_4			N_2O		
	Default Factor	Lower	Upper	Default Factor	Lower	Upper	Default Factor	Lower	Upper
Gas/Diesel Oil	74,100	72,600	74,800	3	1	10	0.6	0.2	2
Residual Fuel Oil	77,400	75,500	78,800	3	1	10	0.6	0.2	2
Wood / Wood Waste	112,000	95,000	132,000	30	10	100	4	1.5	15
Other Primary Solid Biomass	100,000	84,700	117,000	30	10	100	4	1.5	15

The values for wood and other primary solid biomass are approximates according to expert assessment given in the IPCC GHG inventory guidelines.

Tier 1 Worksheet Extract

Category Code: 1.A.1.a.i
Sector: (1) Energy **Category:** (A) Fuel combustion activities **Industry:** (1) Energy Industries
Activity: (a) Main Activity Electricity and Heat Production
Application: (i) Electricity Generation

Fuel type	Energy Consumption			CO_2		CH_4		N_2O	
	A Consumption (Mass, Volume or Energy unit) *Gg*	B Conversion Factor (TJ/unit)	C Consumption (TJ) *C=A*B*	D CO_2 Emission Factor (kg CO_2/TJ)	E CO_2 Emissions (Gg CO_2) *E=C*D/106*	F CH_4 Emission Factor (kg CH_4/TJ)	G CH_4 Emissions (Gg CH_4) *G=C*F/106*	H N_2O Emission Factor (kg N_2O /TJ)	I N_2O Emissions (Gg N_2O) *I=C*H/106*
Gas / Diesel Oil	8.1760	43.0	351.5663	74,100	26.0511	3	0.0011	0.6	0.0002
Residual Fuel Oil	541.8471	40.4	21,890.6229	77,400	1,694.3342	3	0.0657	0.6	0.0131
Wood / Wood Waste	19.5320	15.6	304.6994	112,000	34.1263	30	0.0091	4	0.0012
Other Primary Solid Biomass	1,167.9500	11.6	13,548.2200	100,000	1,354.8220	30	0.4064	4	0.0542
				TOTAL	3,109.3336	TOTAL	0.4823	TOTAL	0.0688

The table above contains the emissions of Nicaragua's electricity sector for the year 2010; calculated through the Tier 1 methodology and IPCC values

Appendice 7: Projections and Estimations

GHG Emissions and GWP Potential from Fossil Fuel Combustion in the Electricity Sector

Own calculations for GHG emissions and GWP, obtained from fossil fuel consumption data provided by the National Energy Institute; (INE, 2011c)

