Modeling Renewable Electricity Generation for TRNC

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ABSTRACT

Several researches have been done on modeling renewable energy for different countries and continents. Employing a unique approach, strategy and methodology, this thesis aims to do the same by using sunlight and wind resources to model a hybrid renewable for the TRNC. The thesis also carries out a comparative analysis of the modeled renewable energy generation and the present electricity generation in the country, by contrasting their economic feasibility.

The thesis also depicts how the renewable energy relates with the country load, based on the amount of energy generated from renewable resources and the size of battery (used to store excess renewable energy generated).

It also shows how base load power plants do not allow lots of renewable penetration, because of the varying nature of wind and solar resources.

Keywords: Renewable Energy, Hybrid Pv/wind system, Solar Resource, Wind Resource, Base Load, Power Plant, Economic Feasibility, Load Shifting, TRNC.

ÖZ

Farklı ülkeler ve kıtalar için yenilenebilir enerjinin modellenmesi üzerine çeşitli araştırmalar yapılmıştır. Eşsiz bir yaklaşım, strateji ve metodoloji kullanan bu tez, KKTC için yenilenebilir bir hibrit modelini güneş ışığı ve rüzgar kaynakları kullanarak gerçekleştirmeyi amaçlamaktadır. Tez aynı zamanda, ekonomik fizibilitelerinin aksine, modellenen yenilenebilir enerji üretiminin ve ülkedeki mevcut elektrik üretiminin karşılaştırmalı bir analizini de yürütmektedir.

Bu tez aynı zamanda yenilenebilir enerjinin yenilenebilir kaynaklardan üretilen enerji miktarına ve pilin büyüklüğüne (üretilen aşırı yenilenebilir enerjiyi depolamak için kullanılan) dayalı olarak ülke yüküyle nasıl bağlantılı olduğunu da göstermektedir.

Ayrıca, rüzgar ve güneş kaynaklarının değişen doğası nedeniyle baz yük santrallerinin yenilenebilir nüfuziyetlere nasıl izin vermediklerini de gösterir.

Anahtar Kelimeler: Yenilenebilir Enerji, Hibrit Pv / rüzgar sistemi, Güneş Kaynak, Rüzgar Kaynak, Baz Yük, Santral, Ekonomik Fizibilite, Yük Kayması, KKTC.

DEDICATION

To my Parents and other family members.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ρ	Air Density
π	Pi
C_p	Power Coefficient
N	Number of Years
r	Radius (blade length)
A	Swept Area
P	Power
V	Wind Speed
AI	Artificial Intelligence
ASB	Available Space in Battery
CHP	Combine Heat and Power
DNE	Does Not Exist
DSM	Demand Side Management
ED	Energy Density
EDB	Energy Drawn from Battery
EI	Energy Intensity
ESB	Energy Stored to Battery
GHG	Greenhouse gas
IEA	International Energy Agency
IMF	International Monetary Fund

IRR	Internal Rate of Return
KE	Kinetic Energy
KIBTEK	Kibris Turk Electric Kurumu
LCOE	Levelized Cost of Electricity
MARR	Minimum Attractive Rate of Return
NPV	Net Present Value
NRE	Non-Renewable Energy
NREL	National Renewable Energy Laboratory
Pv	Photovoltaic
PE	Potential Energy
PV	Present Value
RE	Renewable Energy
REG	Renewable Energy Generated
SD	Storage Device
SIR	Savings-to-Investment Ratio
SPP	Simple Payback Period
TRNC	Turkish Republic of Northern Cyprus
U.S. DOE	United States Department of Energy
USD	United States Dollars
WEO	World Economic Outlook

Chapter 1

INTRODUCTION

TRNC has a great challenge in supplying enough electrical energy due to lack of fossil sources and economic sanctions, if TRNC can make utmost use of the renewable energy resource available on the island, this might be a solution to their electrical energy supply. One of the greatest challenges for governments especially in developing countries, is convincing people to efficiently use electrical energy. Energy saving and environmental protection against greenhouses are the major goals that countries are looking to achieve. The electricity demand is rising and consequently, it puts a great pressure to the economy and other infrastructures. Building new power plants, extracting energy from renewable energy sources, or applying energy management and utilization can be considered to overcome this extra demand.

Renewable energy refers to forms of energy that are derived from natural and inexhaustible sources. Rainfall, sunlight, geothermal heat and waves are some already well-known renewable energy sources. Renewable energies are absolutely capable of providing energy for all forms of uses and consumption. They also represent the oldest forms of energy used by humans, having been the world's primary sources of energy until the transition to fossil-fuels during the industrial revolution. Today, the most conventional sources of energy world-wide are derived from fossil-fuels. In light of the contemporary understanding of the ill-effects of fossil-fuels on the environment, as well as their lack of sustainability due to eventual depletion, a lot of attention is being paid to the exploration and adoption of renewable energy as a feasible and sustainable means of generating energy [29, 30].

Increasingly, the view that renewable energy hold the only solution to solving the world's energy demand both in an environmentally friendly as well as sustainable manner, is continuing to gain traction among people everywhere. This development has been fostered by the growing realization that fossil-fuels represent an unsustainable and environmentally dangerous source of energy [20].

One of the reasons for this perceived unsustainability in the use of fossil-fuels is the ever-increasing global population. As the population increases, so does the world's energy demands, which impels us to continuously plunder the finite resources of the earth, and in so doing, adversely affect its environmental conditions. Besides the earth's resources continuing to diminish, several other problems emanate from the use of fossil-fuels in meeting the world's energy demand. Carbon emissions have continued to increase annually and now represent one of humanity's gravest existential threats, carbon emissions already have an adverse effect on the air we breathe, most of the world's major industrial cities already suffer greatly from air-pollution as a consequence of this. Moreover, nuclear energy has not turned out to be a viable alternative either. It is extremely expensive and comes with even greater risks than those posed by fossil-fuel burning. In addition, both uranium and plutonium are also resources that will ultimately be depleted, and there is yet no solution to the nuclear-waste disposal challenge [20, 26, 27, 29].

Renewable energy alone holds the promise of sating the global energy demand. However, renewables yet have numerous challenges that must be addressed. Political and economic advocates for fossil-fuel sources continue to emphasize the unreliability of renewable sources due to their unpredictability. At present, this criticism is justified [20].

For wind turbines to work economically, they need to be very large (since the length of the blade is directly proportional to the power/energy output), and need to be put up in very large parks mostly offshore (because it's known that we have more winds offshore than onshore). To realize such offshore wind farm we need to invest millions of dollars, however the realization of such wind farm will not totally solve the problems, there will also be need to consider the distribution of the immense quality electricity, which will require a new power transmission line (power line). Lack of enormous efforts, financial problem, and reluctance of the local inhabitants are not motivating/encouraging [20].

Also the advocates of fossil energy are pursuing two main targets: firstly, they want to preserve the energy monopoly, meaning the energy market will be controlled by a few large enterprises. Secondly, they want to preserve the coal, nuclear and gas power plant. In a nutshell, the so called turnaround in the energy policy is definitely losing some of its momentum, we shouldn't let such to happen [20].

Wind Energy: Wind energy is one of the most common forms of renewable energy. The major reason wind energy is so frequently utilized is its relative affordability and effectiveness as a source of renewable energy. At present, wind energy accounts for an estimated 433,000 megawatts (MW) of generated electricity in the world. The use of wind energy come with several advantages, despite its historical use going back several thousands of years, the fact is, wind energy is more affordable and easier to harness today than at any period in history previously. [12, 13, 18, 31, 35].

Solar Energy: Solar energy entails the conversion of heat and light from the Sun into electrical or thermal energy. There are numerous ways of harnessing solar energy in this manner, these include the use of solar electric (photovoltaic), solar heating, artificial photosynthesis and several other methods. The sun holds enormous energy potential that can be used in sating human energy requirements for numerous domestic and extrinsic affairs. The earth receives more solar energy hourly than its entire inhabitants can consume annually. Solar energy is not evenly distributed throughout the Earth, providing solar energy to all regions of the world requires the use of long distance power lines from regions that receive high solar radiation and heat to other regions that do not receive as much throughout the year. Moreover, solar energy remains one of the cleanest energy sources in terms of its complementarity with the environment. It requires little maintenance and is relatively easy to set-up [12, 13, 18, 19].

Hydro Energy: Hydro energy is basically energy gotten from fast moving water. It is one of the oldest forms of energy used in generating electricity. The first hydro energy plant in the United States was built at Michigan in the late 19th century [13, 28].

Fast moving waters can be harnessed for several practical purposes. Hydro-power is primarily used for the generation of electricity. These include orthodox hydroelectric, hydro dams, and many others. These devices essentially convert the kinetic energy of fast running and falling water into usable electrical energy. As stipulated by the laws of thermodynamics, energy conversion is a physical process and it is the basic function of renewable energy devices. They invariably convert some form of energy into electrical energy [18, 28]. Understanding the water cycle can help in understanding the hydropower, because hydropower relies on the water cycle.

Geothermal Energy: Geothermal energy refers to energy that is derived from the heat emanating from the earth's crust. It is an environmentally friendly and perfectly sustainable form of energy. Due to decaying radioactive waste from minerals as well as heat loss from the planets original formation, temperatures at the earth's crust can reach over 4000C. This can be converted to electrical energy and used for all sorts of economic and domestic activities. The extraction of this heat is commonly done via steam and water [13, 18, 21, 31].

Hot water is drilled from the earth and passed on to buildings, homes, and offices. This process requires dispersing the hot water directly into the buildings using pipes, or by channeling it via a heat-exchanger which then sends the heat into the buildings. For electricity generation, geothermal heat is converted to electrical energy by a turbine [13, 21].

When carefully utilized, geothermal is a very useful renewable energy alternative and is also ultimately sustainable because it utilizes heat gotten through natural processes. However, geothermal energy must be carefully extracted because if done recklessly, it could dangerously lower temperatures below the earth's surface. It is also a very safe means of energy generation as it produces no substantial amount of greenhouse gasses [21].

The relative reliability of geothermal energy means it has enormous potential for improvement and harnessing. Though on its own it might be unable to completely meet the world's energy needs, but it has the potential of meeting a significant portion of the world's energy needs [21, 31].

It should be noted however, that there are yet niggling concerns regarding the feasibility of large-scale us of geothermal energy. This is as a consequence of the fact that extracting ground water may result in the release of H_2S and CO_2into the atmosphere. Avoiding these problems are essential to achieving geothermal energy generation [21].

1.1 100% Renewable Energy

Global warming, pollution and other environmental issues have triggered the use of 100% renewable energy for our important energy demands: Electricity, heating/cooling, and transportation, moreover not only environmental issues bring about the endeavor for 100% renewable energy, but economic and energy security is also concerned. Many scientist and professionals has noted that "the world can go 100% renewable, because there exist sufficient renewable resources to allow renewable electricity to play a significant role in the future electricity generation and thus help confront issues related to climate change, energy security and the escalation of energy cost" [25, 31].

The most significant barriers to the widespread implementation of large scale renewable energy and low carbon energy strategies are primarily political and not technological. According to the 2013 **post carbon pathways** report, which review many international studies, the key roadblocks are; climate change denial, the fossil fuels lobby, political inaction, unsustainable energy consumption, outdated energy infrastructure, and financial constraints [37, 25, 30].

1.2 Thesis Objective and Organization

This thesis is carried out to model electricity load, renewable energy and to picture renewable electricity generation for TRNC by calculating the annual REG, annual RE used, annual RE over-generated and annual hours curtailed. This is done with the use of an excel spread sheet created by energyshouldbe.org and renewableYes.org [22, 33]. It shall also show how renewable energy penetration on the production side helps in load shifting on the demand side. Also this thesis investigates the feasibility of using renewable over the current energy system in TRNC. This report is organized as follows: Chapter 1 is the Introduction, Chapter 2 is the Literature Review, Chapter 3 is Background of the Study and Renewable Energy Resources in TRNC, Chapter 4 is the Proposed Model and Results, Chapter 5 is the Conclusion and Future Work, and lastly, the References.

Chapter 2

LITERATURE REVIEW

Many studies in the past have assessed the availability of renewable energy resources and evaluated future electricity demands and ways of reducing these electricity demands in Cyprus.

Few studies have address the integration cost of renewable energy resources and explore their effects to the grid system [4], one of the studies is the Phd thesis of Davut Soyali.

In 2013 Mehmet Yenen and Murat Fahriouglu said in their paper that Cyprus depends so much on energy resources which are imported, such as oil and gas. In the same paper they say KIBTEK has a base load capacity of two 60MW steam plant generators and a peaking capacity of six 17.5MW diesel generators, AKSA provides a capacity of 92MW to the grid and there is a capacity of 1.27MW solar Pv power plant. It was also mentioned that both solar and wind energy are viable renewable resources, but the major setback is their dependence on weather and unpredictable nature [53].

In 2016 Mustafa Dagbasi, Olusola Bamisile and Chinedum Adii mention in their paper that the amount of energy consumed by Human can be aproximated to be 50TWh ($50 \times 10^9 kWh$) daily, most of this amount of energy are majorly drawn out of fossil fuels, by burning these fossil fuels, leading to the release of unwanted gases, $CO_2, NO_2, SO_2, etc.$ into the atmosphere [54].

In 2005, the amount of oil consumed by the world is equal to 85 million barrels daily, which is growing at a horrifying rate. The economies in developing countries have the most influence in this growth. As a result of international economic crisis in the year 2009, the world economy was decreased by 0.6% and there was a global recession of -3.2%, this information is retrieved from WEO and was published by IMF. Estimation was made by IMF that within 2010 to 2015 the average growth could be 6.7% for emergent economies, for developed economies it will be 2.5% and 4.6% for world economy [54].

There's expectation that energy consumption will grow again in most countries where energy consumption is strongly related with their economy. If the population in the developing countries uses the same per capita amount of energy as the population in the developed countries, world energy consumption is expected to increase by a factor of 20 [54].

It was estimated by the U.S. DOE that by 2025 renewable energies will exceed natural gas production and coal will continue to be the most useful energy among fossil fuels [54].

About 44% of the fossil fuel imported into TRNC is used to generate electricity in thermal power plants, which is known to be a very costly way of generating electricity. The increase in electricity consumption goes in parallel with economic growth and population. According to KIBTEK, as at 2014 residential customers was

120,119 in number and others (non residential) was 155,318 in number. On 9th of January 2013 the winter peak value in TRNC was 257MW and on 15th of August 2013 the summer peak value was 259MW, on the other hand winter peak on the 20th of January 2014 was 218MW and the corresponding summer peak on 25th of August 2014 was 279MW [54].

Solar energy input in TRNC last from April to October and is particularly high at areas where the dry summer is well pronounced, the daily sunshine duration in the lowlands varies on an average of 5.5 hours in the winter period to about 12.5 hours in the summer period [54].

In 2015 Olusola Bamisile and Mustafa Dagbasi have also mention in their paper that TRNC solar irradiation is considered one of the highest in Europe, with more than 300 days of the year having some hours of sunny weather and with an annual solar irradiance of $2000kWh/m^2$ on a tilted surface of 27.5° which is so higher than the sunniest area in the world's largest market [55].

In 2015 Akinola Babatunde and Serkan Abbasoglu said in their paper that solar energy can be concentrated using mirror, to provide heat for generating electricity in solar thermal electric power plants for commercial applications. Conversion of solar radiation into electricity can be done directly using Pv systems [40].

It was recorded in 2013 that, 31.1 GW of solar Pv capacity was installed around the world while global Pv capacity was above 100 GW; studies have also shown that additional 100 GW Pv systems will be installed worldwide by 2015 [40].

According to a report by IEA, in 2006 very few countries could boast of solar capacity of 100 MW or more; presently, about 30 countries are on that list and the IEA projects that by 2018 this number will be more than double. Also in the same IEA report, it was mentioned that roughly 60% of global Pv energy is currently manufactured in China whereas in decades ago almost no Pv energy was produced in China [40].

It was confirmed by the U.S. DOE that the current module cost for solar Pv varies from $5.5 to $10 per watt. According to NREL, the price of electricity for solar Pv ranges from $0.15 to $0.59 per kWh. These prices are dependent on location and government solar policies of such locations [40].

According to a paper published in 2017 by Olusola Bamisile, Akinola Babatunde, Ifeoluwalayomi Wole-Osho, and M. Dagbasi, they said GHG emission in the process of extracting, exploiting, exploring and utilizing fossil fuels still pose a great threat to human race. In a year about 160,000 to 250,000 people die due to direct and indirect effect of climate change [5].

Energy is an important aspect of Cyprus economy with most of its energy (electricity) generated from the use of imported fossil fuels. The largest consumer of energy in Cyprus is the transport sector while solar energy contributes only 4% to the total energy consumption [5].

About 10MW capacity of solar installations has been done in Cyprus with a larger percent of this installation coming from solar water collectors [5].

In 2015, Ismaila Yusuf Pindiga and Olusola Bamisile mention in their paper that Nuclear energy is still been debated as being a renewable energy or not, because of it low carbon emission. One of the major criteria of renewable energy sources is the little or no emission of carbon during operation and nuclear energy satisfies this criterion. As argued by Bernard L Cohen, nuclear energy satisfies the time-span necessary for a source of energy to be sufficiently sustainable so as to be considered “renewable energy”. He goes on to explain that Uranium (the major element in nuclear energy production) has been proven to last as long as the earth does. However, a serious critique against this point of view is the factual finiteness of uranium deposit relative to wind and solar. Moreover, it has been argued that the harmful waste emitted by nuclear reactors during the production process disqualifies it from meeting the criteria of renewable energy (K. Johnson, 2009) [24].

Trieu Mai and Co. said that it is very important to explore the possibility of attaining higher levels of renewable electricity penetration [36].

Tapping, mining, transporting and burning of fossil fuels kill lots of people in the past. Some scenarios were given in the journal published by Umair Shahzad [34].

For a RE system to be more stable, energy SD must be used, so as to store excess energy generated and to supply energy during the period of insufficient energy generation [3].

Stochastic nature of RE sources may lead to period of no or low energy generation, so therefore it’s advisable to use more than one RE energy source (hybrid system) [3].

In 1873 professor Augustin Mouchot put forward that: The sources of energy serving as the primary drivers of the European industry were getting depleted and are indeed finite. He ponders whether humanity will return to water and wind or even sunlight in the far/distant future [25].

In 1885, with regards to the discovery of photovoltaic effect in the solid state, German industrialist Wener Von Siemens sensationally remark that: the scientific importance of the discovery will only be fully appreciated along with its practical value when one considers that the supply of sunlight is unlimited, free and infinite in its supply [26].

The International Energy Agency (IEA) in a 2011 statement highlighted the huge long-term benefits of clean solar energy. Energy security, reliance on inexhaustible and import-independent resources, reduced pollution and improved global environment were some of the benefits cited. These are enormous advantages that compel us to commit to investments in these technologies. This responsibility ought to be widely shared. It accounted for almost 8% of the country's electricity output.

2.1 Definition of Terms and Concepts

2.1.1 Net Present Value (NPV)

This is the difference between the present value of cash inflows and the present value of cash outflows [51, 50].

2.1.2 Internal Rate of Return (IRR)

Internal rate of return (IRR), can be defined as the interest rate that equates the present worth of a series of cash flows to zero, it represents an effective metric for evaluating the profitability of probable investments. When implemented, it expresses the return achieved by an investment (or true cost of a loan) and is generally viewed as a reliable measure of efficiency. This fact explains its widespread application and usage, in spite of its numerous well-known problems. With respect to decision-making, IRR is comparable to the discount rate for accepting and rejecting projects. The discount rate has been given several names in the literature, including “cost of capital”, “marginal growth rate”, “MARR”, and “hurdle rate”. In order to accept an investment project, the IRR must be greater than the MARR. For the acceptance of loans, the IRR must be less than the MARR. When the IRR equals the MARR, then there is indifference towards the loan or investment opportunity [52, 50].

2.1.3 Simple Payback Period (SPP)

Payback period refers simply to the time required for the total initial investment in a product to be recovered by the total accumulated savings [53, 50].

2.1.4 Savings-to-Investment Ratio

This refers to the ratio of the benefit to the cost. If SIR is greater than one, this indicates that a project accrues more money than it costs and when it is less than one, this implies that a project rakes in less money than it costs [50].

2.1.5 Curtailing

The process of minimizing the amount of over generation by imposing some kind of restriction or by saving the excess energy generated for future purposes is called curtailing. Since we already know that RE resources are not always available when we need them, and they are sometimes available in abundant when we don’t need them, (i.e. they vary a lot and mostly doesn’t match with demands), there will be need to save or turn off our wind farm or Pv plant at some point to burn coal, this action/process is called curtailing. Curtailing is very important in renewable technologies, because if the supply does not meet the demand there will be a blackout and also if there's over generation it can also lead to black out, so electricity supply must equal to electricity demanded. In conventional power plant we can simply put a stopper on the fuel chamber to decrease the generation, but in renewable there are many different ways to reduce generation depending on the technology involve and the energy source [7].

If the surplus electricity from renewable energy is not used it will have a negative value because it cost money to produce it, ideally we can store this surplus electricity by some storage means.

2.1.6 Combine Heat and Power (CHP)

Combine heat and power can also be referred to as cogeneration; CHP simultaneously generates electricity and useful heats through the use of heat engines. In the process of generating electricity nearly two-thirds of the energy used is wasted in the form of heat to the atmosphere, and also more energy is wasted during the distribution of electricity to the end users. This heats wasted makes our electricity generation and distribution not so efficient. Thinking of it, two-thirds of energy wasted is a lot, so to make use of the energy more efficiently, CHP is on site electricity generation that will capture the heats to provide useful thermal energy [8, 17].

CHP technology can be deployed quickly, they are cost-effective, and have very few geographic limitations, they can use a variety of fuels, both NRE and RE-based [17].

CHP efficiency is about 65-75%, which attracts industries, large commercials and institutions to employ CHP for many years [17].

2.1.7 Baseload

Basically baseload can either be baseload demand or baseload supply. Baseload demand is the minimum level of demand over a period of time on an electrical grid, while baseload supply is the amount of electricity to be generated to meet the minimum demands based on reasonable expectations, so we have baseload on the demand side and baseload on the generation/supply side. Based load generation is usually met by baseload power plant, we need to note that baseload supply is not the opposite of baseload demand, technically baseload supply is the opposite of peak supply (peak supply is met by peaking power plants) [16].

2.1.8 Wind Turbine

Wind turbines are devices design to convert KE into electrical energy, as it name implies, this KE comes from the wind. There are basically two types of wind turbine, the vertical and horizontal axis, the wind turbine works simply in the opposite of a fan, a fan uses electricity to produce wind, and a wind turbine on the other hand uses wind to produce electricity. Wind energy is a form of solar energy as a result of irregularities of the earth surface, uneven heating of the atmosphere by the sun, and the rotation of the earth [15, 27].

The modern wind turbines fall into two basic groups: The vertical-axis design and the horizontal-axis design. We can build these wind turbines on the land or offshore in large bodies of water like oceans and lakes [15].

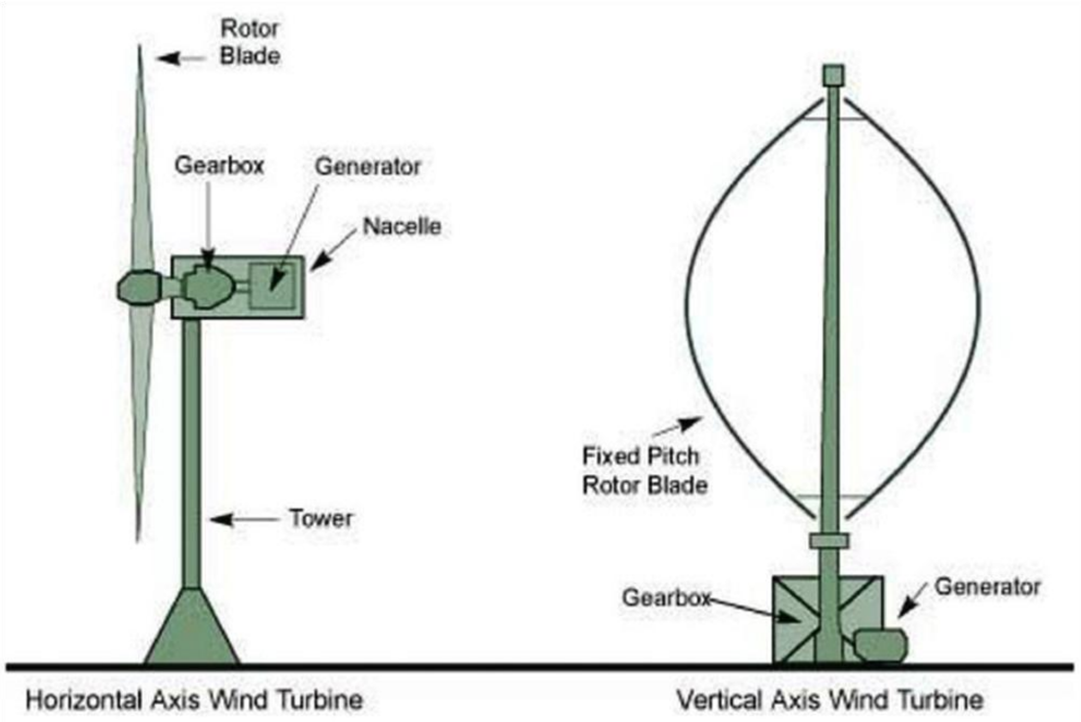


Figure 1: Horizontal and Vertical Axis Wind Turbine [15].

2.1.9 Photovoltaic

Photovoltaic is the term used for the conversion of light into electricity using semiconducting materials, these semiconducting materials exhibit the photovoltaic effect that causes them to absorb photons of light and releases electrons, which is a phenomenon studied in photochemistry, electrochemistry and physics. Photovoltaic converts energy from sunlight into electricity by using solar cells, these solar cells produces direct current electricity from the sunlight which can be used to power equipment or to recharge battery. The name Pv comes from the process of converting light(photons) to electricity (voltage), Pv effect was discovered in 1954 by scientists at Bell telephone, but Edmund Bequerel a French physicist first noted the photoelectric effect in 1839, he found that certain materials will produce small amount of electricity when expose to light. Photovoltaic technology is based on the photoelectric effect and the nature of light which was described by Albert Einstein in the year 1905, for which he later won a Nobel Prize in physics [9, 10, 11].

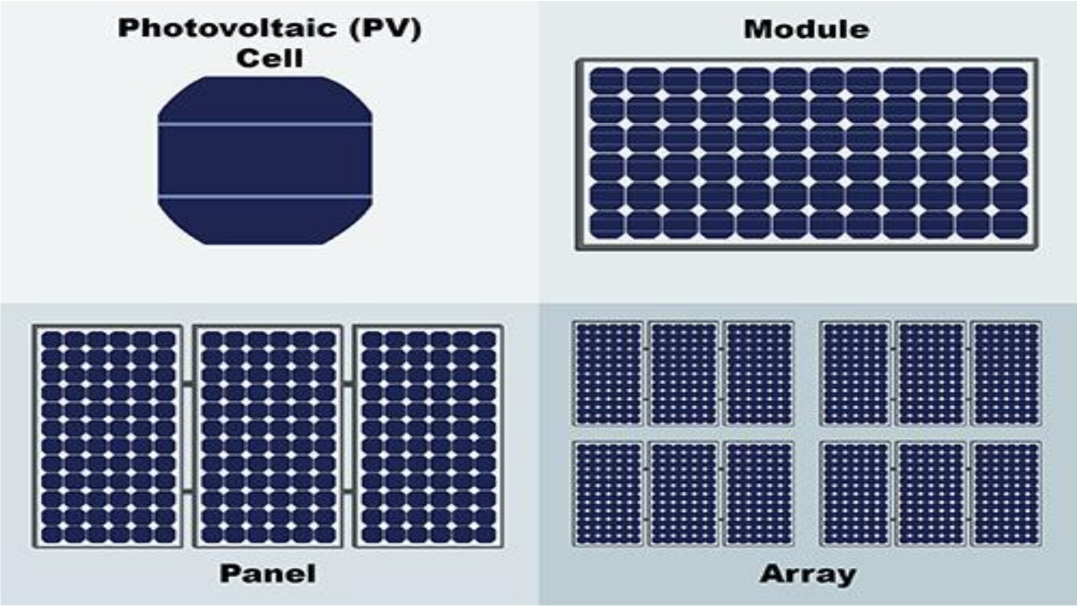


Figure 2: Photovoltaic (Pv) Cell, Module, Panel and Array [10].

Chapter 3

BACKGROUND OF THE STUDY AND RENEWABLE ENERGY RESOURCES IN TRNC

3.1 Introduction

This chapter briefly examines the geography and demography of TRNC, climate and housing in TRNC, current electricity generation and corresponding CO_2 emission, electricity demand in TRNC and the assessment of renewable energy resource in TRNC; elaborating mostly on wind and solar resources.

3.2 Background of the Study

3.2.1 Geography and Demography of TRNC

Turkish Republic of Northern Cyprus (TRNC) is de facto independent republic located on the Mediterranean island of Cyprus officially the northern territory of the republic of Cyprus. Because of the sanction imposed on TRNC, the territory is only recognized by turkey, and TRNC depends on Turkey for military, political and economic supports. [38]

TRNC amount to around a third of the island, with an area of 3,355 square kilometers (1.295sqmi), Turkey lies 75kilometer (47mi) to the north. TRNC lies between latitude of 34° and 36°N, and longitude of 32° and 35° E. Since TRNC belongs to an island, it has a coast which consists of enchanting coves, rocky coast and long golden sandy beaches. These beaches are among the cleanest and safest in the Mediterranean. Between May and October the average water temperature is around 24°c [6, 39].

Cyprus is situated in the location known as the Cyprian Arc. The precise location of this Arc remains widely debated as various studies have produced differing findings. At this moment, no one is certain as to what type of fault the Cyprian Arc is [4, 1].

TRNC most notable landmark is perhaps the northern mountain range, otherwise called the Kyrenia Mountains, or the Five Finger Mountains. A rugged mountainous range running about 130 km parallel to the coastline. It occupies an area roughly 260 sq km, and primarily comprises limestone, dolomite, and marble. This range peaks at Mount Selvili, close to Lapta, at 1,023 m [6].

North Cyprus' largest spring is situated in this range close to the Kyrenia Mountains. The very rich northern coast is mostly filled with olive and carob trees [4].

The Mesaoria plain is situated in the center of the island, between the five-finger Mountains and the Southern Troodos Mountains, it is pivotal to the cultivation of important crops like wheat, barley and oats. This region is thus termed "the breadbasket of Cyprus" [38, 39].

The north and eastern shores of North Cyprus are bounded by the beautiful Mediterranean Sea. The coastline is littered with beautiful beaches which attract tourists from all over the world, especially in the long Cyprus Summers. Guzelyurt and Famagusta have impressive bays, while Zafer, Korucam and Kasa remain attractive peninsulas [4, 1].

Cyprus retains many imprints of several civilizations under whose influence the island has thrived. The island yet contains several Roman villas and theatres, as well as Byzantine cathedrals and monasteries, medieval castles, Ottoman Mosques and various other pre-historic habitats. Cyprus' major economic activities include tourism, textile and craft as well as merchant shipping. Other traditional crafts include embroidery, pottery and copper work. Shown below is a Google Map of Cyprus on the Mediterranean, situated to the east of Greece, South of Turkey, West of Lebanon, and North of Egypt [4, 1].

Figure 3: The Island of Cyprus at the South of Turkey and North-West of Lebanon [42].

3.2.2 Climate and Housing in TRNC

TRNC is generally very sunny. On average, the hours of bright sunshine over the course of the year is measured at 75% of the time the sun is over the horizon. During the six summer months, bright sunshine averages 11.5 hours per day, during the winter, this drops to about 5.5 hours. These rank among the longest periods of sunshine in the world and the solar intensity also ranks among the greatest. Solar energy has been exploited in the TRNC for several years, although only for minimal electricity generation [38, 1].

Currently, the method for construction of houses implemented throughout TRNC is of the structure of a typical multi-storey and single-storey building, is made up of the foundations, the columns, the beams and slabs. All the structures make use of reinforced concrete [4].

The walls are typically built with hollow bricks, cemented with plaster on either side. The external walls typically are about 25 cm in width, while the internal walls are about 15 cm wide. More recently, there has been a trend to use cavity external walls, generally, this consists of two brick walls with an insulated layer of about 5 cm in-between. The floors consist of concrete slabs, all covered with a layer of sand or screed about 10 cm in which all plumbing and other services are placed. The floor finishing is made up of a layer of mortar covered with tiles, marble, or granite blocks [44].

Flat roofs are made up of a slab, typically about 150 mm in width, with an added layer of plaster of 3 cm on the underside, this is applied when the slab is not smooth. The roof is usually water-proofed with a thin layer of bitumen and painted a white or aluminum color on top. More recently, there has been a trend to use an inclined, smooth slab, with light insulation, covered with a layer of mortar and roof tiles [44].

3.2.3 Current Electricity Generation and Corresponding CO_2 Emissions of TRNC

In the TRNC, electricity is produced and controlled by a public corporation known as the Electricity Authority of TRNC (KIBTEK). It is capable of generating about 347.5 MW.

The table below shows the breakdown of electricity generation types and their capacity per station in the TRNC. It should be noted that these table exclude any available renewable energy power generation stations as they are excluded from the general contributory capacity [43].

	KIBTEK/ Technecik	KIBTEK/ Dikmen	AKSA/ Kalecik	
Steam Turbine	120MW			
Gas Turbine	50MW			
Diesel Engine	70MW	20MW	87.5MW	
Installed Capacity	240MW	20MW	87.5MW	347.5MW
Available Capacity	217MW	20MW	87.5MW	324.5MW

Figure 4: Breakdown of Electricity Generation in Type and Capacity per Station in TRNC [4, 43].

3.2.4 Electricity Demand in TRNC

In TRNC domestic demand represents 32% of total electricity consumption, the use of electricity for street lighting is 2%, industry, on the other hand, has 8%, however, the agriculture percentage is 6%, the transmission and distribution loss is 15%, and the remaining 37% is used for commercial [4].

Figure 5 summarize the breakdown share of the electricity demand in customer types or sectors such as street lighting, industry, etc. of the year 2010.

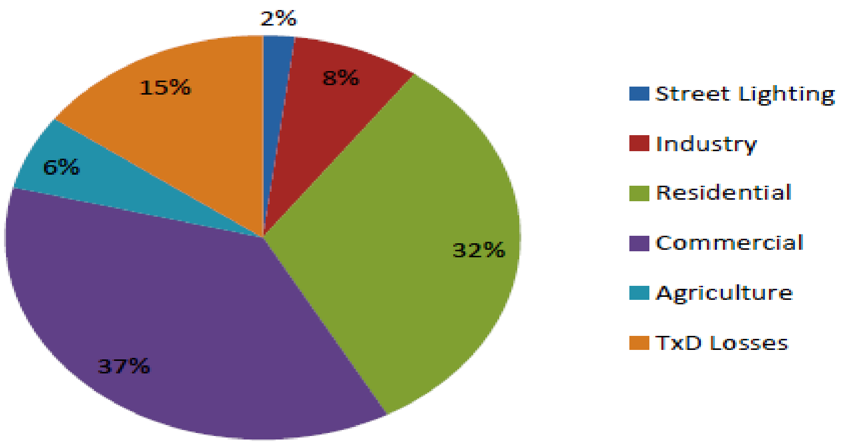


Figure 5: The Breakdown of Total Electricity Demand in Terms of Customer Types for TRNC in 2010 [4].

According to data collected by KIBTEK, electricity demand trend through the years 1997 to 2010 is shown in figure 6. The blue trend-line indicates the average rate of increase per annum of the electricity demand over the time period. The slope of the trend line is 56,799 MWh or 56 GWh per year. For 2010, the TRNC energy demand was 1,243 GWh and 56 GWh is equivalent of 4.5% of the total demand. Without any changes to this trend, this amount would ultimately yield to a 45% increase in electricity consumption by 2020 [4].

Furthermore, studies by M. Ilkan et al. (2005) found that growth in the annual electricity demand of North-Cyprus would be about 3.3% until the year 2020. In 2010, the TRNC's energy demand was 1,243 GWh and 3.3% is equivalent to approximately 41,050 MWh or 41 GWh. He projects that the increase in demand will be approximately 26% by the year 2020 [4].

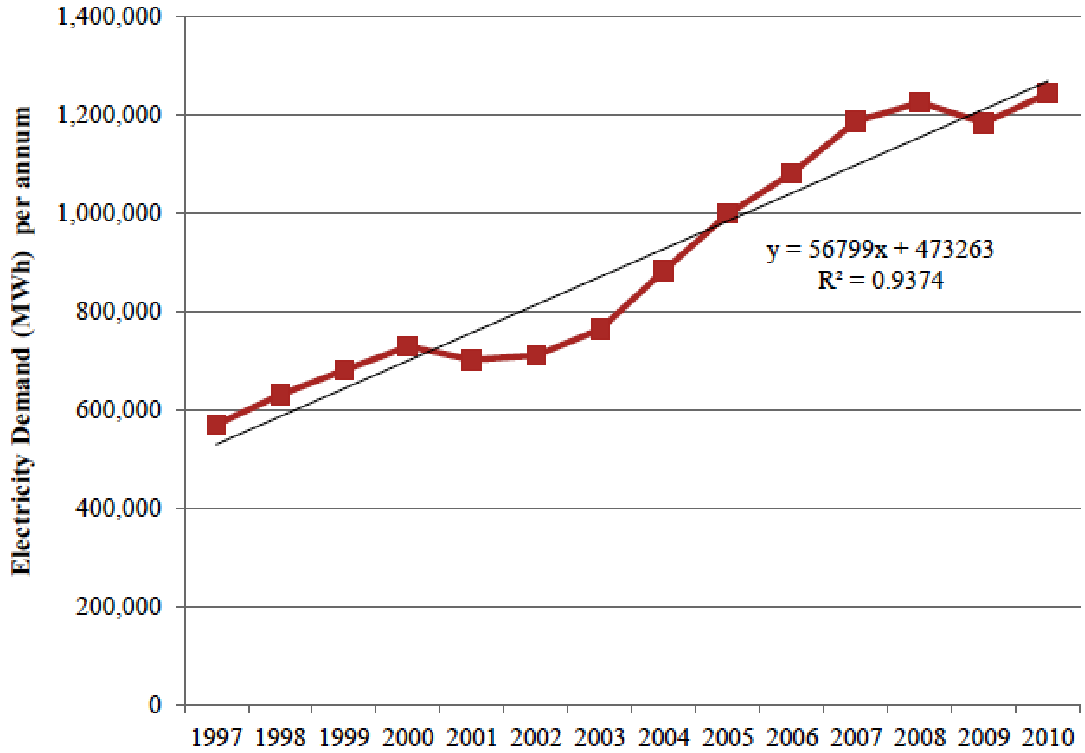


Figure 6: Electricity Demand of TRNC between 1997 and 2010 Shown with Linear Trend Line [4].

What is evident from numerous studies and current trends of TRNC’s electricity demand is that, it will continue to increase in the foreseeable future if significant changes are not implemented, this increase can range from 33% to 46% for TRNC [4].

3.3 Renewable Availability in TRNC

3.3.1 Assessment of Renewable Energy Resources in TRNC

Exploitation of RE depends mainly on the economy of the particular site applying it because most types of RE resources have fairly established technologies. Not only the feasibility cost of adequate resources that play a major role in the viability and sustainability of RE projects, but technical and environmental issues also play a major role [4].

In Barker studies on tidal energy potential, he concluded that sites which have a mean range exceeding 3m can be exploited. Furthermore he established that none of this potential exists in the Eastern Mediterranean [4].

TRNC lack of rivers with significant yearly flows causes the lack of hydropower opportunities. Geographically there are little or no geothermal resources, the potential for small hydro plants is very limited. Hence heat stored in rock is conveyed to the surface by means of fluid and steam [4].

TRNC biomass resources includes a wide range of biomass residues, forest and agricultural, sewage water sludge, municipal solid waste and a considerable potential of energy crops, which include traditional herbaceous crops, or short rotation woody crops. It was estimated that the electricity production from biomass will be about 1.4% of the total electricity consumption in the year 2010. In addition the installed capacity is about 0.95MW, and will be using municipal sewage to produce electricity [4].

There are some areas in TRNC with onshore wind velocity of 5-6m/s and few areas with 6.5-7m/s. Anticyclones moving from west to east affects the wind energy utilization in TRNC, during the winter it moves from the Siberian anticyclone and during the summer it’s from the low pressure created in the area of India and expanded until the area of TRNC, sea breezes generated in coastal areas as a result of the different heat capacities of sea and land, which give rise to different rates of heating and cooling; and mountain valley winds created when cool mountain air warms up in the morning and begins to rise while cool air from the valley moves to replace it, and the flow is reverse during the night [4].

Collection of sunshine duration data at a number of meteorological stations started in 1959. From the considerations affecting the use of solar energy, the classification may be extended to three different zones; coastal, central plains and mountains. From statistical analysis it’s shown that all part of TRNC enjoy sunny climate [4].

3.3.2 Wind Resource in Cyprus

TRNC is located at the Northern part of the island (Cyprus) and Cyprus is surrounded by the Mediterranean Sea. Its climate is characterized as two distinct seasons; the rainy season, from November to march and the long dry season from the beginning of April till the end of October, during the raining season the island is under the influence of depressions crossing the Mediterranean sea from west to east, while in the dry season the island is subjected to the shallow low pressure through which extends from continental depression centered Asia. However, in coastal areas the local sea-breeze circulation is usually very strong due to a large differential heating between sea and land [4].

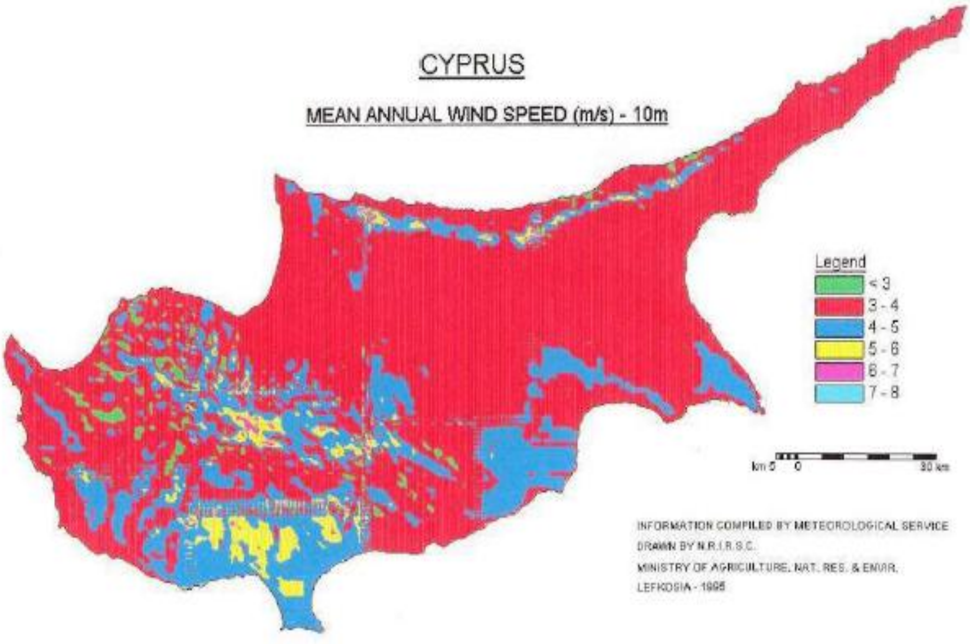


Figure 7: Annual Mean Wind Speed (m/s) for the Period of 1982 to 1992 of Cyprus [41]

Figure 8: Topological Map of Cyprus [4, 41]

Table 1 shows the wind availability of Cyprus in tabular form, where the column named Energy Density (ED) (kW/m2) is the energy density and it is the energy available in the regime for a unit rotor area and time. Thus it’s a function of the velocity and distribution of wind in the regime. Energy Intensity (EI) (kWh/m2 per annum) is the total energy available in the spectra. It is calculated by multiplying ED by the time factor that is 8760 hours for an annum [4].

Table 1: Tabulated Results Generated Using WERA and Collated Wind Data of Above Sites [4].

Station Name	K	C	VFmax (m/s)	Vemax (m/s)	Energy Density (kW/m^2)	Energy Intensity (kWh/m^2)
Paphos	2.87	4.43	3.82	5.33	0.0545	477.72
Larnaca	2.87	3.67	3.16	4.41	0.0310	271.62
Paralimni	2.16	4.86	3.64	6.58	0.0871	762.77
Limassol	1.94	3.64	2.51	5.24	0.0408	357.1
Akrotiri	2.11	4.18	3.08	5.73	0.0566	495.89
Athalassa	2.91	4.68	4.05	5.6	0.0639	559.64
Ercan	2.91	4.65	4.02	5.57	0.0627	548.94
Polis	1.92	3.76	2.56	5.45	0.0455	398.25

Figure 9, is the graphical representation of the Energy Intensity column per chosen site. Among the sites Paralimni has the highest value of energy intensity at 762 kWh/m2 per annum and Larnaca has the lowest at a value of 271 kWh/m2 per annum [4]. In this thesis I use Larnaca data, because Larnaca is the nearest station to TRNC provinces from [14].