Year	Net Generation (GWh)	Sales (GWh)	Fossil Fuel Consumption		GHG Emissions (tons)			GWP 100 years (CO2e x 10^6)		
			Diesel	Fuel Oil	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1991	1,307.57	1,082.93	87.40	47,585.10	564,311	21.87	4.37	564.31	0.46	1.36
1992	1,427.01	1,110.99	51.59	62,707.53	742,881	28.79	5.76	742.88	0.60	1.79
1993	1,536.39	1,106.99	1,852.70	57,124.69	698,522	27.11	5.42	698.52	0.57	1.68
1994	1,541.43	1,071.34	10,988.73	56,674.33	803,385	31.37	6.27	803.38	0.66	1.94
1995	1,610.38	1,113.94	8,968.10	68,582.00	919,962	35.84	7.17	919.96	0.75	2.22
1996	1,719.87	1,195.60	2,420.62	82,190.91	1,002,076	38.89	7.78	1,002.08	0.82	2.41
1997	1,703.66	1,352.19	9,107.10	79,614.71	1,052,231	40.97	8.19	1,052.23	0.86	2.54
1998	1,966.30	1,382.23	25,414.79	98,197.65	1,468,888	57.46	11.49	1,468.89	1.21	3.56
1999	1,985.02	1,466.37	11,328.08	99,642.09	1,316,080	51.25	10.25	1,316.08	1.08	3.18
2000	2,095.53	1,500.00	4,929.67	116,049.43	1,433,117	55.65	11.13	1,433.12	1.17	3.45
2001	2,300.11	1,561.35	3,982.99	127,558.11	1,557,924	60.47	12.09	1,557.92	1.27	3.75
2002	2,424.96	1,655.70	972.33	128,004.93	1,526,900	59.20	11.84	1,526.90	1.24	3.67
2003	2,561.11	1,746.79	1,760.50	128,480.58	1,542,037	59.81	11.96	1,542.04	1.26	3.71
2004	2,647.35	1,843.59	2,268.03	133,464.66	1,607,154	62.34	12.47	1,607.15	1.31	3.87
2005	2,738.39	1,945.78	2,068.12	124,671.75	1,500,663	58.21	11.64	1,500.66	1.22	3.61
2006	2,828.71	2,051.36	5,020.33	136,273.13	1,673,595	64.97	12.99	1,673.59	1.36	4.03
2007	2,862.75	2,095.20	17,697.62	130,457.76	1,757,666	68.50	13.70	1,757.67	1.44	4.25
2008	3,036.05	2,228.93	5,329.32	133,486.84	1,644,341	63.85	12.77	1,644.34	1.34	3.96
2009	3,109.26	2,297.35	3,786.04	147,292.01	1,789,136	69.43	13.89	1,789.14	1.46	4.30
2010	3,320.92	2,452.61	2,159.86	143,140.86	1,720,385	66.73	13.35	1,720.39	1.40	4.14

Load Curve Projections for a Typical Labor Day

SIN: Calculated from estimated annual growth rates from the loads of 2006 and 2011. **SWH & PV:** Calculated from energy generated X number of systems.

Time	2011			2020			2030			2040			2050		
	SIN	SWH	PV	SIN	SWH	PV	SIN	SWH	PV	SIN	SWH	PV	SIN	SWH	PV