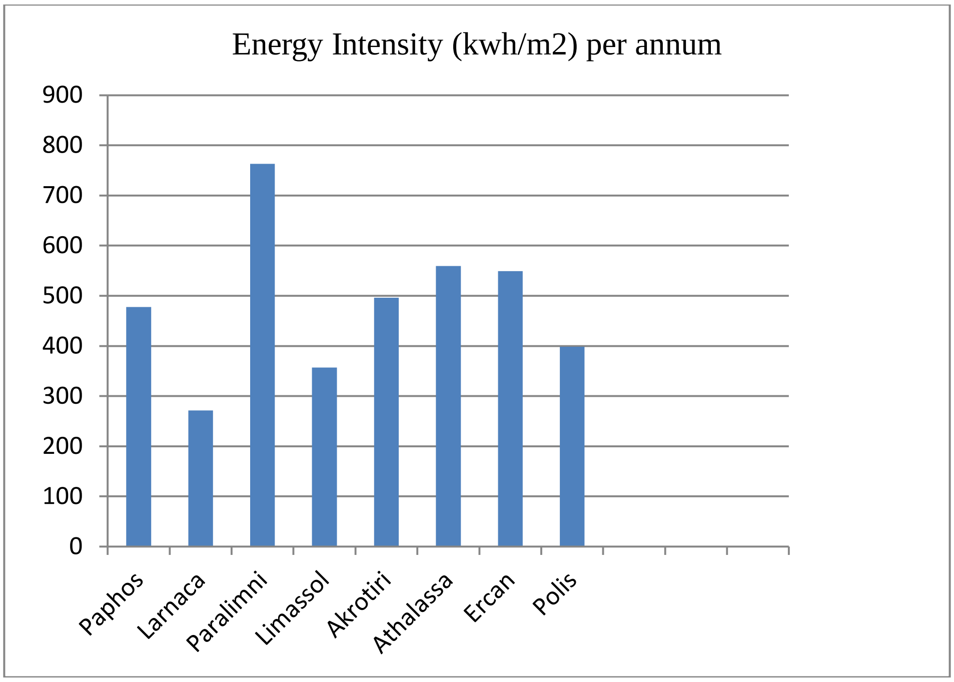


Figure 9: Graphical Representation of the Energy Intensity Column per Chosen Site [4].

Table 2: Theoretically Calculated Load Factors at Each Site [4].

Station Name	Energy Instensity (kWh/m^2) per year	Load Factor (%)
Paphos	477.72	14.9
Larnaca	271.62	8.4
Paralimni	762.77	23.85
Limassol	357.1	11.2
Akrotiri	495.89	15.5
Athalassa	559.64	17.5
Ercan	548.94	17.2
Polis	398.25	12.5

3.3.3 Solar Resource in Cyprus

The map of global horizontal irradiation of Cyprus based on annual average sunshine from April 2004 to March 2010 provided by SolarGIS database is shown in figure 10 [4].

On a horizontal surface the average annual solar radiation received is (1725kW/m^2) per year. Direct solar radiation is about 69% of the total amount which equals

(1188kW/m^2), and the diffuse radiation is 31% (537kW/m^2). For properly sited power plants, the annual solar potential for generation is estimated to be between 1950kW/m^2 to 2050kW/m^2 per year [4].

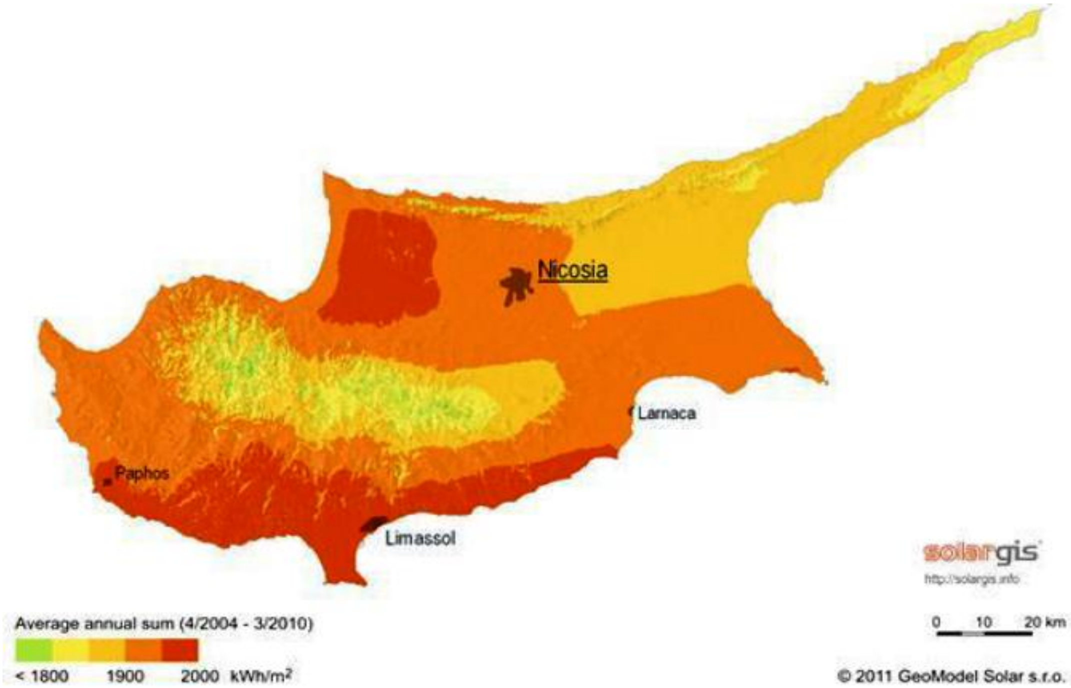


Figure 10: Map of Global Horizontal Irradiation of Cyprus Based on Annual Average Sunshine from April 2004 to March 2010 Provided by SolarGIS Database [4].

By utilizing this energy, Cyprus has become the highest user of solar water heaters in Europe. The European Solar Thermal Industry Federation ranks Cyprus as the leader in installed solar collectors per capita. With more than 900,000 m^2 of installed solar collectors, there is the potential to produce almost 700,000 kWh of thermal energy. Using these systems Cyprus has more than double the number of installed solar thermal collectors and produces twice the energy of Austria which is the next European user [4].

Figure 11 is the pictorial representation of Larnaca global horizontal radiation weather data. This figure shows the global solar radiation profile throughout the year per hours of the each day of each month. For example, it can be observed that in summer, solar time is from 6am until 6pm and the global horizontal radiation peaks midday at up to $1000\frac{W}{m2}$ [4].

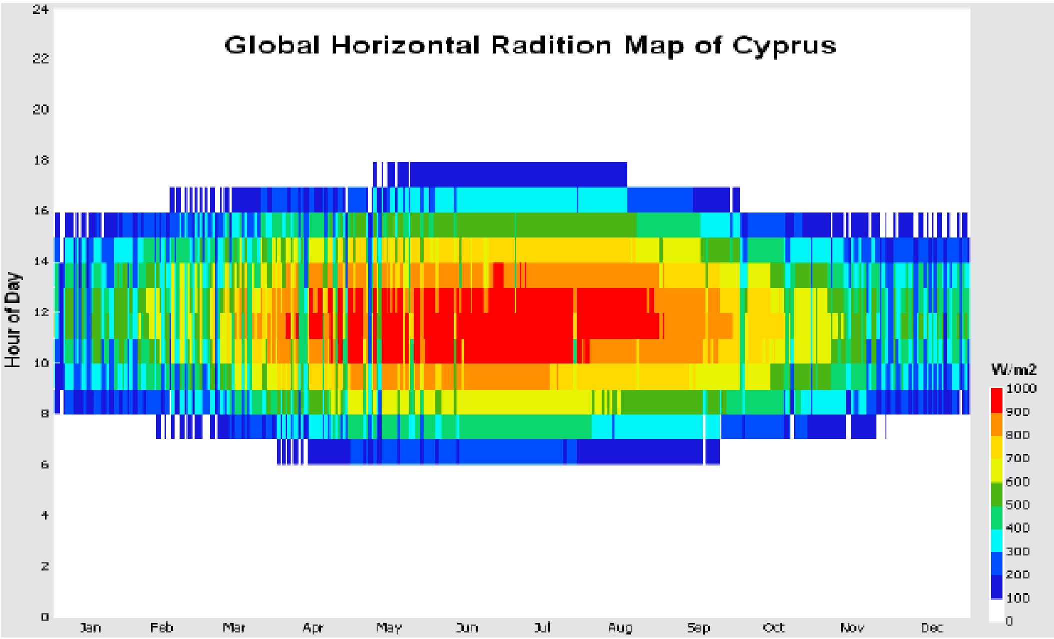


Figure 11: The Horizontal Global Radiation Map of Cyprus. Hourly Mean Data Downloaded From the International Weather Databases of U.S Department of Energy [4].

Continuous global horizontal radiation map of Cyprus is shown in figure 12. From this graph it can be observed that global horizontal solar radiation levels are the lowest at around ~450 W/m2 during winter season. However, the radiation levels steadily increase approaching to summer season and peaks in June/July at around ~950 W/m2. This steady pattern of solar radiation that this creates constitutes as a predictive resource to be exploited via solar energy conversion systems. On the other hand, from the sudden drops in the radiation levels on the plot, it can be observed that during the winter, spring and autumn seasons the weather is cloudier compared to summer season (June, July and August). This however, requires more extensive weather forecasting tools or weather monitoring systems for large solar energy conversion systems. Clouds in the sky creating partial shadows on photovoltaic systems or blocking direct beam radiation for concentrated solar systems will lower the performance or overall output of the solar energy conversion system [4].

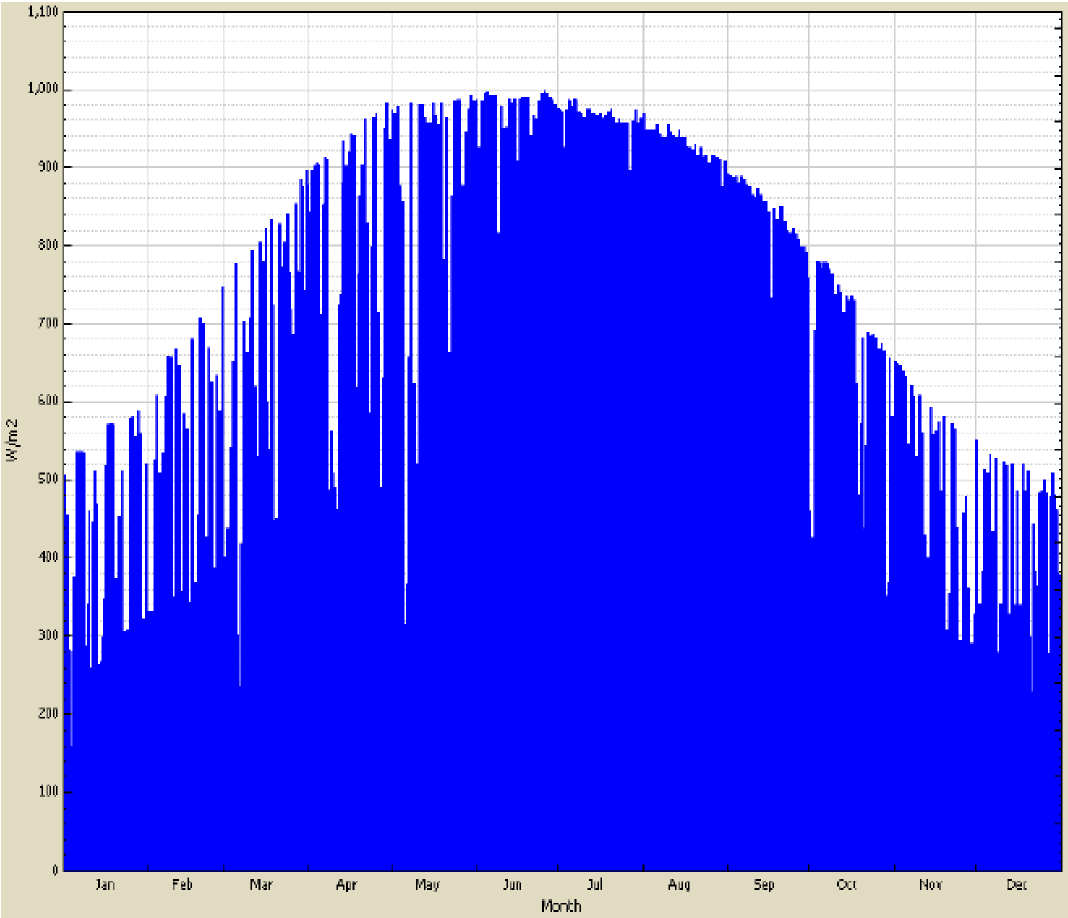


Figure 12: Continuous Monthly Global Horizontal Radiation Map of Cyprus. Hourly Mean Data Downloaded from the International weather Databases of U.S Department of Energy [4].

Chapter 4

THE PROPOSED MODEL AND RESULTS

4.1 Introduction

In this chapter the proposed model in comparison to current electricity generation of TRNC and also the results for different system size is given in tabular form and corresponding 2-D and 3-D plots are given; so as to see the periods of over-generation and backup, it will also show how baseload power relates with renewable energy. Also the comparison between solar and wind is investigated to see which one has higher potential in TRNC. Lastly the result of the economic feasibility between the current electricity generation and the proposed model will be shown. The inputs from the inputs-outputs table are in white background, while the outputs are in green backgrounds.

4.2 The Proposed Model

This work is proposing TRNC to make use of wind energy along side with solar energy (hybrid system) to meet most of their energy demand, Figure 13 bellow illustrates the current electricity generation in TRNC, and Figure 14 shows the block diagram of the proposed energy system.

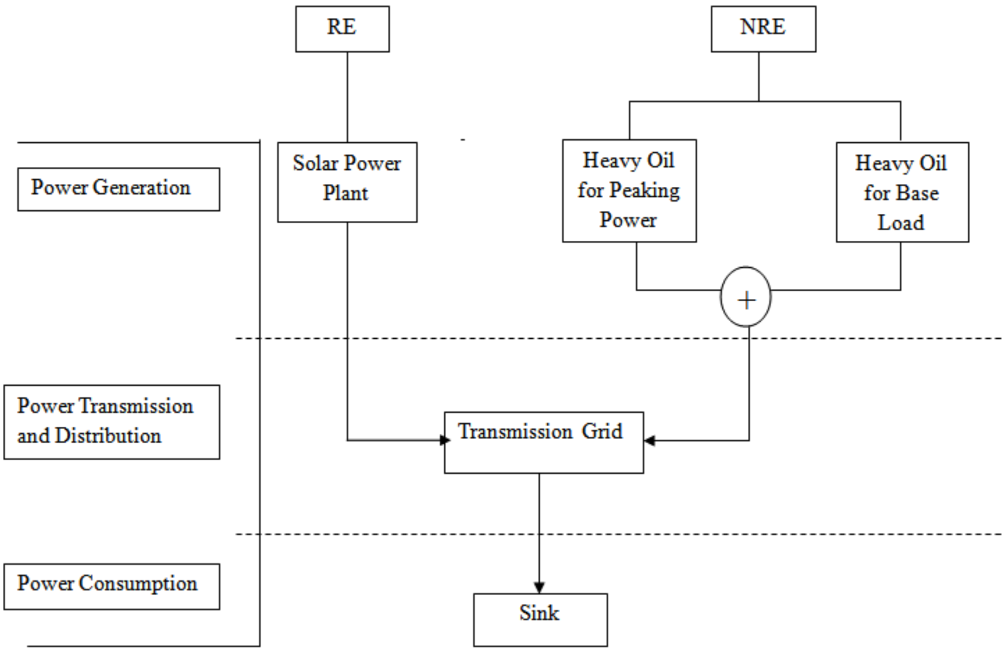


Figure 13: Block Diagram of Current Electricity Generation System in TRNC

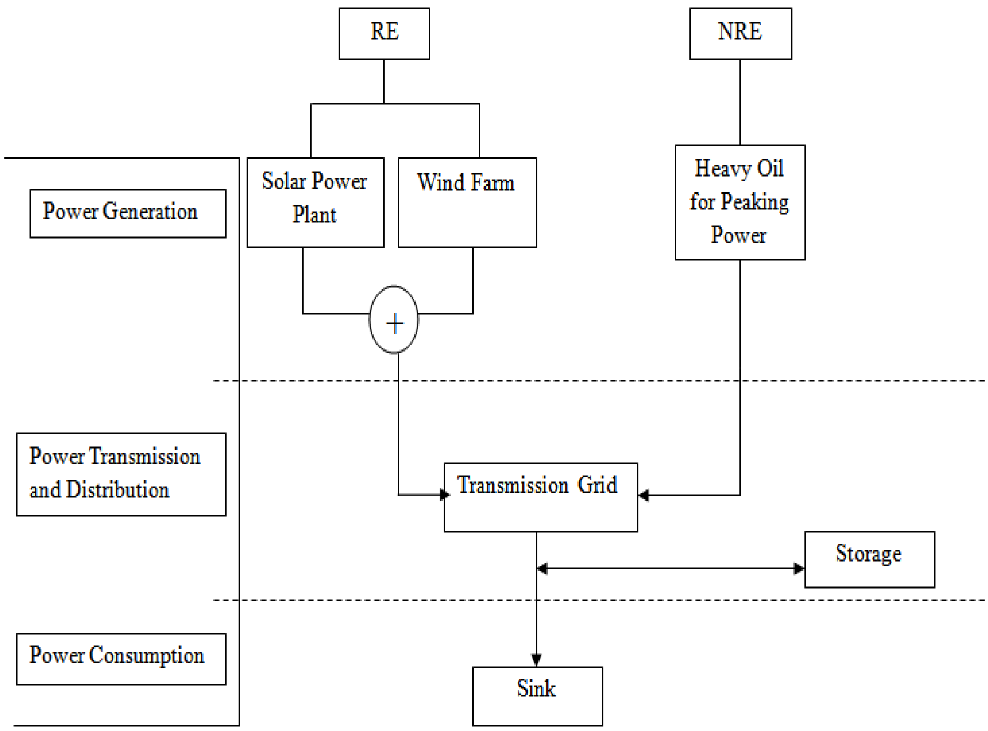


Figure 14: Block Diagram of the Proposed Electricity Generation System

Currently TRNC already have a photovoltaic power plant located at Serhatköy with capacity of 1.2MW, it's obvious that this is a very small amount of renewable that is in use. This thesis is suggesting to increase the photovoltaic power plant and build along side with it wind farm, so as to make utmost use of these two renewable sources (solar and wind). It is known that solar has a very high potential in TRNC compare to wind, but using one of the renewable energy might lead to a large battery size. A hybrid system with proportional system size for each energy source is needed (i.e. using significant amount of solar and wind), this will help in reducing the size of the battery.

In Figure 13 it can be seen that TRNC uses baseload power plant as part of their electricity generation, while in Figure 14 it is proposed that baseload power plant should be abolished since it does not allow lots of renewable energy penetration. This point will be shown in the following figures in section 4.3.

4.3 Results

In this section, the result of the model (which was achieved by using the wind and solar data obtain from [14]) are shown for two different scenario investigated with brief explanation. This model uses the hourly energy output from wind and solar in MWh for a year. The solar energy comes from [14], while the wind energy was calculated based on the wind speed from [14], using equation (1) from [32].

$$P = \frac{1}{2}\rho A V^3 C_p \tag{1}$$

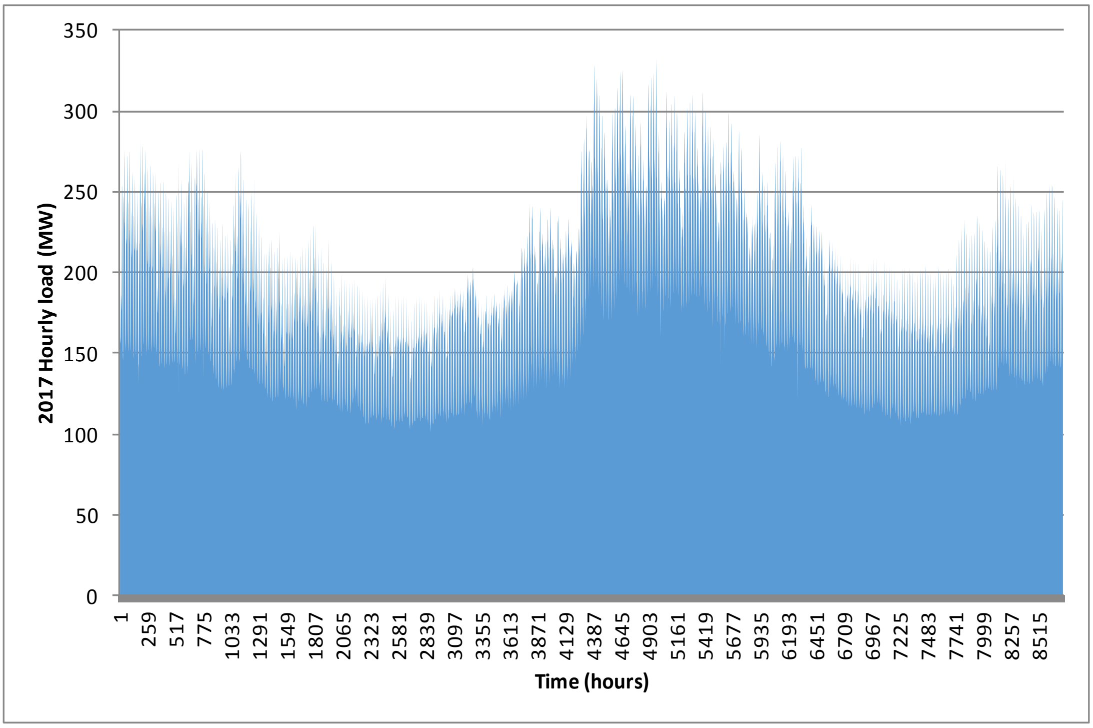
$$A = \pi r^2 \tag{2}$$

Table 3: Parameters Use to Calculate Wind Energy.

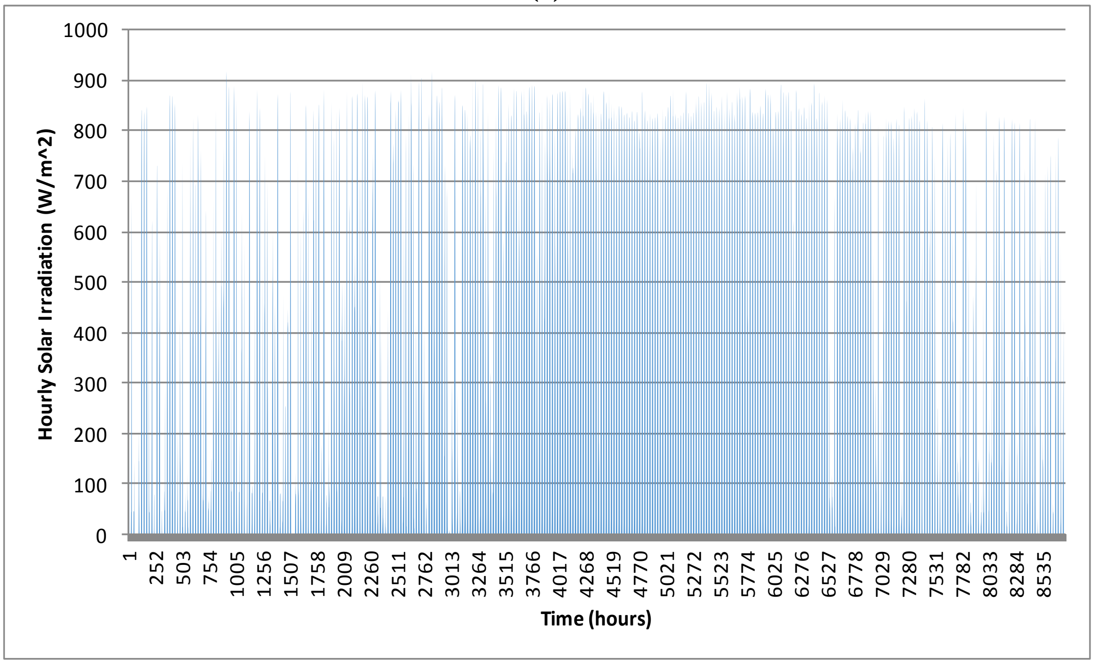
Parameters	Values
ρ	$1.22 Kg/m^3$
R	35.36m
C_p	0.4
π	3.14

We can't see electricity itself but to understand electricity it's very helpful to see a picture and the way to do so is by modeling. Why model? We model so we can quickly try many mixes of electricity generation to find which mix works based on assumptions made.