00:00	327.20	0.00	0.00	384.19	0.00	0.00	459.22	0.00	0.00	548.91	0.00	0.00	656.11	0.00	0.00
01:00	309.40	0.00	0.00	363.29	0.00	0.00	434.24	0.00	0.00	519.05	0.00	0.00	620.42	0.00	0.00
02:00	304.40	0.00	0.00	357.42	0.00	0.00	427.22	0.00	0.00	510.66	0.00	0.00	610.39	0.00	0.00
03:00	293.90	0.00	0.00	345.09	0.00	0.00	412.48	0.00	0.00	493.04	0.00	0.00	589.34	0.00	0.00
04:00	293.90	0.00	0.00	345.09	0.00	0.00	412.48	0.00	0.00	493.04	0.00	0.00	589.34	0.00	0.00
05:00	300.60	0.00	0.00	352.95	0.00	0.00	421.89	0.00	0.00	504.28	0.00	0.00	602.77	0.00	0.00
06:00	283.92	0.08	0.00	332.76	0.69	0.01	395.89	2.65	0.05	470.37	5.95	0.11	558.68	10.61	0.19
07:00	297.74	0.05	0.00	349.16	0.46	0.05	416.00	1.76	0.19	495.19	3.97	0.43	589.33	7.07	0.75
08:00	321.20	0.00	0.00	377.06	0.00	0.09	450.48	0.00	0.32	538.13	0.00	0.71	642.83	0.00	1.25
09:00	338.80	0.00	0.00	397.70	0.00	0.11	475.09	0.00	0.41	567.47	0.00	0.90	677.79	0.00	1.58
10:00	345.20	0.00	0.00	405.20	0.00	0.12	484.02	0.00	0.46	578.08	0.00	1.03	690.40	0.00	1.81
11:00	351.80	0.00	0.00	412.94	0.00	0.13	493.26	0.00	0.48	589.11	0.00	1.07	703.55	0.00	1.89
12:00	356.10	0.00	0.00	418.00	0.00	0.12	499.31	0.00	0.47	596.35	0.00	1.04	712.24	0.00	1.83
13:00	360.40	0.00	0.00	423.06	0.00	0.11	505.39	0.00	0.43	603.66	0.00	0.94	721.02	0.00	1.66
14:00	340.70	0.00	0.00	399.95	0.00	0.09	477.83	0.00	0.34	570.80	0.00	0.75	681.86	0.00	1.32
15:00	355.50	0.00	0.00	417.36	0.00	0.06	498.71	0.00	0.23	595.88	0.00	0.50	711.97	0.00	0.89
16:00	350.00	0.00	0.00	410.93	0.00	0.03	491.12	0.00	0.10	586.94	0.00	0.22	701.45	0.00	0.38
17:00	369.07	0.03	0.00	433.16	0.23	0.00	517.14	0.88	0.00	617.21	1.98	0.00	736.59	3.54	0.00
18:00	402.80	0.00	0.00	472.95	0.00	0.00	565.32	0.00	0.00	675.73	0.00	0.00	807.71	0.00	0.00
19:00	480.37	0.03	0.00	563.84	0.23	0.00	673.35	0.88	0.00	803.93	1.98	0.00	959.77	3.54	0.00
20:00	478.80	0.00	0.00	562.19	0.00	0.00	671.99	0.00	0.00	803.23	0.00	0.00	960.10	0.00	0.00
21:00	446.70	0.00	0.00	524.50	0.00	0.00	626.94	0.00	0.00	749.38	0.00	0.00	895.73	0.00	0.00
22:00	375.00	0.00	0.00	440.31	0.00	0.00	526.31	0.00	0.00	629.10	0.00	0.00	751.96	0.00	0.00
23:00	339.30	0.00	0.00	398.39	0.00	0.00	476.20	0.00	0.00	569.21	0.00	0.00	680.37	0.00	0.00