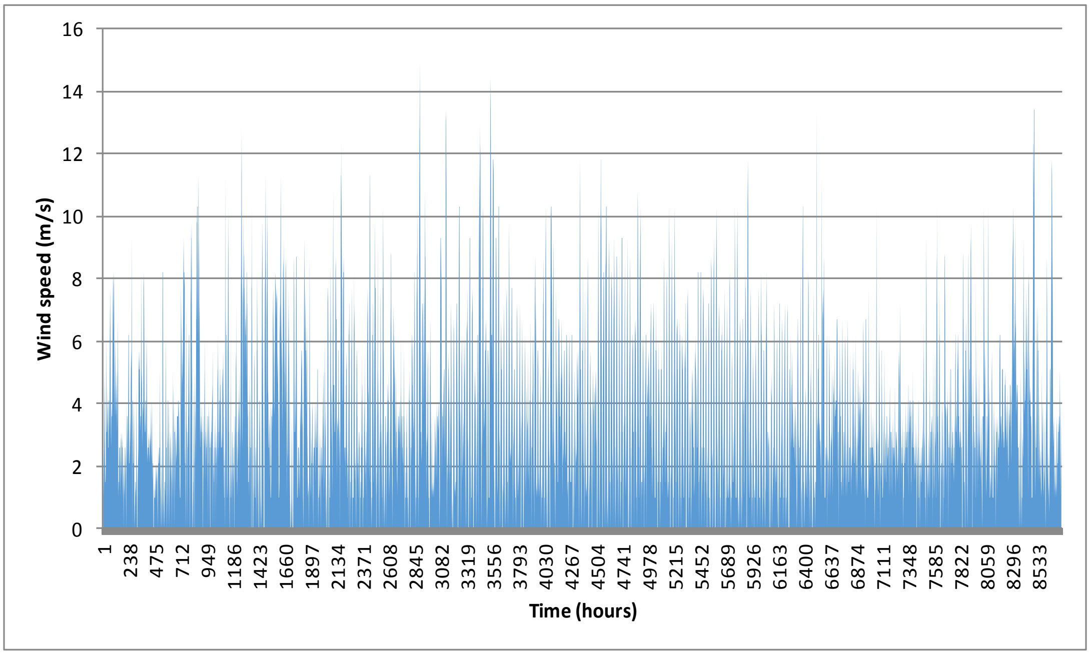
This model takes into account a solar power plant and a wind farm. Two scenarios was considered/investigated in this model. First scenario is renewable with baseload generation, and the other is renewable with no baseload, so as to see how baseload does not allow lots of renewable penetration.


2017 Hourly load (MW)
Time (hours)

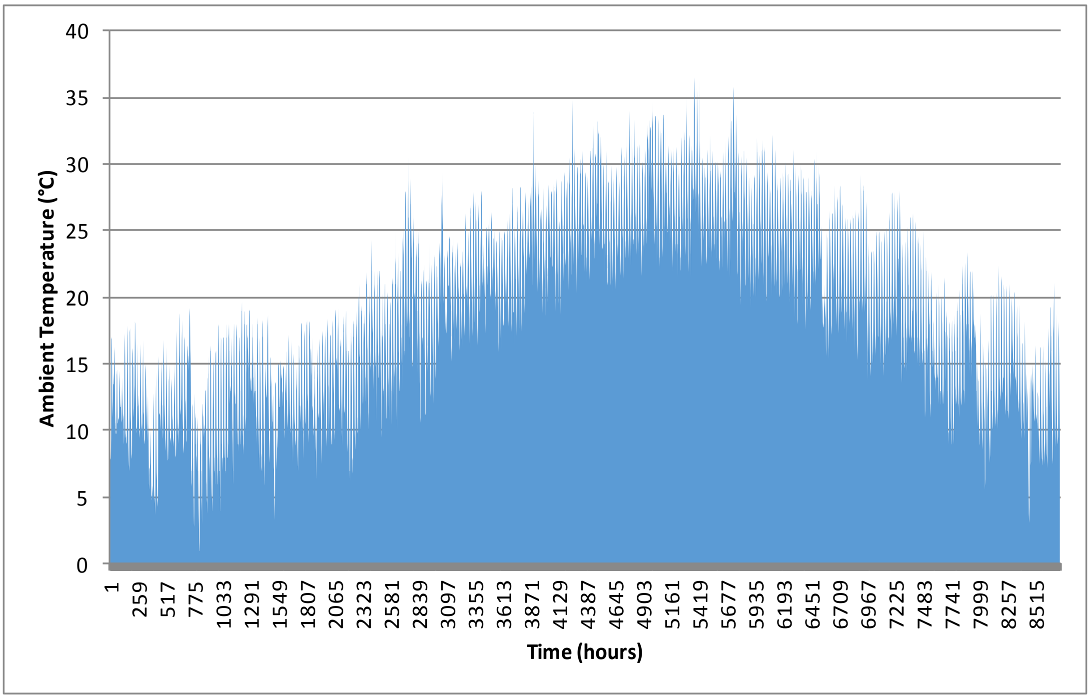
(a)


Hourly Solar Irradiation (W/m^2)
Time (hours)

(b)



(c)



(d)

Figure 15: TRNC Annual Load and Meteorological Conditions Used in Modeling. (a) 2017 Load (b) Beam Irradiance (c) Wind Speed and (d) Ambient Temperature.

The following mathematical equations and logical statements will help in other to understand the methodology and the results giving in the tables.

$$PV\ Annual\ Savings = \frac{Annual\ Savings}{(1+Discount\ Rate)^n} \quad (3)$$

$$PV\ Life\ Cycle\ Investment = \frac{Life\ Cycle\ Investment}{(1+Discount\ Rate)^n} \quad (4)$$

$$NPV = (\sum PV\ Annual\ Savings) - (\sum PV\ Life\ Cycle\ Investments) \quad (5)$$

$$SIR = \frac{(\sum PV\ Annual\ Savings)}{(\sum PV\ Life\ Cycle\ Investments)} \quad (6)$$

$$SPP = \frac{Initial\ Investment}{Annual\ Savings} \quad (7)$$

$$wind\ scaled\ RE\ (MWh) = \frac{wind\ installed\ capacity(MW) \times wind\ energy(MWh)}{name\ plate(MW)} \quad (8)$$

$$solare\ scaled\ RE(MWh) = \frac{solar\ installed\ capacity(MW) \times solar\ energy(MWh)}{name\ plate(MW)} \quad (9)$$

$$REG(MWh) = \text{wind scalled RE(MWh)} + \text{solar scaled RE(MWh)} \quad (10)$$

$$Annual\ REG(MWh) = \sum_{n=1}^{8760}(REG) \quad (11)$$

If $[Load(MWh) - REG(MWh)] > 0$ energy is been drawn from the battery, if there's no energy stored in the battery at that hour, back up will be in use.

If $[Load(MWh) - REG(MWh)]$ <0 the remaining energy generated at that hour will be stored in the battery, if and only if there's available space in the battery.

ESB is calculated with the following nested if statement

if $(((REG + baseload) - \ load\ ) > \ 0)$

{

if $(ASB\ > \ ((REG + baseload) - \ load))$

{

$ESB = \ (REG + baseload) - \ load$;

}

else

{

$ESB = ASB$;

}

}

else

{

$ESB = 0$;

}

RE Used (MWh) is calculated using the following if statement

if $([(load + ESB) - (REG + EDB)]$<0)

{

$RE\ Used\ (MWh) = (load + ESB)$;

}

$else$

{

$RE\ Used\ (MWh) = REG;$

}

$$Annual\ RE\ used\ (MWh) = \sum_{n=1}^{8760} RE\ Used\ (MWh) \tag{12}$$

The percentage of annual RE used (MWh) is calculated with the following if statement

$\text{if (anual load} = 0)$

{

$Annual\ RE\ used\ (\%) = 0;$

}

else

{

$Annual\ RE\ used\ (\%) = \frac{\text{Annual RE used (MWh)}}{Annual\ load\ (MWh)} \times 100$

}

$$Annual\ RE\ overgenerated(MWh) = \text{Annual REG} - \text{Annual RE used} \tag{13}$$

The percentage of annual RE over-generated (MWh) is calculated with the following if statement.

$\text{if (anual load} = 0)$

{

$Annual\ RE\ overgenerated\ (\%) = 0;$

}

else

{

$$Annual\ RE\ overgenerated\ (\%) = \frac{\text{Annual RE overgenerated (MWh)}}{Annual\ load\ (MWh)} \times 100\ ;$$

}

Energy curtailed (MWh) is calculated with the following if statement

$if([(load + ESB) - (REG + EDB)] < 0)$

{

$Energy\ curtailed\ (MWh)\ =\ -[(load + ESB)\ \ - (REG + EDB)];$

}

$else$

{

0;

}

Hours curtailed (hours) is calculated with the following if statement,

if ($Energy\ curtailed$>0)

{

$Hours\ curtailed(hours) = 1;$

}

else

{

$Hours\ curtailed(hours) = 0;$

}

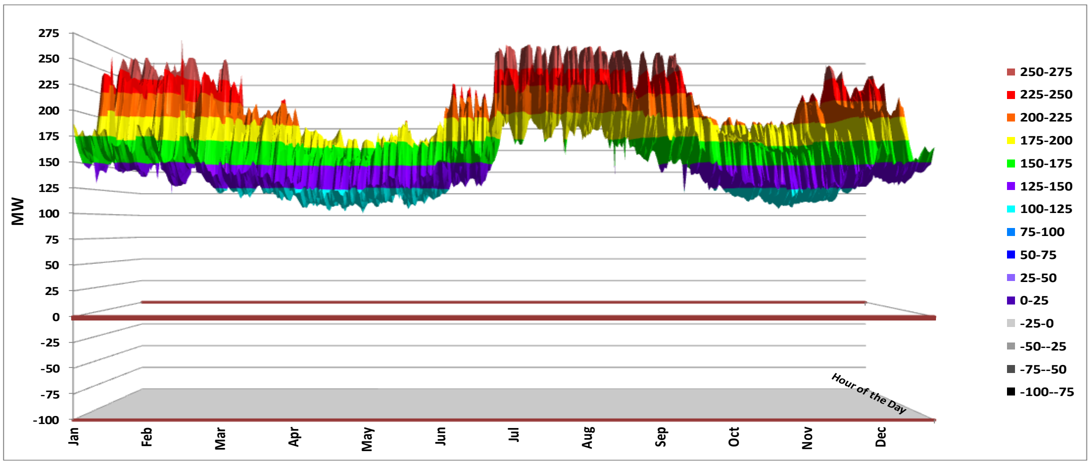
Annual hours curtailed is the sum of all the hours curtailed, used as a counter, if we curtailed at specific hour the counter is increased by 1, else it will be zero, from the above if statement.

$$Annual\ Hours\ curtailed(hours) = \sum_{n=1}^{8760} Hours\ curtailed \quad (14)$$

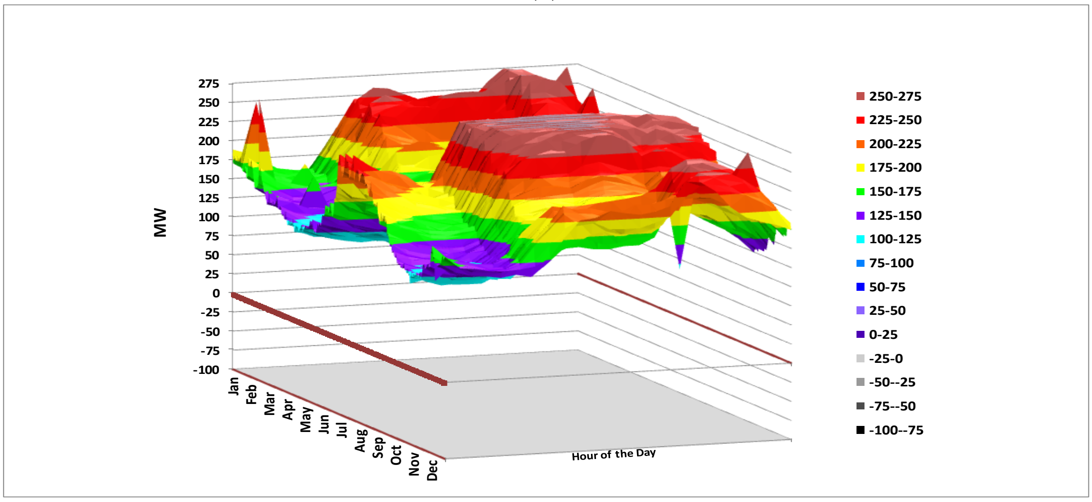
Table 4: Input and Output for 0% Renewable Energy

	SCENERIO 1	SCENERIO 2	
Energy storage(Battery)	8,000	8,000	MWh
Solar Installed Capacity	0	0	MW
Wind Installed Capacity	0	0	MW
Annual load	1,629,305	1,629,305	MWh
Annual RE Generated	0	0	MWh
Renewable Used and Useful When Net Load > 0			
Annual RE USED	0	0	MWh
Annual RE USED	0	0	%
Annual RE Over-Generated	0	0	MWh
Annual RE Over-Generated	0%	0%	%
Annual Hours Curtailed	0	0	Hours
Peak (maximum load minus renewable)	322	322	MW
Minimum (load minus renewables)	101	101	MW
Energy Withdrawn From Storage	0	0	MWh
Baseload generation	60	0	MW
Annual Load	1,629,305	1,629,305	MWh
Annual Baseload	525,600	0	MWh
Net Annual Load-Baseload	1,103,705	1,629,305	MWh
Annual RE Generated	0	0	MWh
Renewable Used and Useful When Net Load > baseload (assuming baseload is "must take")			
Annual RE USED	0	0	MWh
Annual RE USED	0	0	MWh
Annual RE Over-Generated	0	0	MWh
Annual RE Over-Generated	0	0	%
Annual Hours Curtailed	0	0	Hours

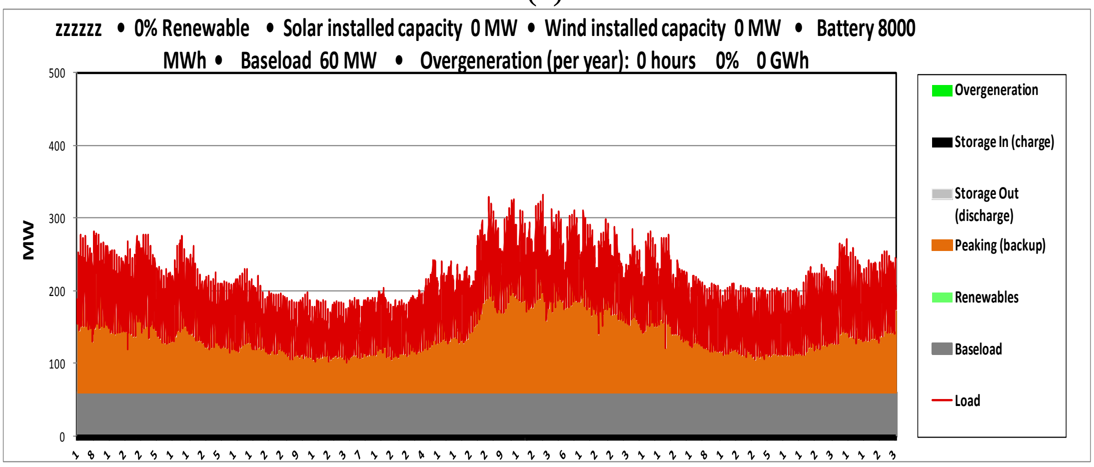
From Table 4 above the solar system size is 0MW, wind is 0MW and battery size of 800MWh. The annual REG is 0 MWh, TRNC 2017 annual load is 1,629,305MWh, baseload is 60MW, which will plot the TRNC load in Figure 15 bellow.



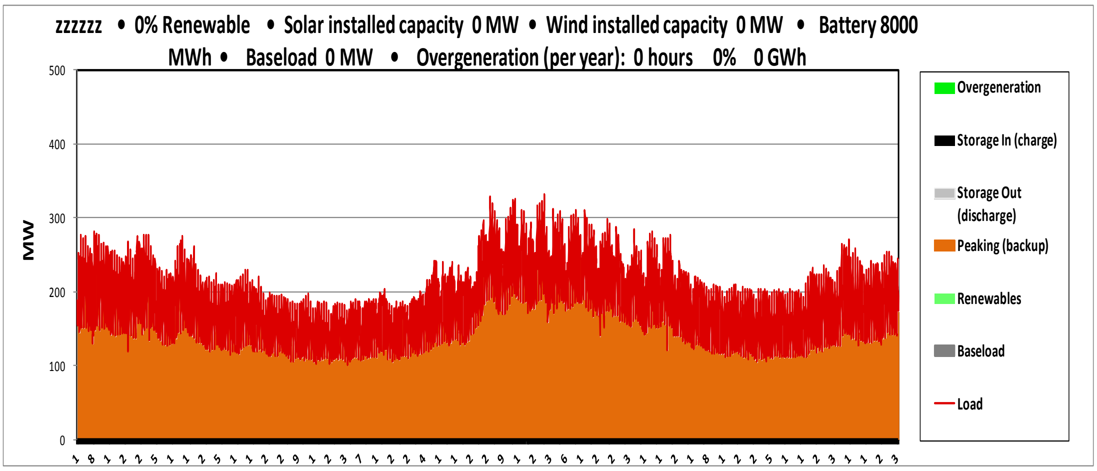
(a)



(b)



(c)



(d)

Figure 16: Load Plot 0% Renewable. (a) 3-D Plot Parallel View. (b) 3-D Plot Elevated View. (c) 2-D Plot with Baseload (Scenario 1). (d) 2-D Plot with No Baseload (Scenario 2).

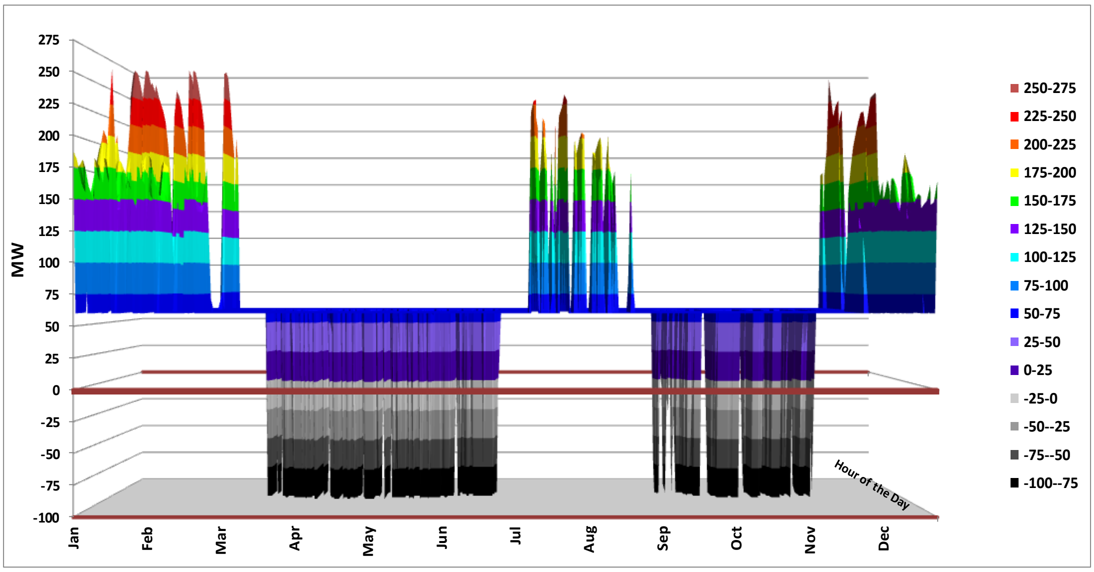
The load plot above is similar to that of a village belonging to the city of Hafar Al-Batin, in the eastern province, Saudi Arabia [2], and generally most cities/countries with winter and summer season have similar load curve.

Table 5: Input and Output; 69% Renewable for Scenario 1 and 79% Renewable for Scenario 2.

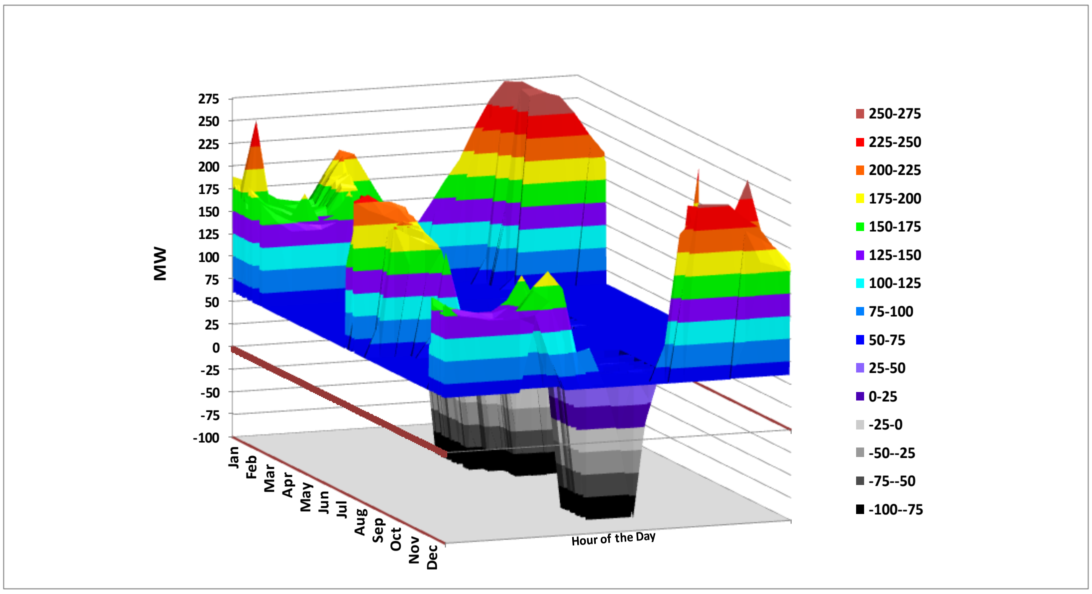
	SCENERIO 1	SCENERIO 2	
Energy storage(Battery)	8000	8000	MWh
Solar Installed Capacity	800	800	MW
Wind Installed Capacity	0	0	MW
Annual Load	1,629,305	1,629,305	MWh
Annual RE Generated	1,291,641	1,291,641	MWh
Renewable Used and Useful When Net Load > 0			
Annual RE USED	1,131,066	1,288,195	MWh
Annual RE USED	69	79	%
Annual RE Over-Generated	160,575	3,446	MWh
Annual RE Over-Generated	10%	0%	%
Annual Hours Curtailed	699	17	Hours
Peak (maximum load minus renewable)	278	278	MW
Minimum (load minus renewable)	-522	-428	MW
Energy Withdrawn From Storage	527,845	546,906	MWh
Baseload Generation	60	0	MW
Annual Load	1,629,305	1,629,305	MWh
Annual Baseload	525,600	0	MWh
Net Annual Load-Baseload	1,103,705	1,629,305	MWh

Annual RE Generated	1,291,641	1,291,641	MWh
Renewable Used and Useful When Net Load > baseload (assuming baseload is "must take")			
Annual RE USED	1,085,856	1,288,195	MWh
Annual RE USED	67	79	MWh
Annual RE over-generated	205,785	3,446	MWh
Annual RE over-generated	19	0	%
Annual Hours Curtailed	889	17	Hours

Clearly, it can be seen from Table 5 that with a solar system size of 800MW, wind of 0MW and battery size of 800MWh. The annual REG is 1,291,641MWh to meet TRNC 2017 annual load of 1,629,305MWh. Also we have 0% over-generation without using baseload, with baseload of 60MW we have 10% of over-generation and if we assume baseload as must take energy over-generation will increase to 19%.