Scenario Data

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Nicaragua Net Generation (GWh)	3,487.0	3,661.3	3,844.4	4,036.6	4,238.4	4,450.4	4,672.9	4,906.5	5,151.8	5,409.4	5,679.9	5,963.9	6,262.1	6,575.2	6,904.0	7,249.2	7,611.6	7,992.2	8,391.8	8,811.4
- Electricity Sales: SIN (GWh)	2,580.4	2,709.4	2,844.8	2,987.1	3,136.4	3,293.3	3,457.9	3,630.8	3,812.4	4,003.0	4,203.1	4,413.3	4,633.9	4,865.6	5,108.9	5,364.4	5,632.6	5,914.2	6,209.9	6,520.4
- Electricity Sales: Residential (GWh)	877.32	921.19	967.25	1,015.61	1,066.39	1,119.71	1,175.69	1,234.48	1,296.20	1,361.01	1,429.06	1,500.52	1,575.54	1,654.32	1,737.03	1,823.89	1,915.08	2,010.83	2,111.38	2,216.95
Residential Connections	753,621	779,998	807,298	835,553	864,797	895,065	926,393	958,816	992,375	1,027,108	1,063,057	1,100,264	1,138,773	1,178,630	1,219,882	1,262,578	1,306,768	1,352,505	1,399,843	1,448,837
- Managua (Department)	280,254	290,063	300,215	310,723	321,598	332,854	344,504	356,561	369,041	381,957	395,326	409,162	423,483	438,305	453,646	469,523	485,957	502,965	520,569	538,789
- Managua (Municipality)	212,275	219,705	227,394	235,353	243,590	252,116	260,940	270,073	279,526	289,309	299,435	309,915	320,762	331,989	343,608	355,635	368,082	380,965	394,299	408,099
- Subsidized	131,706	136,316	141,087	146,025	151,136	156,425	161,900	167,567	173,432	179,502	185,784	192,287	199,017	205,982	213,192	220,653	228,376	236,370	244,642	253,205
- Not Subsidized	80,569	83,389	86,308	89,328	92,455	95,691	99,040	102,506	106,094	109,807	113,651	117,628	121,745	126,006	130,417	134,981	139,706	144,595	149,656	154,894
- Possible SWH Customers	8,057	8,339	8,631	8,933	9,245	9,569	9,904	10,251	10,609	10,981	11,365	11,763	12,175	12,601	13,042	13,498	13,971	14,460	14,966	15,489
Solar Water Heaters (SWH)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Annual Sales Volume	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114
Solar Water Heaters Operating	36	42	54	72	96	126	162	204	252	306	366	432	504	582	666	756	852	954	1,062	1,176
- Electricity Savings (MWh)	64.0	74.7	96.1	128.1	170.8	224.2	288.2	362.9	448.3	544.4	651.1	768.5	896.6	1,035.4	1,184.8	1,344.9	1,515.7	1,697.2	1,889.3	2,092.1
- Fuel Oil No. 6 Savings (gallons)	4,202	4,903	6,304	8,405	11,206	14,708	18,911	23,813	29,417	35,720	42,724	50,428	58,833	67,938	77,744	88,250	99,456	111,363	123,970	137,277
- Economical Savings (U$)	10,798	12,598	16,197	21,596	28,795	37,793	48,591	61,189	75,586	91,783	109,780	129,577	151,173	174,569	199,764	226,759	255,554	286,148	318,543	352,736
- CO_2 Reduction (tons)	49.7	58.0	74.6	99.5	132.6	174.1	223.8	281.9	348.2	422.8	505.7	596.9	696.4	804.2	920.2	1,044.6	1,177.2	1,318.2	1,467.4	1,624.9