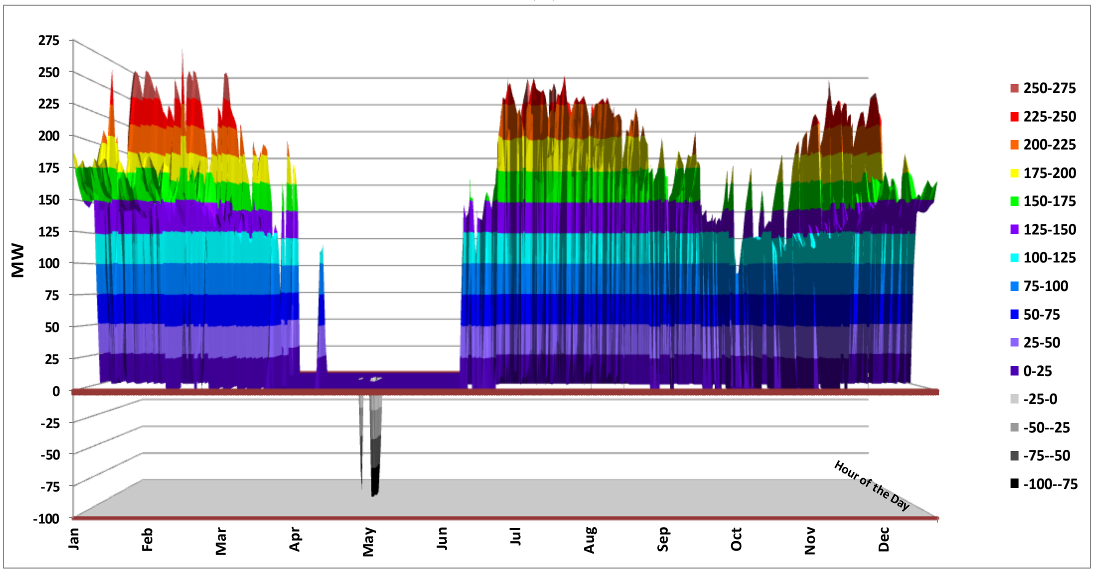


(a)



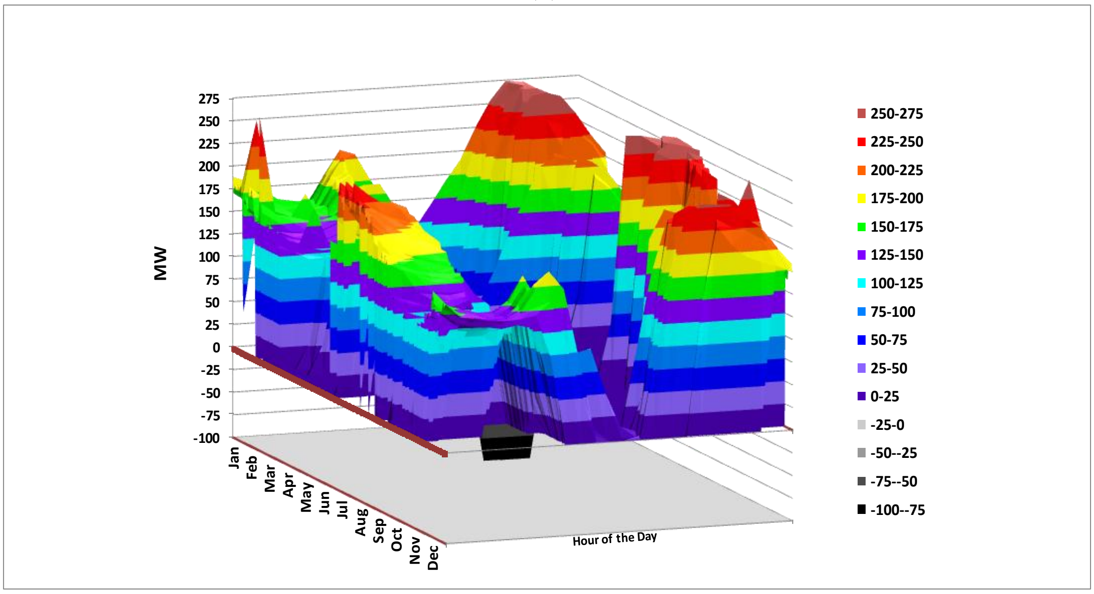
MW
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

(b)



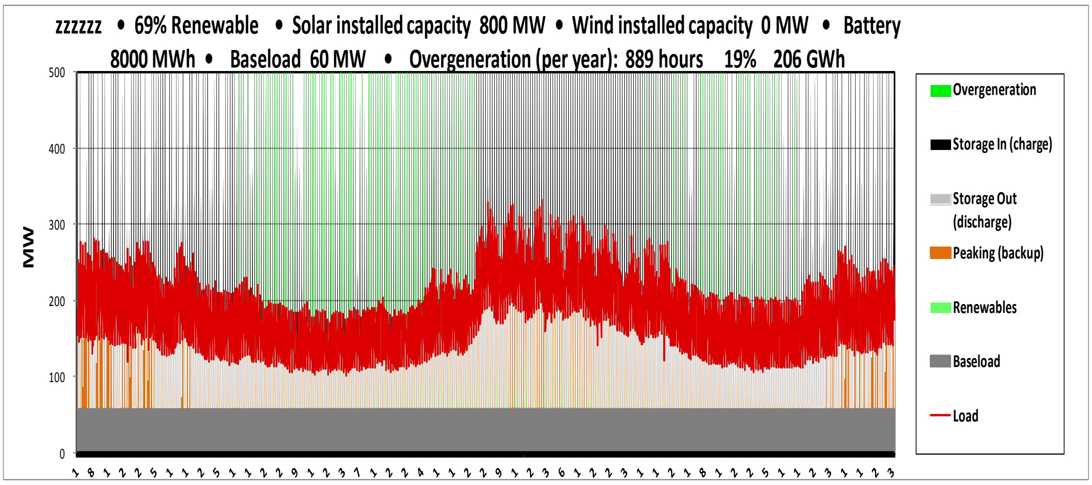
MW
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

(c)

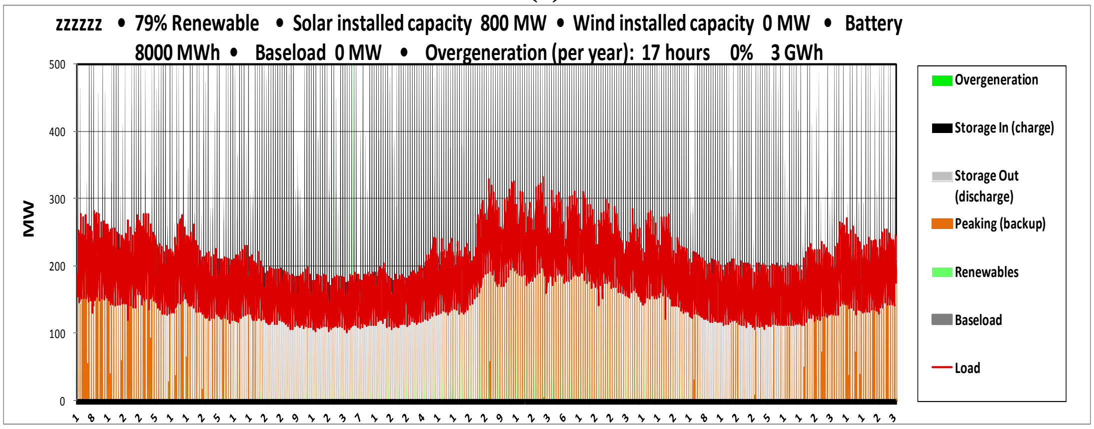


MW
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

(d)



(e)



(f)

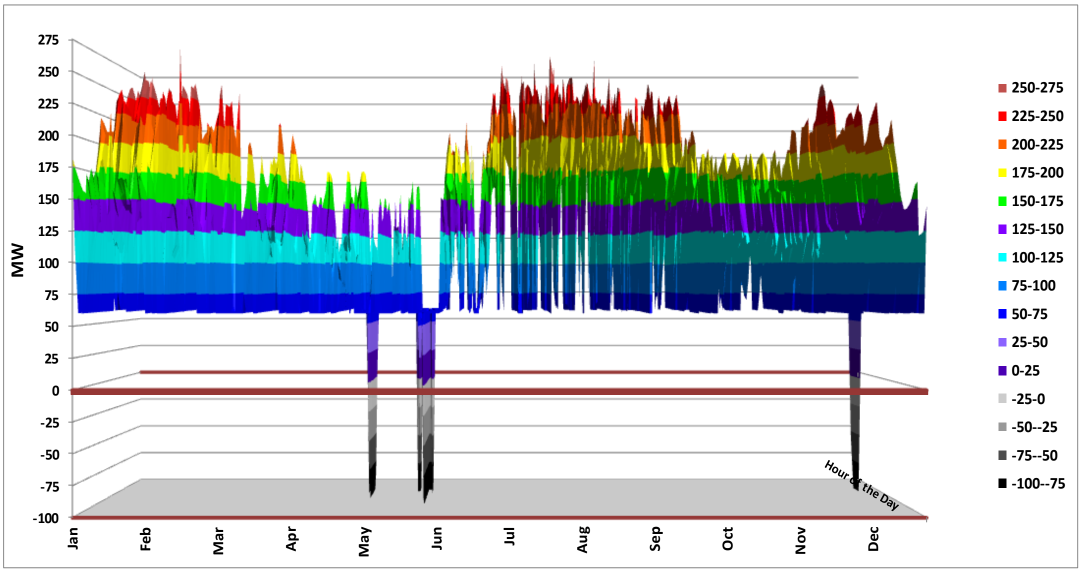
Figure 17: Load Plot with 69% Renewable for Scenario 1 and 79% Renewable For Scenario 2. (a) 3-D Plot Parallel View with Baseload (Scenario 1). (b) 3-D Plot Elevated View with Baseload (Scenario 1). (c) 3-D Plot Parallel View with no Baseload (Scenario 2). (d) 3-D Plot Elevated View with no Baseload (Scenario 2). (e) 2-D Plot with Baseload (Scenario 1). (f) 2-D Plot with no Baseload (Scenario 2).

From Figure 15(a) it can be seen that the minimum demand (load) is at about 100MW, when we penetrate some amount of renewable, some of the load fall below 100MW as shown in Figure 16(a). This symbolize that the load between 100Mw and 0MW is the amount of demand that has been met by the amount of renewable energy penetrated. The remaining above 100MW is the load left to be meet, while the load bellow 0MW symbolize the amount of over-generation, and the same applies for the rest of the 3-D plots shown in this chapter. The 3-D plot also quickly help in seeing the periods of backup and over-generation, the 100MW and 0MW has been indicated with the black and orange line, across the 3-D plots.

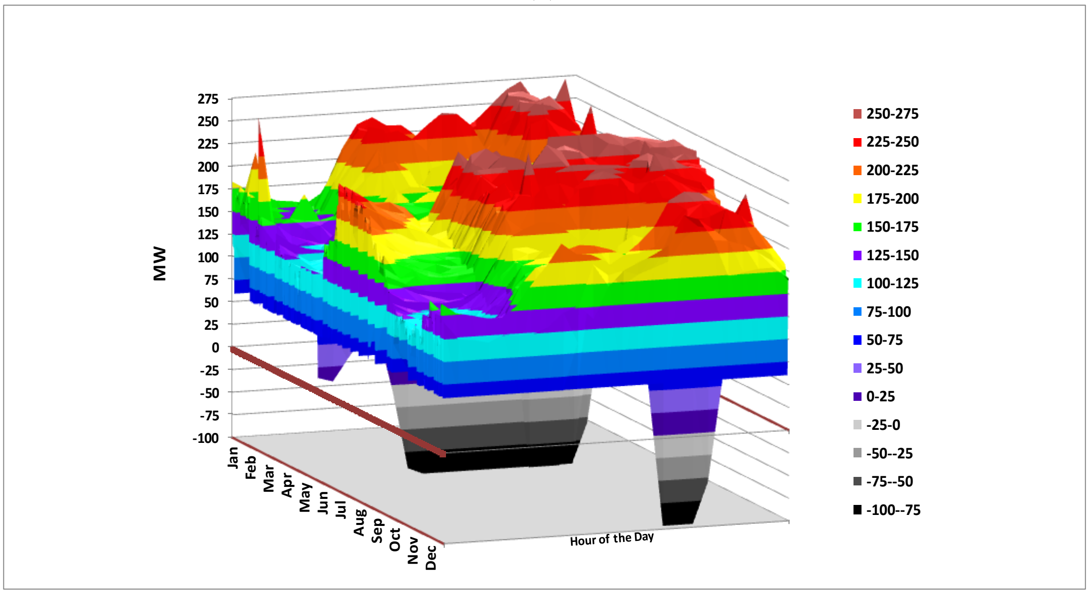
Table 6: Input and Output; 33% Renewable for Scenario 1 and 34% Renewable for Scenario 2.

	SCENERIO 1	SCENERIO 2	
Energy storage(Battery)	8000	8000	MWh
Solar Installed Capacity	0	0	MW
Wind Installed Capacity	800	800	MW
Annual Load	1,629,305	1,629,305	MWh
Annual RE Generated	556,873	556,873	MWh
Renewable Used and Useful When Net Load > 0			
Annual RE USED	536,442	548,793	MWh
Annual RE USED	33	34	%
Annual RE Over-Generated	20,431	8,080	MWh
Annual RE Over-Generated	1	0	%
Annual Hours Curtailed	54	22	Hours
Peak (maximum load minus renewable)	311	11	MW
Minimum (load minus renewable)	-1,219	-664	MW
Energy Withdrawn From Storage	164,058	126,872	MWh
Baseload Generation	60	0	MW
Annual Load	1,629,305	1,629,305	MWh
Annual Baseload	525,600	0	MWh
Net Annual Load-Baseload	1,103,705	1,629,305	MWh
Annual RE Generated	556,873	556,873	MWh
Renewable Used and Useful When Net Load > baseload (assuming baseload is “must take”)			
Annual RE USED	532,878	548,793	MWh
Annual RE USED	33	34	%
Annual RE over-generated	23,995	8,080	MWh
Annual RE over-generated	2	0	%
Annual Hours Curtailed	68	22	Hours

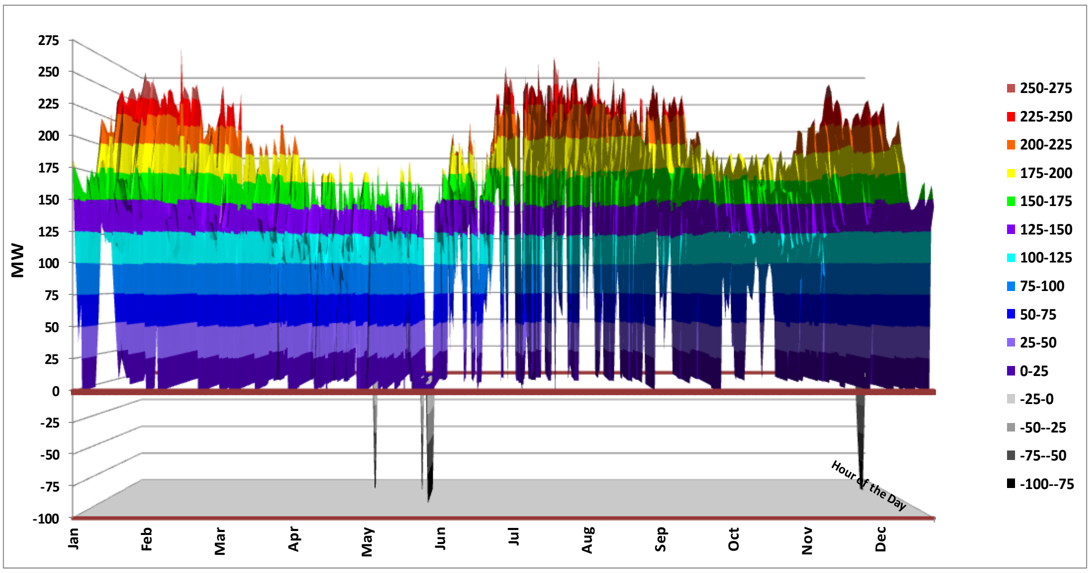
It can be seen from Table 6 that with a solar system size of 0MW, wind of 800MW and battery size of 800MWh. The annual REG is 556,873MWh to meet TRNC 2017 annual load of 1,629,305MWh. Also we have 0% over-generation without using baseload, with baseload of 60MW we have 1% of over-generation and if we assume baseload as must take energy over-generation will increase to 2%.



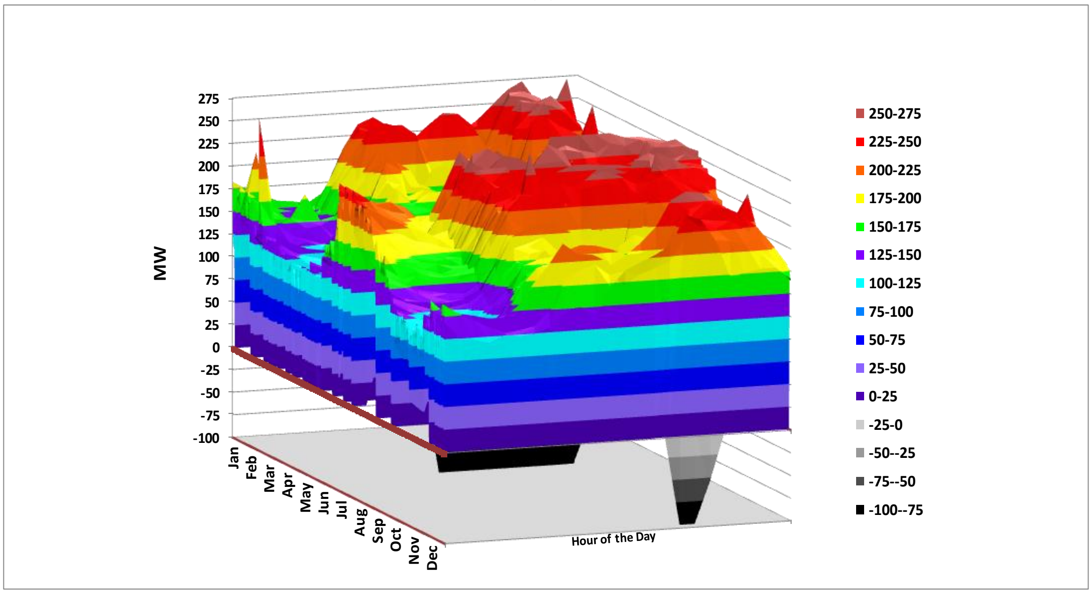
(a)



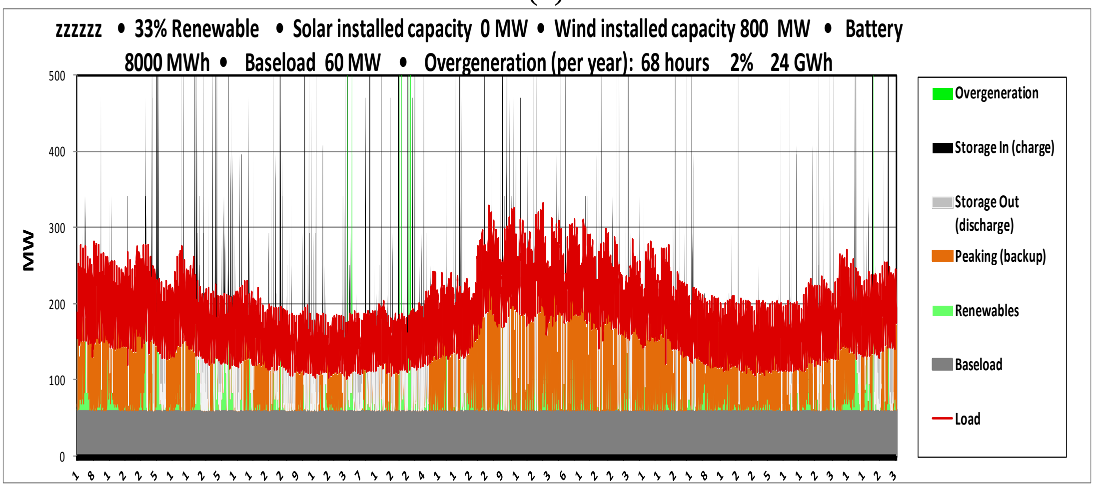
(b)


MW
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

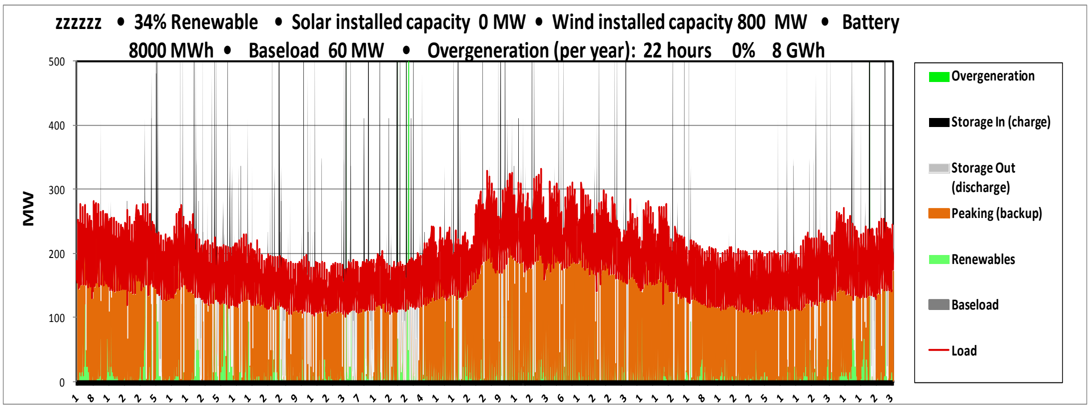
(c)


MW
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

(d)


zzzzzz • 33% Renewable • Solar installed capacity 0 MW • Wind installed capacity 800 MW • Battery 8000 MWh • Baseload 60 MW • Overgeneration (per year): 68 hours 2% 24 GWh
MW
500
400
300
200
100
0
Overgeneration
Storage In (charge)
Storage Out (discharge)
Peaking (backup)
Renewables
Baseload
Load

(e)



(f)

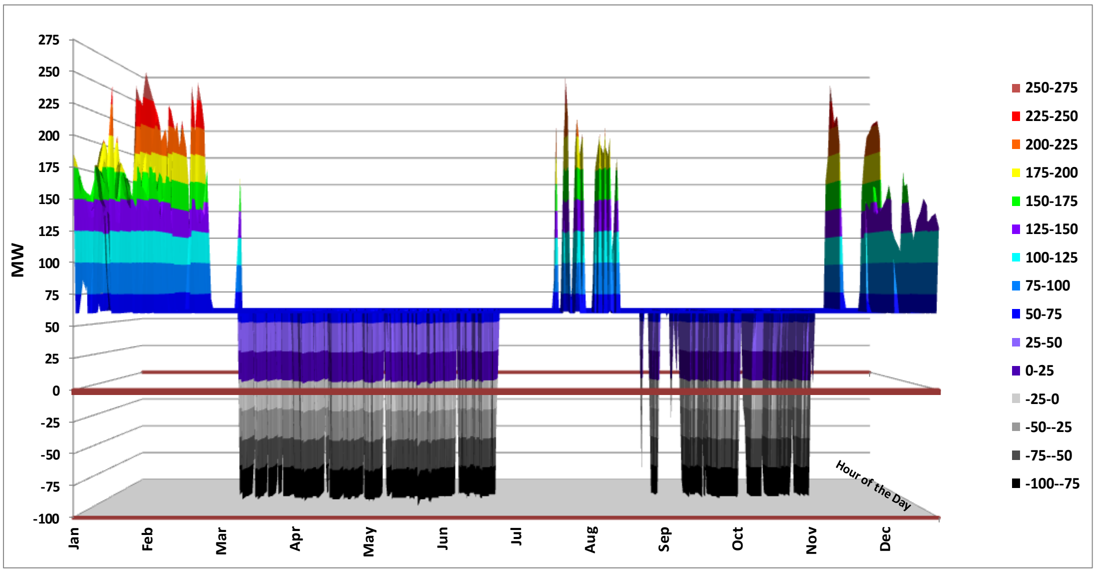
Figure 18: Load Plot with 33% Renewable for Scenario 1 and 34% Renewable for Scenario 2. (a) 3-D Plot Parallel View with Baseload (Scenario 1). (b) 3-D Plot Elevated View with Baseload (Scenario 1). (c) 3-D Plot Parallel View with No Baseload (Scenario 2). (d) 3-D Plot Elevated View with No Baseload (Scenario 2). (e) 2-D Plot with Baseload (Scenario 1). (f) 2-D Plot with No Baseload (Scenario 2).

Table 7: Input and Output; 71% Renewable for Scenario 1 and 81% Renewable for Scenario 2.

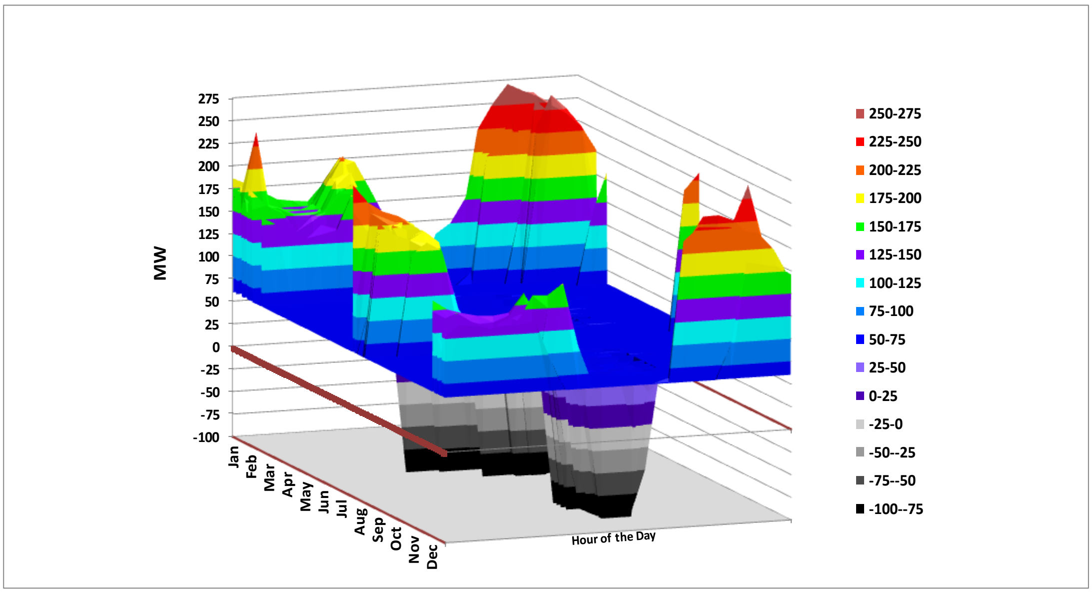
	SCENERIO 1	SCENERIO 2	
Energy storage(Battery)	8000	8000	MWh
Solar Installed Capacity	700	700	MW
Wind Installed Capacity	300	300	MW
Annual Load	1,629,305	1,629,305	MWh
Annual RE Generated	1,339,013	1,339,013	MWh
Renewable Used and Useful When Net Load > 0			
Annual RE USED	1,154,156	1,312,927	MWh
Annual RE USED	71	81	%
Annual RE Over-Generated	184,857	26,086	MWh
Annual RE Over-Generated	11	2	%
Annual Hours Curtailed	742	93	Hours
Peak (maximum load minus renewable)	273	275	MW
Minimum (load minus renewable)	-989	-989	MW
Energy Withdrawn From Storage	498,473	517,759	MWh
Baseload Generation	60	0	MW
Annual Load	1,629,305	1,629,305	MWh
Annual Baseload	525,600	0	MWh
Net Annual Load-Baseload	1,103,705	1,629,305	MWh
Annual RE Generated	1,339,013	1,339,013	MWh
Renewable Used and Useful When Net Load > baseload (assuming baseload is “must take”)			
Annual RE USED	1,105,949	1,312,927	MWh

Annual RE USED	68	81	%
Annual RE over-generated	233,064	26,086	MWh
Annual RE over-generated	21	2	%
Annual Hours Curtailed	935	93	Hours

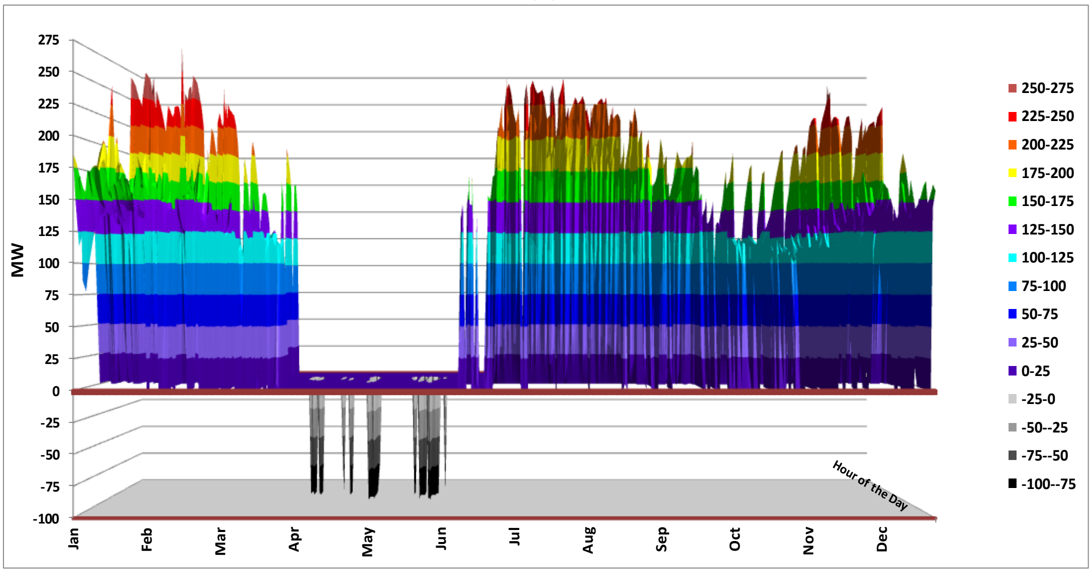
Clearly, it can be seen from Table 7 that with a solar system size of 700MW, wind of 3000MW and battery size of 800MWh. The annual REG is 1,339,013MWh to meet TRNC 2017 annual load of 1,629,305MWh. Also we have 2% over-generation without using baseload, with baseload of 60MW we have 11% of over-generation and if we assume baseload as must take energy over-generation will increase to 21%.



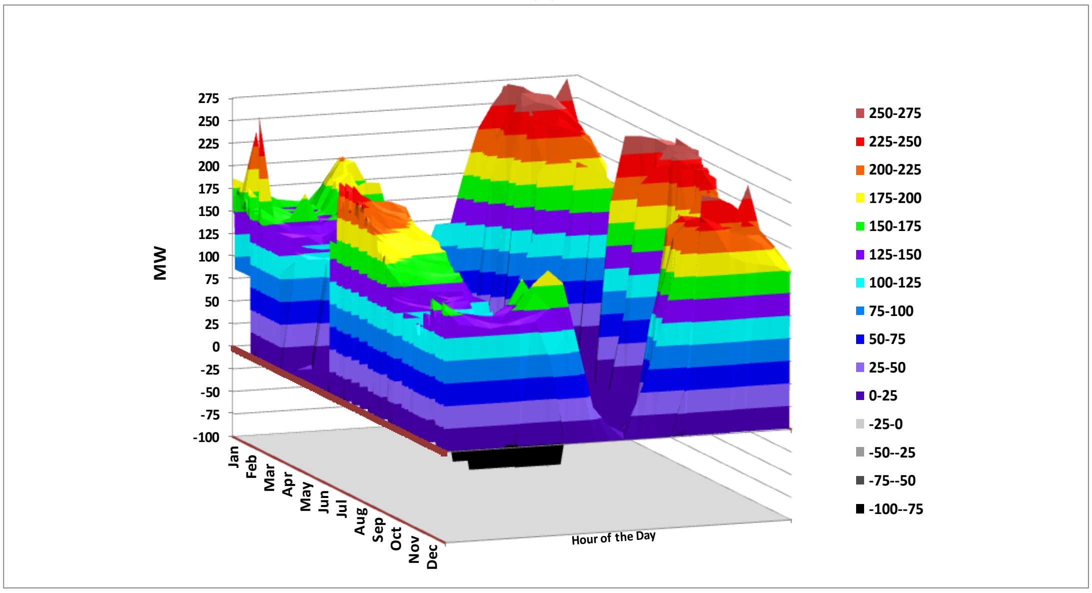
(a)


MW
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

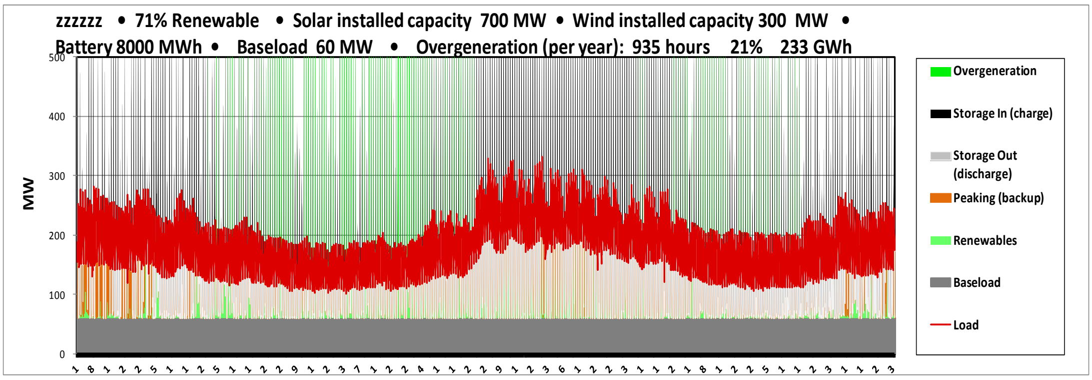
(b)


MW
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

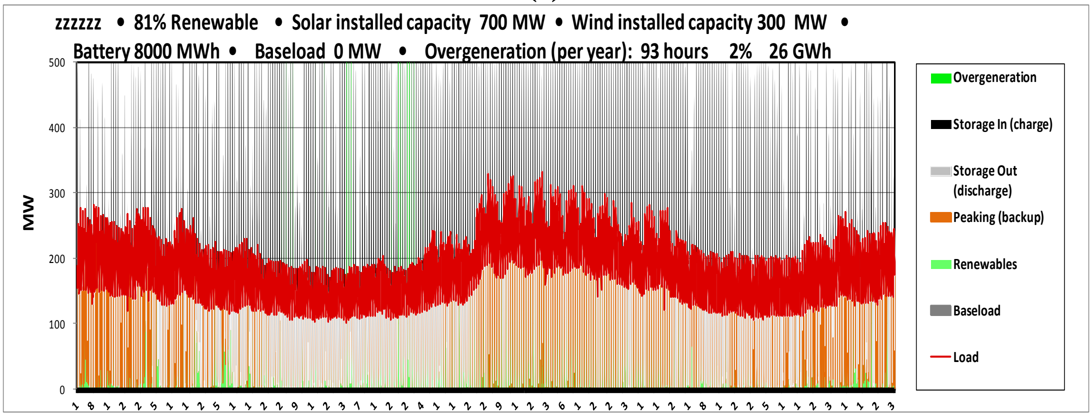
(c)


MW
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

(d)



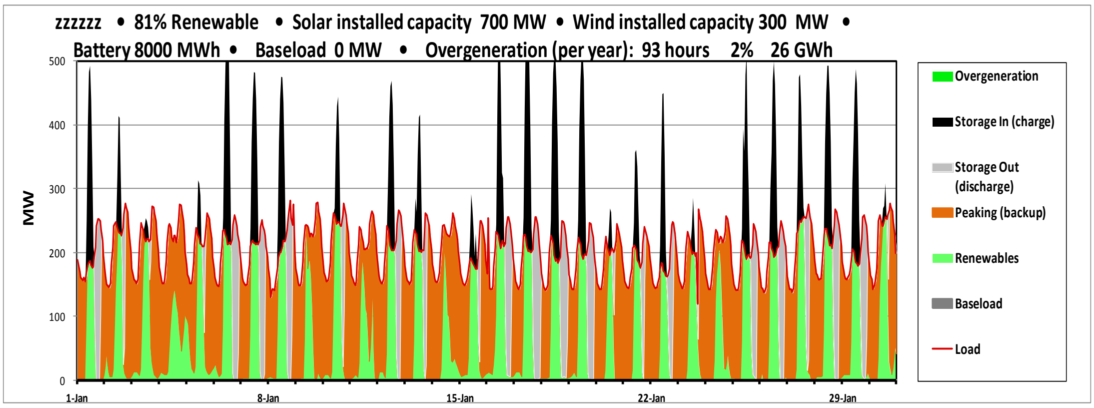
(e)



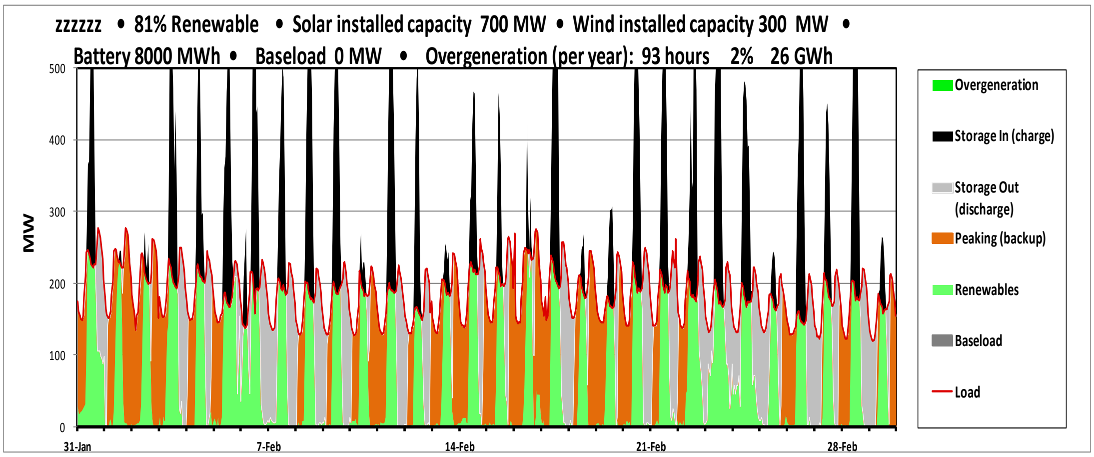
(f)

Figure 19: Load Plot with 71% Renewable for Scenario 1 and 81% Renewable for Scenario 2. (a) 3-D Plot Parallel View with Baseload (Scenario 1). (b) 3-D Plot Elevated View with Baseload (Scenario 1). (c) 3-D Plot Parallel View with No Baseload (Scenario 2). (d) 3-D Plot Elevated View with No Baseload (Scenario 2). (e) 2-D Plot with Baseload (Scenario 1) (f) 2-D Plot with No Baseload (Scenario 2).

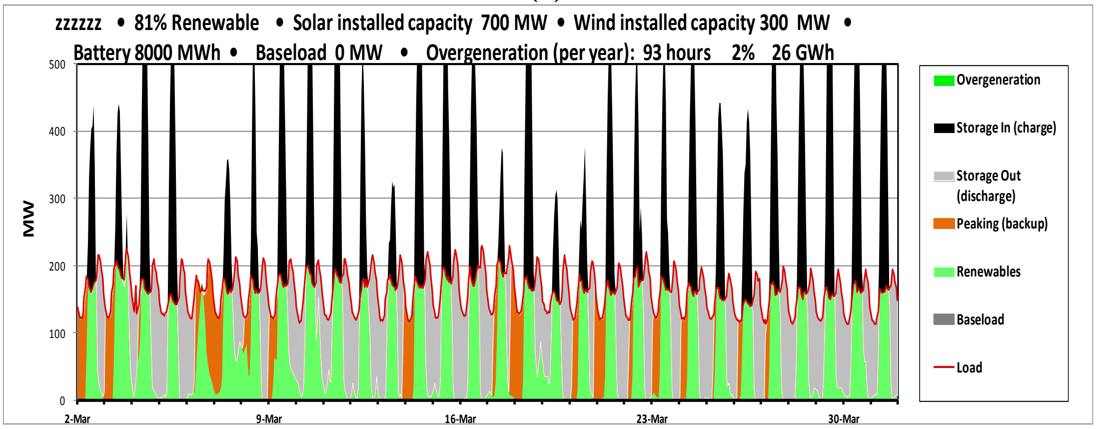
The Figure 19(d) above is a plot of too much information in one graph, it's a plot of all the 365 days in a year. It will be nice to slide through it to see the period of backups clearly, Figure 20 bellow will plot 30 days interval, for a better view.



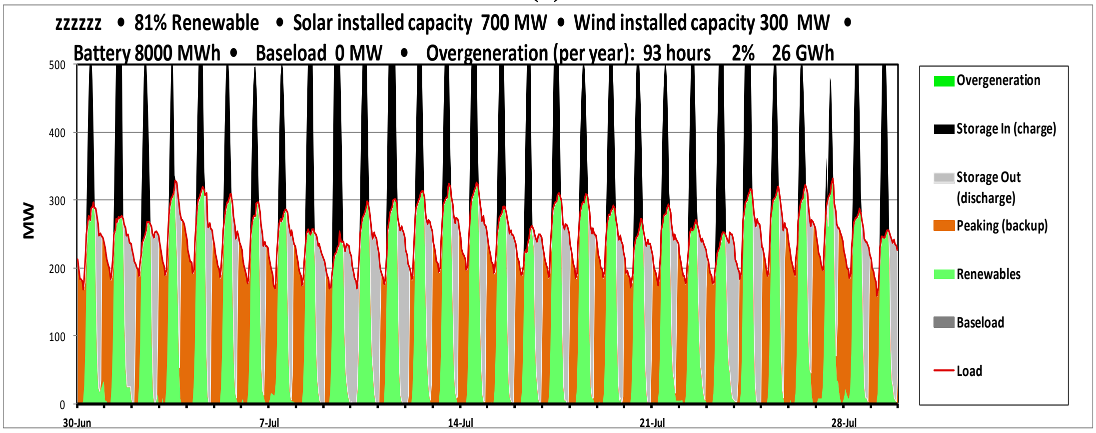
(a)


zzzzzz • 81% Renewable • Solar installed capacity 700 MW • Wind installed capacity 300 MW •
Battery 8000 MWh • Baseload 0 MW • Overgeneration (per year): 93 hours 2% 26 GWh
MW
500
400
300
200
100
0
31-Jan
7-Feb
14-Feb
21-Feb
28-Feb
Overgeneration
Storage In (charge)
Storage Out (discharge)
Peaking (backup)
Renewables
Baseload
Load

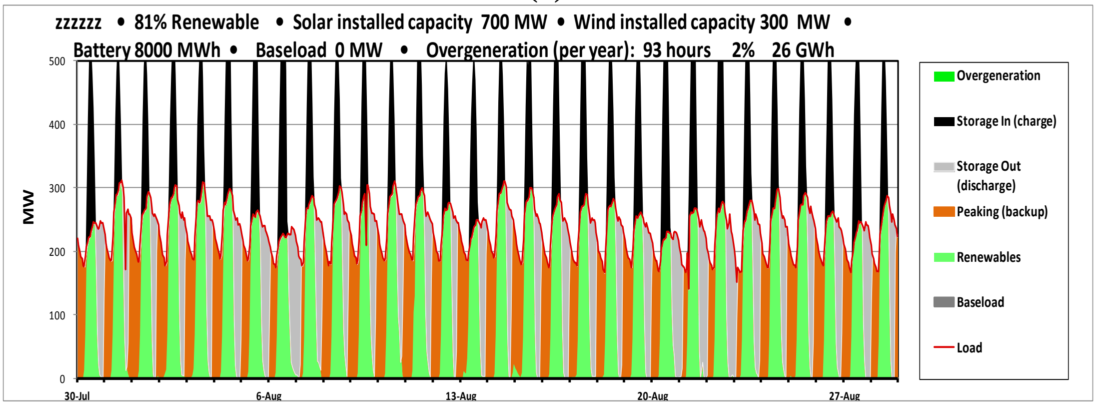
(b)


zzzzzz • 81% Renewable • Solar installed capacity 700 MW • Wind installed capacity 300 MW •
Battery 8000 MWh • Baseload 0 MW • Overgeneration (per year): 93 hours 2% 26 GWh
MW
500
400
300
200
100
0
2-Mar
9-Mar
16-Mar
23-Mar
30-Mar
Overgeneration
Storage In (charge)
Storage Out (discharge)
Peaking (backup)
Renewables
Baseload
Load