- CH_4 Reduction (tons)	1.93	2.25	2.89	3.86	5.14	6.75	8.68	10.93	13.50	16.39	19.60	23.14	26.99	31.17	35.67	40.49	45.63	51.09	56.88	62.98
- N_2O Reduction (tons)	0.39	0.45	0.58	0.77	1.03	1.35	1.74	2.19	2.70	3.28	3.92	4.63	5.40	6.23	7.13	8.10	9.13	10.22	11.38	12.60
Photovoltaic Systems (PV)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Annual Sales Volume	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80
PV Systems Operating	6	14	26	42	62	86	114	146	182	222	266	314	366	422	482	546	614	686	762	842
- Electricity Savings (MWh)	8.0	18.7	34.7	56.1	82.8	114.8	152.2	194.9	243.0	296.4	355.1	419.2	488.6	563.4	643.5	728.9	819.7	915.8	1,017.3	1,124.1
- Fuel Oil No. 6 Savings (gallons)	526	1,226	2,278	3,679	5,431	7,533	9,986	12,789	15,943	19,447	23,301	27,506	32,061	36,967	42,222	47,829	53,785	60,093	66,750	73,758
- Economical Savings (U$)	1,351	3,151	5,852	9,454	13,955	19,357	25,660	32,863	40,966	49,969	59,873	70,677	82,381	94,986	108,491	122,897	138,203	154,409	171,515	189,522
- CO_2 Reduction (tons)	6.2	14.5	27.0	43.5	64.3	89.2	118.2	151.4	188.7	230.2	275.8	325.6	379.5	437.6	499.8	566.1	636.6	711.3	790.1	873.1
- CH_4 Reduction (tons)	0.24	0.56	1.04	1.69	2.49	3.46	4.58	5.87	7.31	8.92	10.69	12.62	14.71	16.96	19.37	21.94	24.68	27.57	30.62	33.84
- N_2O Reduction (tons)	0.05	0.11	0.21	0.34	0.50	0.69	0.92	1.17	1.46	1.78	2.14	2.52	2.94	3.39	3.87	4.39	4.94	5.51	6.12	6.77
PV and SWH	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Total Solar Systems Operating	42	56	80	114	158	212	276	350	434	528	632	746	870	1,004	1,148	1,302	1,466	1,640	1,824	2,018
- Electricity Savings (MWh)	72.1	93.4	130.8	184.2	253.6	339.0	440.4	557.8	691.3	840.7	1,006.2	1,187.7	1,385.2	1,598.7	1,828.3	2,073.8	2,335.4	2,613.0	2,906.6	3,216.2
- Fuel Oil No. 6 Savings (gallons)	4,728	6,129	8,581	12,084	16,637	22,242	28,897	36,603	45,359	55,167	66,025	77,934	90,894	104,905	119,966	136,078	153,241	171,455	190,720	211,035
- Economical Savings (U$)	12,149	15,749	22,049	31,050	42,750	57,151	74,251	94,052	116,552	141,753	169,653	200,254	233,554	269,555	308,255	349,656	393,757	440,557	490,058	542,259
- CO_2 Reduction (tons)	56.0	72.5	101.6	143.0	196.9	263.3	342.0	433.3	536.9	653.0	781.5	922.5	1,075.9	1,241.7	1,420.0	1,610.7	1,813.9	2,029.5	2,257.5	2,498.0
- CH_4 Reduction (tons)	2.17	2.81	3.94	5.54	7.63	10.20	13.26	16.79	20.81	25.31	30.29	35.76	41.70	48.13	55.04	62.43	70.31	78.66	87.50	96.82
- N_2O Reduction (tons)	0.43	0.56	0.79	1.11	1.53	2.04	2.65	3.36	4.16	5.06	6.06	7.15	8.34	9.63	11.01	12.49	14.06	15.73	17.50	19.36