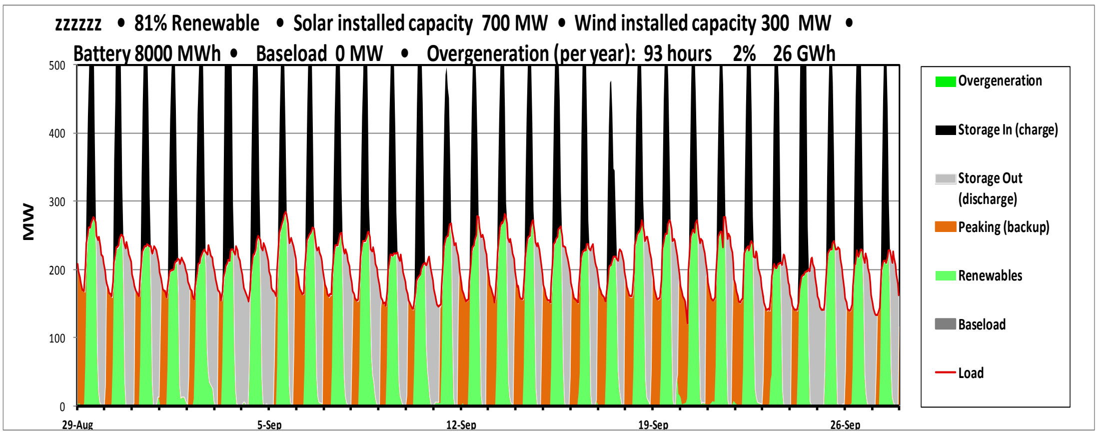
(c)


zzzzzz • 81% Renewable • Solar installed capacity 700 MW • Wind installed capacity 300 MW •
Battery 8000 MWh • Baseload 0 MW • Overgeneration (per year): 93 hours 2% 26 GWh
MW
500
400
300
200
100
0
30-Jun
7-Jul
14-Jul
21-Jul
28-Jul
Overgeneration
Storage In (charge)
Storage Out (discharge)
Peaking (backup)
Renewables
Baseload
Load

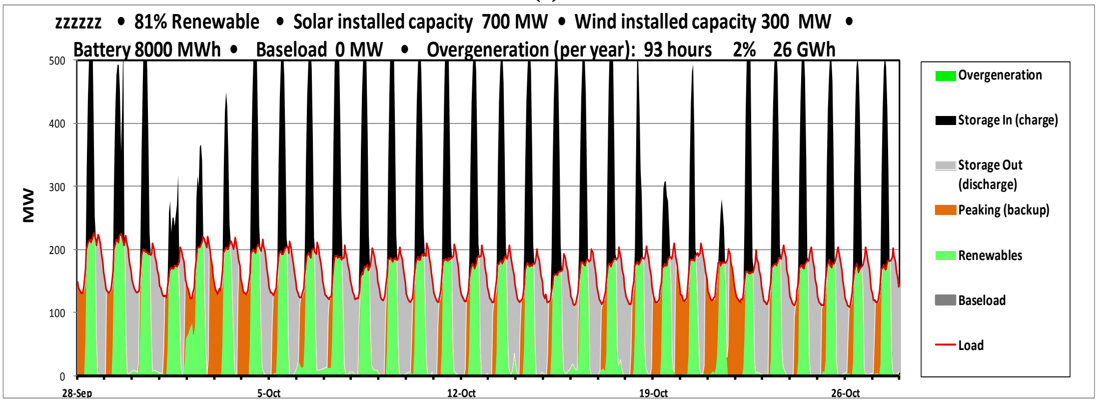
(d)


zzzzzz • 81% Renewable • Solar installed capacity 700 MW • Wind installed capacity 300 MW •
Battery 8000 MWh • Baseload 0 MW • Overgeneration (per year): 93 hours 2% 26 GWh
MW
500
400
300
200
100
0
30-Jul
6-Aug
13-Aug
20-Aug
27-Aug
Overgeneration
Storage In (charge)
Storage Out (discharge)
Peaking (backup)
Renewables
Baseload
Load

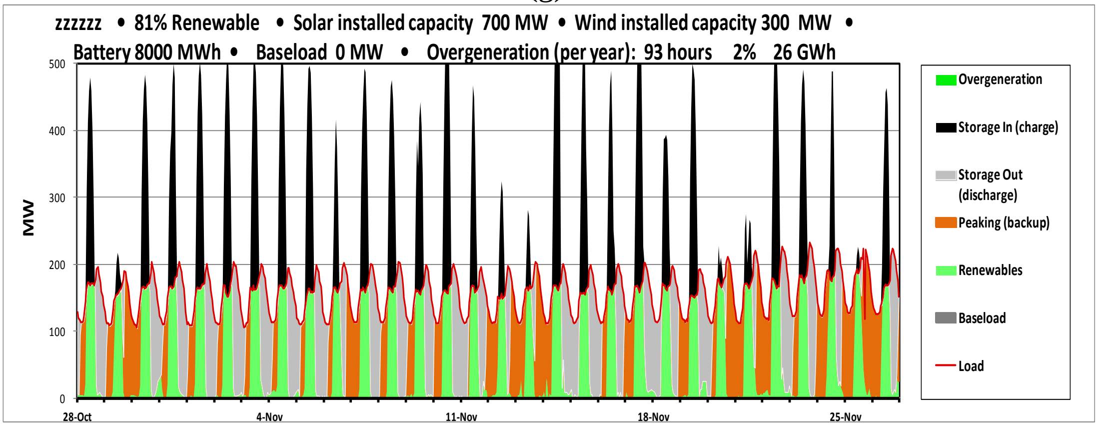
(e)


zzzzzz • 81% Renewable • Solar installed capacity 700 MW • Wind installed capacity 300 MW •
Battery 8000 MWh • Baseload 0 MW • Overgeneration (per year): 93 hours 2% 26 GWh
MW
Overgeneration
Storage In (charge)
Storage Out (discharge)
Peaking (backup)
Renewables
Baseload
Load
29-Aug
5-Sep
12-Sep
19-Sep
26-Sep

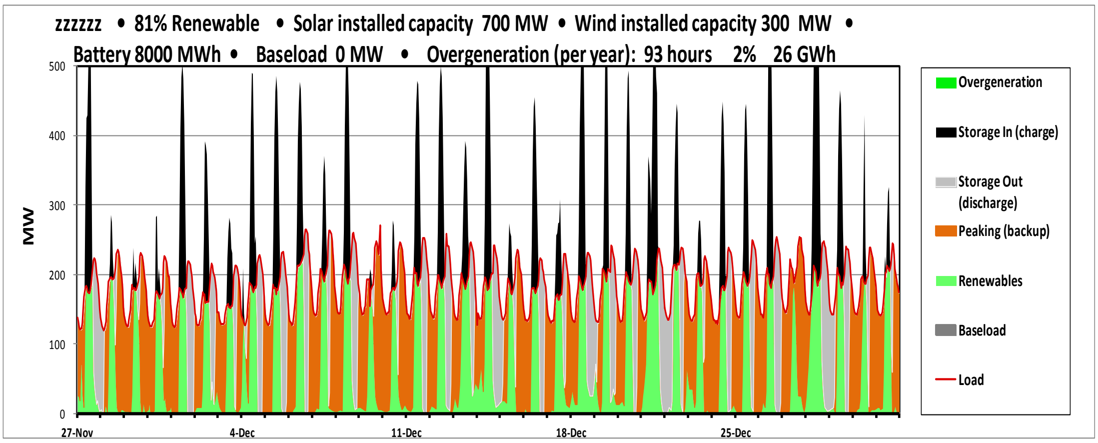
(f)


zzzzzz • 81% Renewable • Solar installed capacity 700 MW • Wind installed capacity 300 MW •
Battery 8000 MWh • Baseload 0 MW • Overgeneration (per year): 93 hours 2% 26 GWh
MW
Overgeneration
Storage In (charge)
Storage Out (discharge)
Peaking (backup)
Renewables
Baseload
Load
28-Sep
5-Oct
12-Oct
19-Oct
26-Oct

(g)


zzzzzz • 81% Renewable • Solar installed capacity 700 MW • Wind installed capacity 300 MW •
Battery 8000 MWh • Baseload 0 MW • Overgeneration (per year): 93 hours 2% 26 GWh
MW
Overgeneration
Storage In (charge)
Storage Out (discharge)
Peaking (backup)
Renewables
Baseload
Load
28-Oct
4-Nov
11-Nov
18-Nov
25-Nov

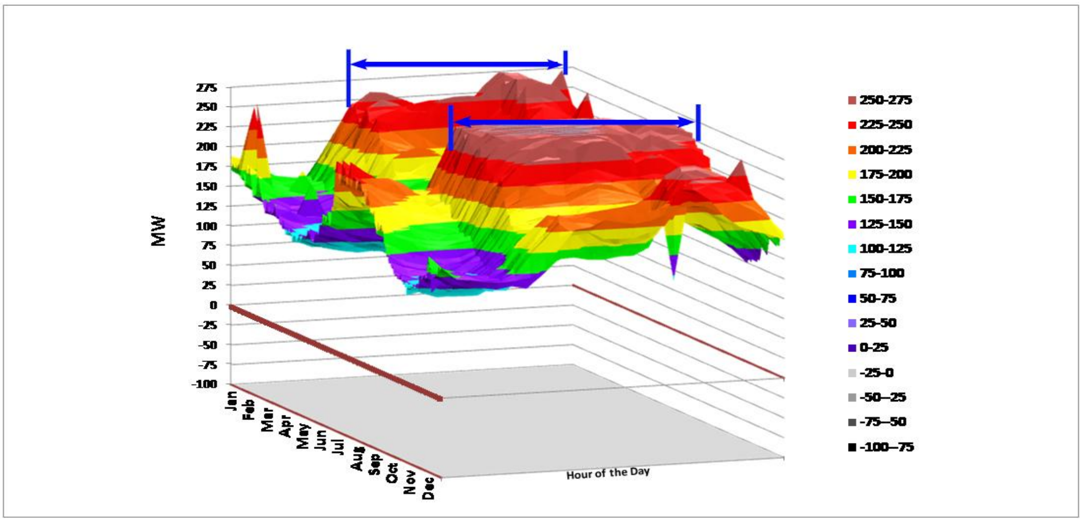
(h)



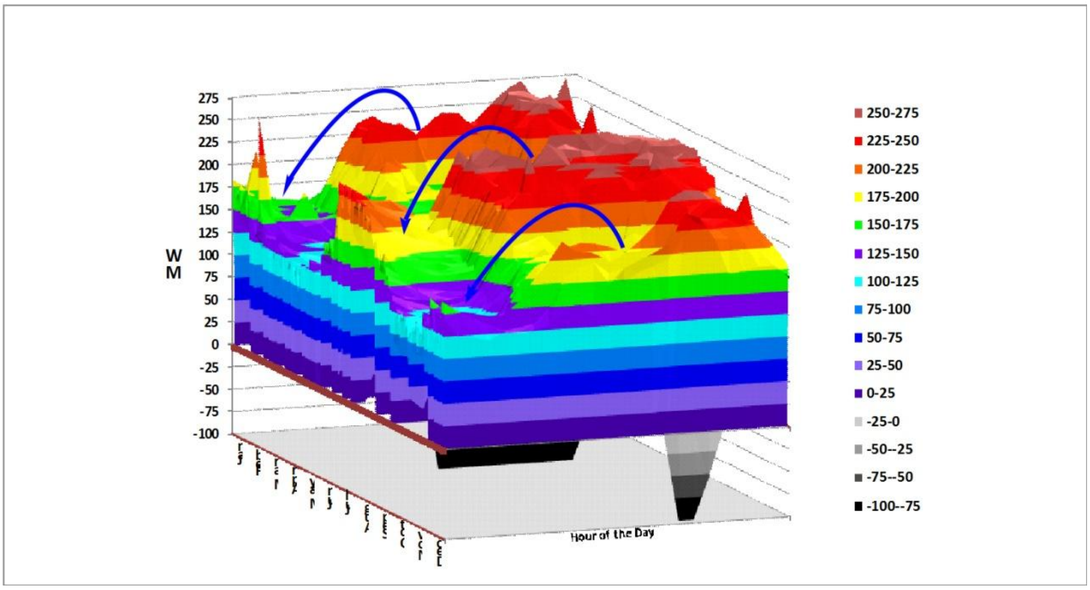
(i)

Figure 20: Load Plot with 92% Renewable for Scenario 2. (a) From 1st of January – 30th of January (b) From 31st of January – 1st of March (c) From 2nd of March – 31st of March (d) From 30th of June – 29th of July (e) From 30th of July – 28th of August (f) From 29th of August – 27th of September (g) From 28th of September – 27th of October (h) From 28th of October – 26th of November (i) From 27th of November – 31st of December.

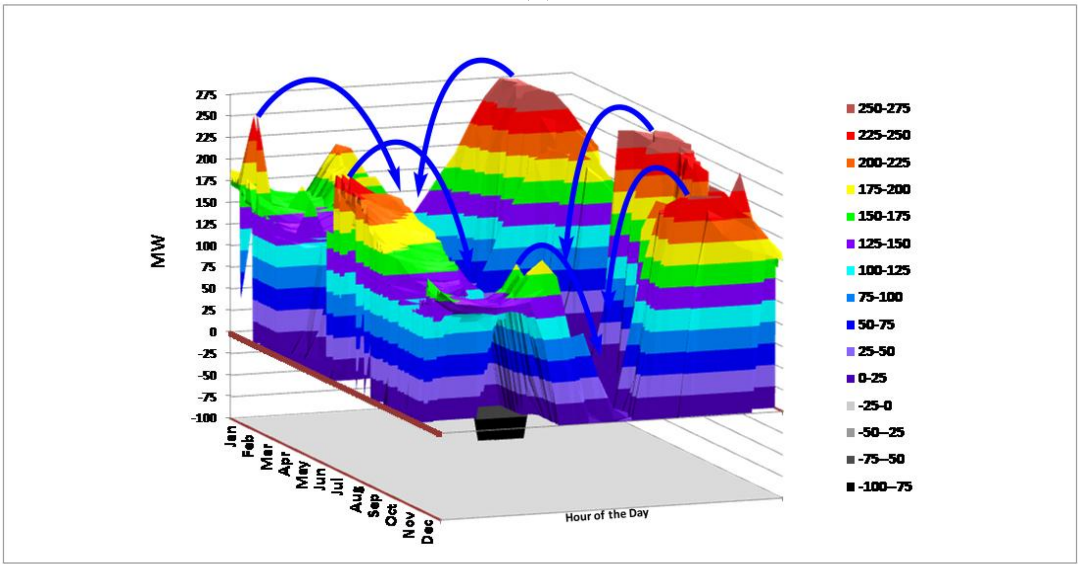
The more renewable energy penetration the more narrow the peak becomes which will give room for load shifting on the DSM, Figure 21 bellow illustrate this phenomenon better.



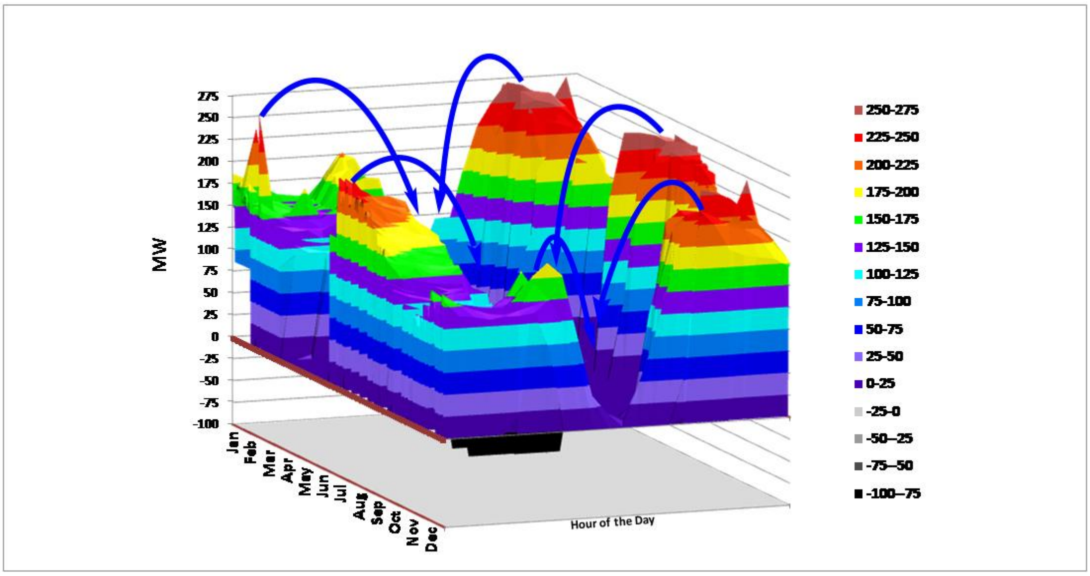
(a)


275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

(b)


MW
275
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Hour of the Day
250-275
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50-75
25-50
0-25
-25-0
-50--25
-75--50
-100--75

(c)



(d)

Figure 21: 3-D Plot Elevated View for Scenario 2. (a) 0% Renewable Energy (2017 TRNC Load) (b) 34% Renewable Energy. (c) 79% Renewable Energy. (d) 81% Renewable Energy

Economic Analysis

In this section we shall show the result of the cost feasibility between the proposed model and the current electricity generation in TRNC, by considering the NPV, SIR, IRR and SPP values.

On 14th October 2016, T-Vine published a news article, it reported that the Turkish and Turkish Cypriot energy ministers (Berat Albayrak and Sunat Atun) have signed an historical deal that will see Turkey provide electricity to North Cyprus via underwater cable. According to T-Vine, this agreement was formalized on Tuesday, 11th October, 2016. Sunat Atun also said that TRNC had paid 2million TL on fuel for four years to produce its own electricity, Sunat Atun also said this agreement will make electricity cheaper for TRNC, and that over a third could be saved off fuel cost [46].

From Sunat Atun’s statement it can be said that TRNC spends 500,000TL on fuel yearly for electricity production. According to [47], on 16/11/2016, 1USD=3.2222TL, so using this rate, 500,000TL will equal USD155, 173.484, 81% of 155,173.484 equals USD 125,690.522.

To carry out the feasibility test we also need to know the cost of battery and LCOE for both wind and solar energy. Figure 22 and 23 bellow show the costs for different battery types.

	Flooded Lead Acid	VRLA AGM	Lithium-Ion (NMC)
Initial Cost per capacity ($/kWh)	131	221	530
Cost per Life Cycle ($/kWh)	$0.17	$0.71	$0.19
Specific Energy (Wh/kg)	30	40	150
Regular Maintenance	Yes	No	No
Number of Cycles to 80% SOH	200-1000	200-650	1000-400
Typical State of Charge Window	50%	50%	80%
High Temperature Sensitivity	Degrades above 25°C	Degrades above 25°C	Degrades above 45°C
Available Power Constant Current	0.2C	0.3C	1C
Fast Charging Time (hrs)	8 - 16	4 - 8	2 - 4

Figure22: Different Batteries and Their Various Specifications [48].

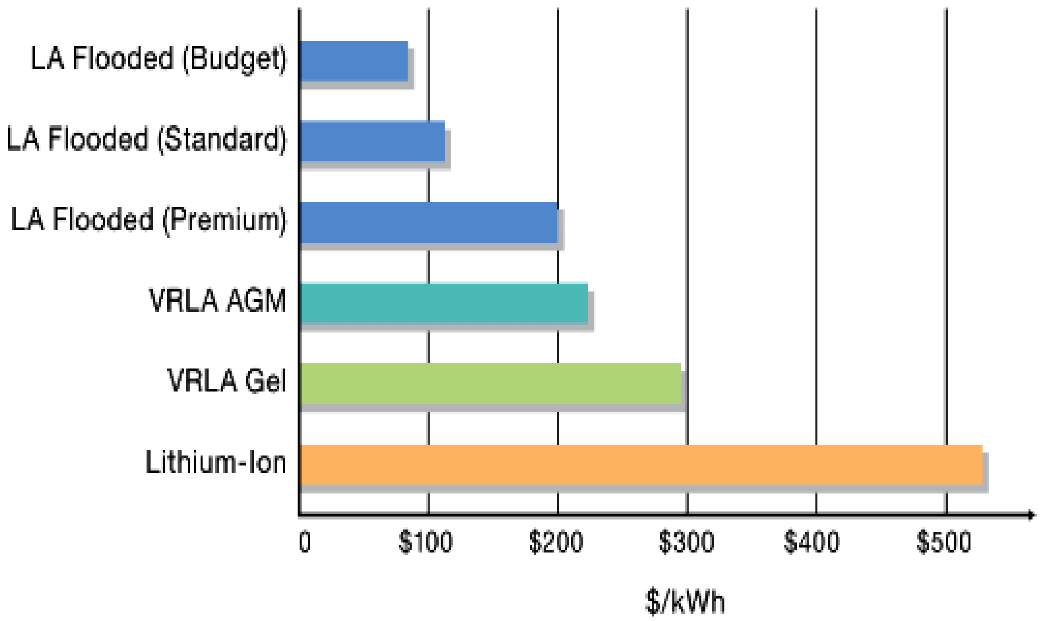


Figure23: Initial Cost per Battery Capacity [48].

From Figure22 and 23 above we can see that Lithium-Ion is the best battery and the most expensive, while LA Flooded is the cheapest one, in this study, LA Flooded will be considered, which cost USD 131/kWh. A battery size of 8000MWh will cost $USD(131 \times 8000 \times 1000) = USD1{,}048{,}000{,}000$.

Now the LCOE will be calculated, according to IRENA. The global weighted average LCOE for onshore wind is USD 0.06/kWh, while the global weighted average for solar Pv projects is USD 0.10/kWh [49], therefore the LCOE can be calculated as follows: $(0.10 \times 700 \times 1000) + (0.06 \times 300 \times 1000) = USD718{,}000$.

The basic project cost=1,048,000,000+718,000=USD1,048,718,000.

Residual Value is 10% of the basic project cost= USD104,871,800.

Table 8: Economic Feasibility Result

Annual Savings	USD125,691
Discount Rate	4%
Analysis Period (years)	20
Residual Value	104,871,800
Net Present Value (NPV)	$-99{,}147{,}704$
Savings-to-Investment Ratio (SIR)	0
Internal Rate of Return (IRR)	DNE
Simple Payback Period (SPP)	8,343.7

Chapter 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

Clearly, we can conclude from this thesis work that, in order for TRNC to be able to make optimal use of their renewable energy resources, which can be of a better solution to their current energy challenges, they must abandon baseload generation. As we can see from this work, that baseload does not allow lots of renewable penetration, because baseload causes lots of over-generation. And to make use of renewable there will be need to use more of the solar energy due to the high potential solar holds in this region. It can be seen that, with installed capacity (system size) of 800MW for both solar and wind, solar generates more renewable energy compared to wind. Even though solar have numerous potential over wind. It's still very advisable to use a hybrid system so as to reduce the battery size and also to reduce downtown when the other resources are not available. Also it is clear that renewable electricity generation will also help in demand side management. We can see that the peak of the load plot with no RE is very broad, which will be very difficult for load shifting; however, we can see that when we penetrated some amount of renewable, the peak is not so broad. This can easily allow load shifting down the valley, which was also illustrated in the result section. The only disadvantage and challenge that TRNC might face changing their electricity production into renewable is that the high cost of setting up a renewable energy plant, which makes the current system far cheaper, because there's a ready system that will need to be abandon, which also cost money to set up. From the economic analysis we can see that NPV is negative, SIR is zero, IRR does not exist and the SPP is greater than lifecycle of a typical wind turbine and Pv panels.