Scenarios Results

Business as Usual	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
- Electricity Consumption (GWh)	2,580	2,709	2,845	2,987	3,136	3,293	3,458	3,631	3,812	4,003	4,203	4,413	4,634	4,866	5,109	5,364	5,633	5,914	6,210	6,520
- Diesel Consumption (10^3 gal)	2,181	2,203	2,225	2,248	2,270	2,293	2,316	2,339	2,362	2,386	2,410	2,434	2,458	2,483	2,508	2,533	2,558	2,584	2,609	2,635
- Fuel Oil Consumption (10^3 gal)	144,572	146,018	147,478	148,953	150,442	151,947	153,466	155,001	156,551	158,117	159,698	161,295	162,908	164,537	166,182	167,844	169,522	171,218	172,930	174,659
- CO2 Emissions (tons)	1,737,589	1,754,965	1,772,515	1,790,240	1,808,142	1,826,224	1,844,486	1,862,931	1,881,560	1,900,376	1,919,379	1,938,573	1,957,959	1,977,539	1,997,314	2,017,287	2,037,460	2,057,834	2,078,413	2,099,197
- CH4 Reduction (tons)	67,394	68,068	68,748	69,436	70,130	70,832	71,540	72,255	72,978	73,708	74,445	75,189	75,941	76,700	77,467	78,242	79,025	79,815	80,613	81,419
- N2O Reduction (tons)	13,479	13,614	13,750	13,887	14,026	14,166	14,308	14,451	14,596	14,742	14,889	15,038	15,188	15,340	15,493	15,648	15,805	15,963	16,123	16,284
Solar Water Heaters	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
- Electricity Consumption	2,580	2,709	2,845	2,987	3,136	3,293	3,458	3,630	3,812	4,002	4,202	4,413	4,633	4,865	5,108	5,363	5,631	5,913	6,208	6,518
- Diesel Consumption (10^3 gal)	2,181	2,203	2,225	2,248	2,270	2,293	2,316	2,339	2,362	2,386	2,410	2,434	2,458	0	0	0	0	0	0	0
- Fuel Oil Consumption (10^3 gal)	133,774	133,420	131,281	127,357	121,648	114,154	104,875	93,812	80,965	66,333	49,918	31,718	11,735	0	0	0	0	0	0	0
- CO2 Emissions	1,609,774	1,605,848	1,580,793	1,534,610	1,467,303	1,378,872	1,269,320	1,138,647	986,857	813,950	619,930	404,796	168,553	0	0	0	0	0	0	0
- CH4 Reduction (tons)	62,440	62,288	61,317	59,528	56,919	53,492	49,247	44,182	38,299	31,598	24,078	15,740	6,584	0	0	0	0	0	0	0
- N2O Reduction (tons)	12,488	12,458	12,263	11,906	11,384	10,698	9,849	8,836	7,660	6,320	4,816	3,148	1,317	0	0	0	0	0	0	0
PV Systems	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
- Electricity Consumption	2,580	2,709	2,845	2,987	3,136	3,293	3,458	3,631	3,812	4,003	4,203	4,413	4,633	4,865	5,108	5,364	5,632	5,913	6,209	6,519
- Diesel Consumption (10^3 gal)	2,181	2,203	2,225	2,248	2,270	2,293	2,316	2,339	2,362	2,386	2,410	2,434	2,458	2,483	2,508	2,533	2,558	2,584	2,609	2,635
- Fuel Oil Consumption (10^3 gal)	144,047	144,792	145,201	145,274	145,011	144,413	143,480	142,212	140,608	138,670	136,397	133,789	130,847	127,570	123,960	120,015	115,737	111,125	106,180	100,901
- CO2 Emissions	1,731,368	1,740,449	1,745,556	1,746,691	1,743,855	1,737,051	1,726,281	1,711,545	1,692,846	1,670,187	1,643,567	1,612,990	1,578,458	1,539,972	1,497,534	1,451,146	1,400,811	1,346,529	1,288,304	1,226,137
- CH4 Reduction (tons)	67,153	67,505	67,704	67,748	67,639	67,375	66,958	66,388	65,663	64,786	63,754	62,570	61,232	59,741	58,096	56,299	54,348	52,245	49,989	47,580
- N2O Reduction (tons)	13,431	13,501	13,541	13,550	13,528	13,475	13,392	13,278	13,133	12,957	12,751	12,514	12,246	11,948	11,619	11,260	10,870	10,449	9,998	9,516
SWH & PV Systems	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
- Electricity Consumption	2,580	2,709	2,845	2,987	3,136	3,293	3,457	3,630	3,812	4,002	4,202	4,412	4,633	4,864	5,107	5,362	5,630	5,912	6,207	6,517
- Diesel Consumption (10^3 gal)	2,181	2,203	2,225	2,248	2,270	2,293	2,316	2,339	2,362	2,386	2,410	2,434	2,458	2,483	2,508	2,533	2,558	0	0	0
- Fuel Oil Consumption (10^3 gal)	139,844	139,889	138,897	136,869	133,805	129,705	124,570	118,398	111,192	102,950	93,673	83,360	72,014	59,632	46,216	31,766	16,281	0	0	0
- CO2 Emissions	1,681,625	1,682,415	1,670,942	1,647,205	1,611,208	1,562,952	1,502,439	1,429,670	1,344,648	1,247,374	1,137,850	1,016,079	882,061	735,799	577,295	406,551	223,568	0	0	0
- CH4 Reduction (tons)	65,225	65,256	64,812	63,892	62,497	60,627	58,282	55,462	52,167	48,398	44,153	39,434	34,240	28,571	22,428	15,811	8,719	0	0	0
- N2O Reduction (tons)	13,045	13,051	12,962	12,778	12,499	12,125	11,656	11,092	10,433	9,680	8,831	7,887	6,848	5,714	4,486	3,162	1,744	0	0	0

Population and Household Estimates (1990-2050)

	Population				Households			
	Nicaragua	Managua (D)	Managua (M)	Managua (U)	Nicaragua	Managua (D)	Managua (M)	Managua (U)
Share (%)	**Ref: 2005**	23.17%	74.23%	96.95%	**Ref: 2005**	24.84%	73.70%	96.60%
Growth	**1.05%**				**2.67%**			
1990	*4,136,603*	958,544	711,512	689,808	713,207	177,182	130,584	126,149
1991	4,180,037	968,608	718,983	697,051	720,696	179,042	131,955	127,474
1992	4,223,928	978,779	726,532	704,370	728,263	180,922	133,340	128,812
1993	4,268,279	989,056	734,161	711,766	735,910	182,822	134,741	130,165
1994	4,313,096	999,441	741,870	719,240	743,637	184,741	136,155	131,532
1995	**4,357,099**	**1,093,760**	**835,335**	**803,773**	**751,637**	**202,358**	**155,944**	**150,045**
1996	4,357,099	1,009,638	749,438	726,578	771,706	191,714	141,294	136,496
1997	4,357,099	1,009,638	749,438	726,578	792,310	196,833	145,067	140,141
1998	4,357,099	1,009,638	749,438	726,578	813,465	202,088	148,940	143,882
1999	4,357,099	1,009,638	749,438	726,578	835,184	207,484	152,917	147,724
2000	*5,098,028*	1,181,327	876,881	850,133	857,484	213,024	157,000	151,668
2001	5,098,028	1,181,327	876,881	850,133	880,379	218,712	161,192	155,718
2002	5,098,028	1,181,327	876,881	850,133	903,885	224,551	165,496	159,876
2003	5,098,028	1,181,327	876,881	850,133	928,019	230,547	169,914	164,144
2004	5,098,028	1,181,327	876,881	850,133	952,797	236,703	174,451	168,527
2005	**5,450,392**	**1,262,978**	**937,489**	**908,892**	**978,335**	**243,047**	**179,127**	**173,044**
2006	*5,522,606*	*1,328,973*	*975,954*	946,184	1,004,457	249,536	183,910	177,664
2007	*5,595,538*	*1,347,123*	*985,322*	955,266	1,031,276	256,199	188,820	182,408
2008	*5,668,877*	*1,365,316*	*994,560*	964,222	1,058,811	263,039	193,862	187,278
2009	*5,742,309*	*1,383,475*	*1,005,705*	975,027	1,087,081	270,063	199,038	192,279
2010	*5,815,526*	*1,401,276*	*1,014,384*	983,441	1,116,106	277,273	204,352	197,412
2011	*5,888,945*	*1,417,390*	*1,021,679*	990,514	1,145,906	284,677	209,808	202,683
2012	*5,962,782*	*1,433,493*	*1,028,808*	997,425	1,176,502	292,277	215,410	208,095
2013	*6,036,395*	*1,449,324*	*1,035,582*	1,003,993	1,207,914	300,081	221,162	213,651
2014	*6,109,149*	*1,464,900*	*1,042,012*	1,010,227	1,240,166	308,093	227,067	219,356
2015	*6,180,406*	*1,480,270*	*1,048,134*	1,016,162	1,273,278	316,319	233,129	225,212
2016	*6,250,194*	*1,493,995*	*1,052,930*	1,020,812	1,307,274	324,765	239,354	231,226
2017	*6,318,939*	*1,507,331*	*1,057,296*	1,025,044	1,342,179	333,436	245,744	237,399
2018	*6,386,596*	*1,520,448*	*1,061,355*	1,028,980	1,378,015	342,339	252,306	243,738
2019	*6,453,124*	*1,532,784*	*1,064,715*	1,032,237	1,414,808	351,480	259,042	250,246
2020	*6,518,478*	*1,542,795*	*1,066,313*	1,033,786	1,452,583	360,864	265,959	256,927
2021	6,518,478	1,542,795	1,145,193	1,110,260	1,491,367	370,499	273,060	263,787
2022	6,518,478	1,542,795	1,145,193	1,110,260	1,531,187	380,392	280,351	270,830
2023	6,518,478	1,542,795	1,145,193	1,110,260	1,572,069	390,548	287,836	278,061
2024	6,518,478	1,542,795	1,145,193	1,110,260	1,614,044	400,976	295,521	285,486

		Population				Households			
		Nicaragua	Managua (D)	Managua (M)	Managua (U)	Nicaragua	Managua (D)	Managua (M)	Managua (U)
0.81%	2025	*6,827,935*	*1,591,869*	1,181,620	1,145,576	1,627,128	404,226	297,917	287,800
	2026	6,883,288	1,595,012	1,183,953	1,147,838	1,640,319	407,503	300,332	290,133
	2027	6,939,090	1,607,943	1,193,551	1,157,143	1,653,617	410,807	302,767	292,485
	2028	6,995,344	1,620,978	1,203,227	1,166,524	1,667,023	414,137	305,221	294,856
	2029	7,052,054	1,634,119	1,212,981	1,175,981	1,680,537	417,495	307,696	297,247
0.69%	2030	*7,109,224*	1,647,367	1,222,815	1,185,514	1,692,064	420,358	309,806	299,286
	2031	7,157,988	1,658,666	1,231,202	1,193,646	1,703,671	423,242	311,931	301,339
	2032	7,207,087	1,670,044	1,239,648	1,201,834	1,715,357	426,145	314,071	303,405
	2033	7,256,523	1,681,499	1,248,151	1,210,077	1,727,123	429,068	316,225	305,487
	2034	7,306,298	1,693,033	1,256,712	1,218,378	1,738,970	432,011	318,394	307,582
0.58%	2035	*7,356,414*	1,704,646	1,265,332	1,226,735	1,749,098	434,527	320,249	309,373
	2036	7,399,258	1,714,574	1,272,702	1,233,879	1,759,284	437,058	322,114	311,175
	2037	7,442,351	1,724,560	1,280,114	1,241,065	1,769,530	439,603	323,990	312,988
	2038	7,485,696	1,734,603	1,287,569	1,248,293	1,779,836	442,163	325,877	314,810
	2039	7,529,292	1,744,706	1,295,068	1,255,564	1,790,202	444,738	327,775	316,644
0.50%	2040	*7,573,143*	1,754,867	1,302,611	1,262,876	1,799,163	446,965	329,415	318,229
	2041	7,611,050	1,763,651	1,309,131	1,269,197	1,808,169	449,202	331,064	319,822
	2042	7,649,148	1,772,479	1,315,684	1,275,550	1,817,219	451,450	332,721	321,423
	2043	7,687,435	1,781,351	1,322,269	1,281,935	1,826,316	453,710	334,387	323,031
	2044	7,725,915	1,790,268	1,328,888	1,288,352	1,835,457	455,981	336,061	324,648
0.43%	2045	*7,764,587*	1,799,229	1,335,540	1,294,801	1,844,645	458,264	337,743	326,273
	2046	7,797,877	1,806,943	1,341,266	1,300,352	1,852,553	460,228	339,191	327,672
	2047	7,831,310	1,814,690	1,347,016	1,305,927	1,860,496	462,202	340,645	329,077
	2048	7,864,886	1,822,470	1,352,792	1,311,526	1,868,473	464,183	342,106	330,488
	2049	7,898,606	1,830,284	1,358,592	1,317,149	1,876,484	466,173	343,572	331,905
	2050	*7,932,471*	1,838,131	1,364,416	1,322,796	1,884,529	468,172	345,045	333,328

Values in *italic* were obtained from:

Estimates and Projections (1950-2050); (INIDE, 2007b)

Values in **bold** were obtained from:

Census 2005, Nicaragua; (INIDE, 2007a)

Values without formatting were estimated from growth rates calculated from the values provided by (INIDE, 2007b) and share percentages calculated from (INIDE, 2007a).

Digital Media: DVD

The attached DVD contains the following:

- A digital copy of this document
- Electricity statistics for Nicaragua
- Fossil fuel statistics
- Detailed meteorological data
- Full data sets of the scenario projections
- Montreal Protocol
- Kyoto Protocol
- UNFCCC Handbook
- IPCC AR4 Assessment Report
- Trial versions of modeling and simulation softwares:
    - EnergyPLAN
    - Homer
    - Insel
    - LEAP
    - PV*SOL
    - RetScreen
    - T*SOL
    - SMARTS
- And many other sources used during this investigation…