I strongly recommend TRNC to look into using more renewable in their electricity generation so as to cut low their expenses on fossil fuels, and more importantly to also reduce the negative environmental effect that fossil fuels can cause.

Because of the present high cost of setting up renewable power plants, in order to introduce hybrid renewable energy systems into TRNC existing power supply network, more research should be put into finding ways to bring down the cost of building and maintaining renewable energy plants to make it cost effective and also help reduce the effect of fossil fuel on our environment. Also in-depth study should be carried on network (power transmission) and technical competitiveness, because this study only focus on the power generation.

5.2 Future Works

The following can be suggested for future work:

- Modeling smart energy systems; by considering all the three basic energy demands, heating/cooling, electricity and transportation; In order to really go 100% renewable we need to integrate all the three basic demands, by then there will be need for more electric vehicles.
- Suggesting grid energy storage beyond batteries; as we already know that batteries are very expensive and don't last forever, which is one of the major challenges of renewable energy that need to be address.

- Investigating all the available renewable energy resources in TRNC and modeling a more complex hybrid renewable system based on the investigated available resources, so as to make optimal use of all the available renewable energy resource on the island and to help reduce battery size.
- Designing and upgrading the current power plants, by making them nimble more and more intelligent (suggesting power plants with AI ability)

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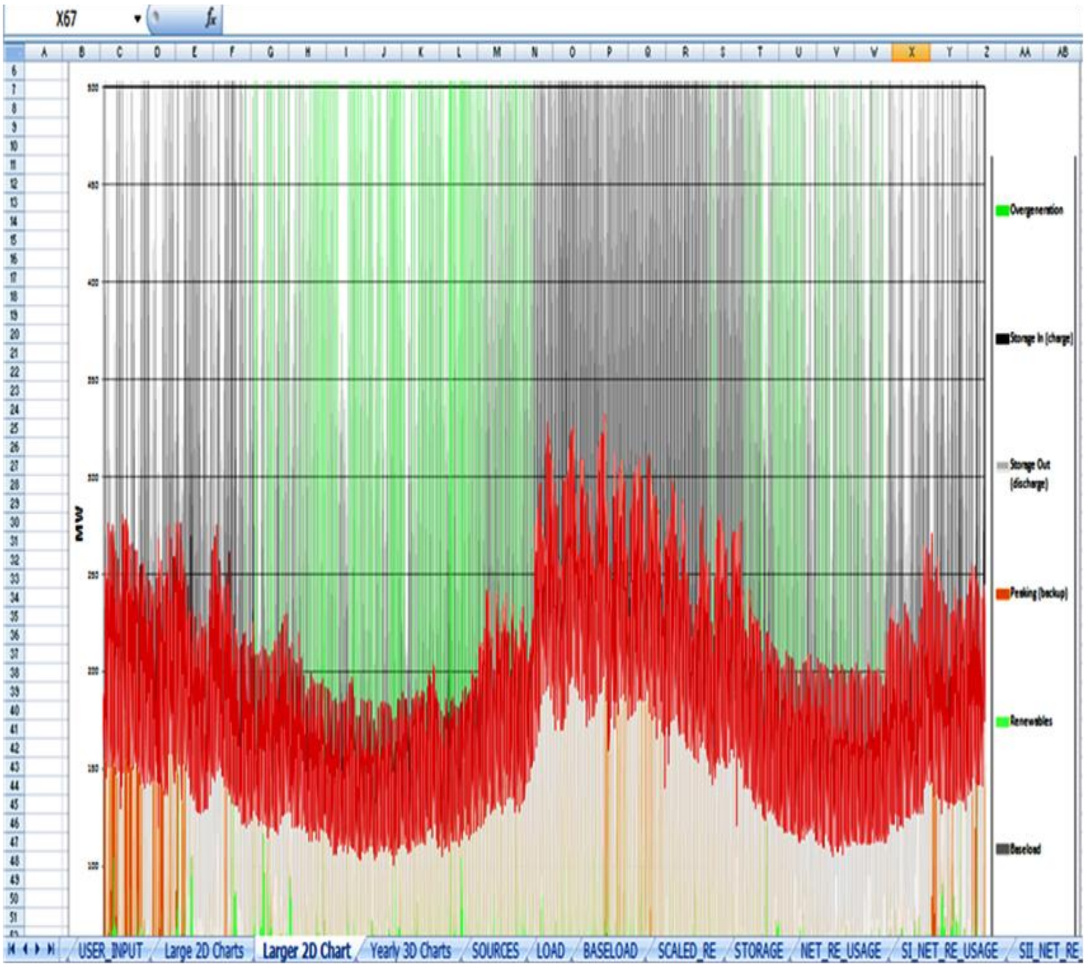
APPENDIX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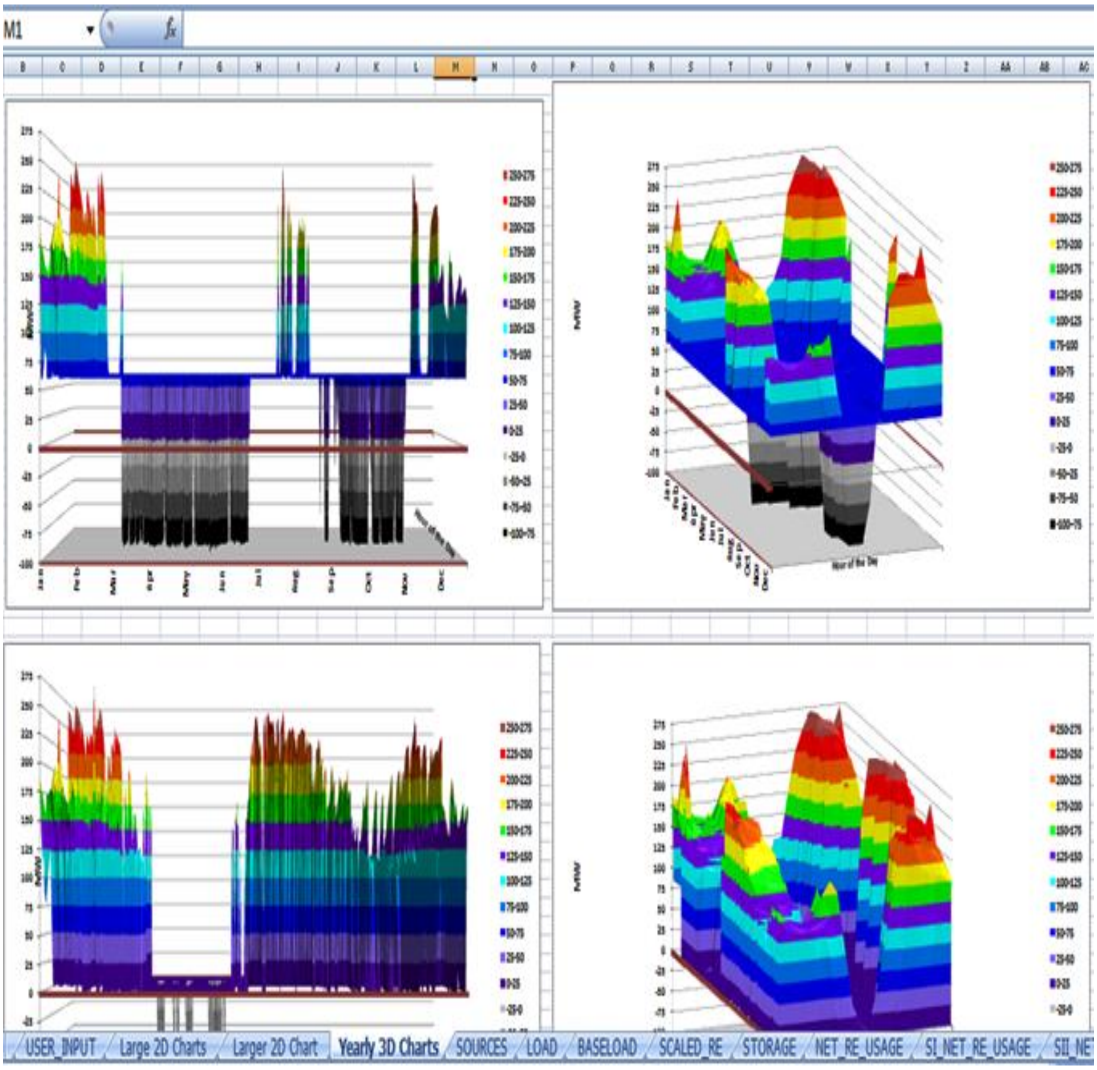
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L2 TRNC Water System Hydro

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1			Source							See Notes sheet								
2			Name	famagusta	nicosia	lefke	girne	guzelyurt		Solar	TRNC 40 180	TRNC Wa		TRNC Sewage Treatment Biogas Gen				
3			Nameplate (in MW	1.5	1.5	1.5	1.5	1.5		1		10		0.25		note: Nameplate for the hyd		
4	DATE	HOUR		MWh	MWh	MWh	MWh	MWh		MWh		MWh		MWh				
5	1-Jan	0000		0.010200252	0.0102	0.0102	0.010200252	0.010200252		0		0		0				
6	1-Jan	0100		0.016836929	0.016837	0.016837	0.016836929	0.016836929		0		0		0				
7	1-Jan	0200		0.008871575	0.008872	0.008872	0.008871575	0.008871575		0		0		0				
8	1-Jan	0300		0.003233081	0.003233	0.003233	0.003233081	0.003233081		0		0		0				
9	1-Jan	0400		0.00095795	0.000958	0.000958	0.00095795	0.00095795		0		0		0				
10	1-Jan	0500		0.004706408	0.004706	0.004706	0.004706408	0.004706408		0		0		0				
11	1-Jan	0600		0.013242701	0.013243	0.013243	0.013242701	0.013242701		0		0		0				
12	1-Jan	0700		0.028538288	0.028538	0.028538	0.028538288	0.028538288		0.101746		0		0				
13	1-Jan	0800		0.052564632	0.052565	0.052565	0.052564632	0.052564632		0.341517		0		0				
14	1-Jan	0900		0.081602013	0.081602	0.081602	0.081602013	0.081602013		0.541828		0		0				
15	1-Jan	1000		0.127073025	0.127073	0.127073	0.127073025	0.127073025		0.653739		0		0				
16	1-Jan	1100		0.081602013	0.081602	0.081602	0.081602013	0.081602013		0.680746		0		0				
17	1-Jan	1200		0.052564632	0.052565	0.052565	0.052564632	0.052564632		0.611663		0		0				
18	1-Jan	1300		0.028538288	0.028538	0.028538	0.028538288	0.028538288		0.46686		0		0				
19	1-Jan	1400		0.016836929	0.016837	0.016837	0.016836929	0.016836929		0.29425		0		0				
20	1-Jan	1500		0.0076636	0.007664	0.007664	0.0076636	0.0076636		0.104205		0		0				
21	1-Jan	1600		0.003233081	0.003233	0.003233	0.003233081	0.003233081		0.002261		0		0				
22	1-Jan	1700		0.003233081	0.003233	0.003233	0.003233081	0.003233081		0		0		0				
23	1-Jan	1800		0.003233081	0.003233	0.003233	0.003233081	0.003233081		0		0		0				
24	1-Jan	1900		0.003233081	0.003233	0.003233	0.003233081	0.003233081		0		0		0				
25	1-Jan	2000		0.004706408	0.004706	0.004706	0.004706408	0.004706408		0		0		0				

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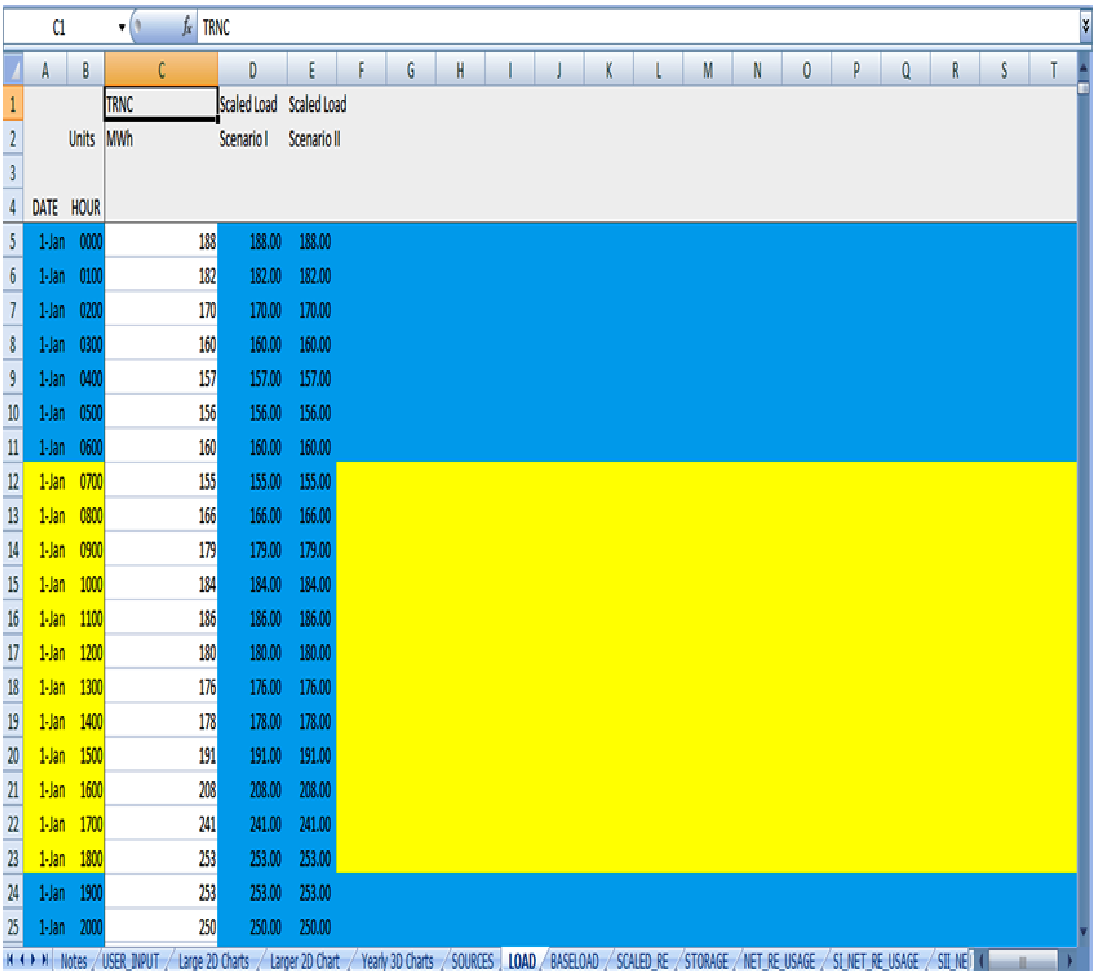
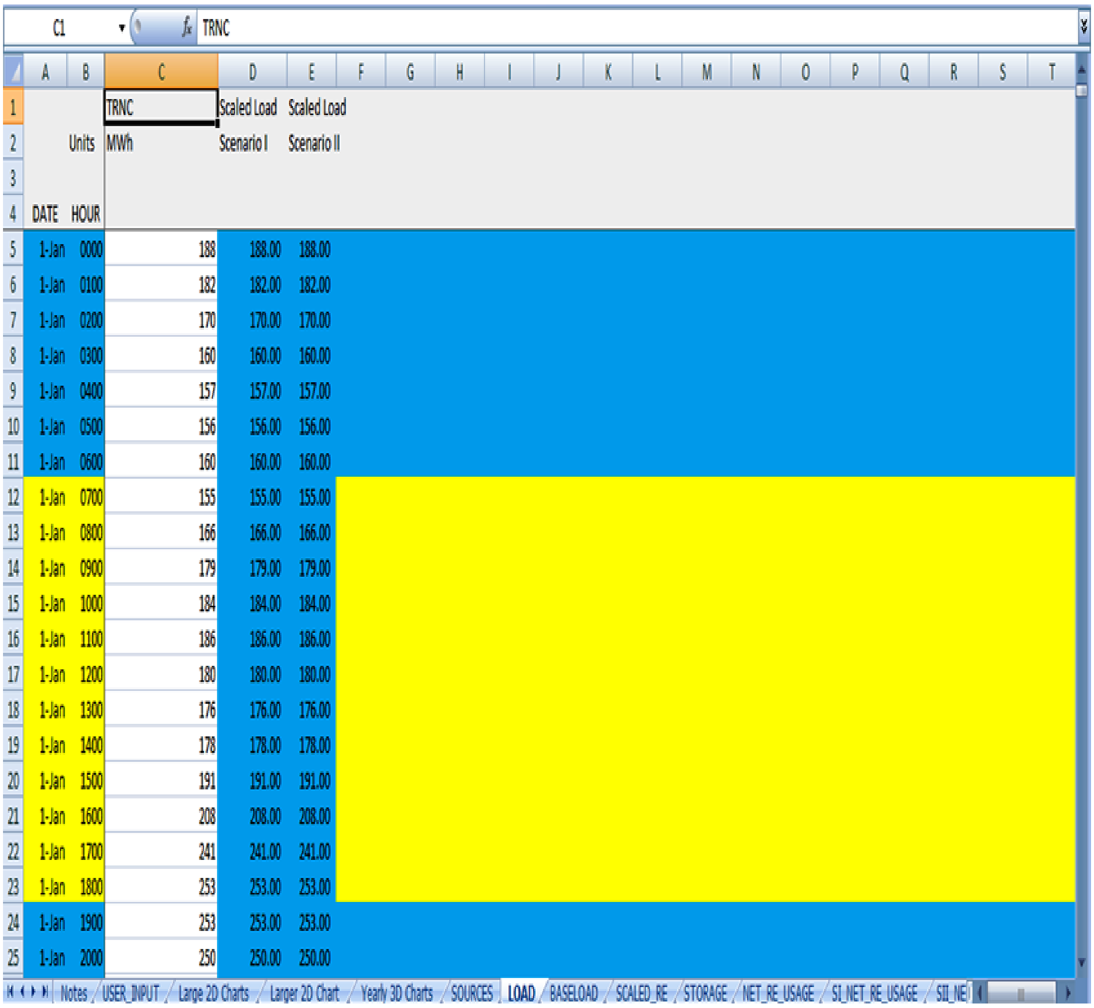
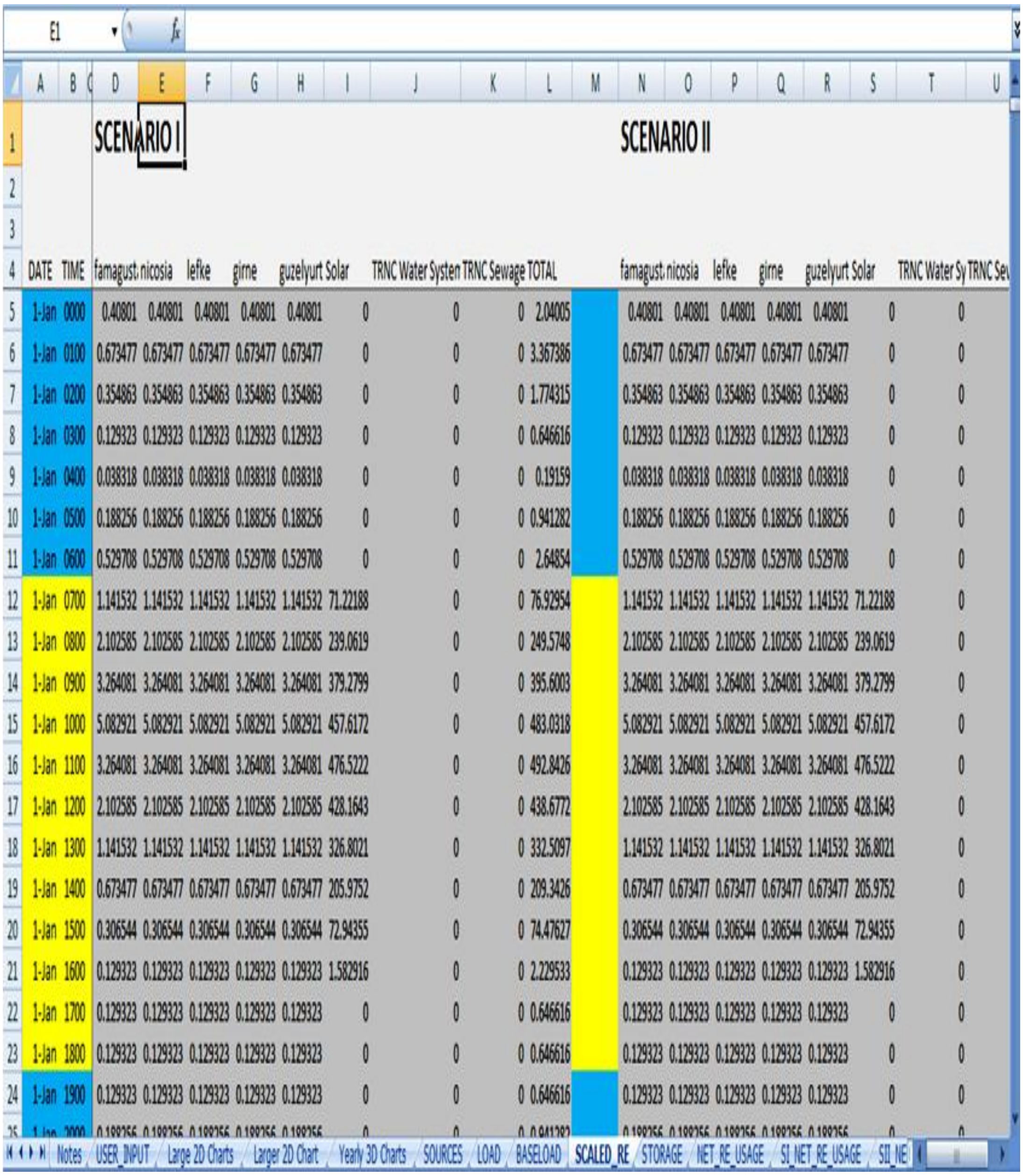


DATE	HOUR	TRNC MWh	Scaled Load Scenario I	Scaled Load Scenario II
1-Jan	0000	188	188.00	188.00
1-Jan	0100	182	182.00	182.00
1-Jan	0200	170	170.00	170.00
1-Jan	0300	160	160.00	160.00
1-Jan	0400	157	157.00	157.00
1-Jan	0500	156	156.00	156.00
1-Jan	0600	160	160.00	160.00
1-Jan	0700	155	155.00	155.00
1-Jan	0800	166	166.00	166.00
1-Jan	0900	179	179.00	179.00
1-Jan	1000	184	184.00	184.00
1-Jan	1100	186	186.00	186.00
1-Jan	1200	180	180.00	180.00
1-Jan	1300	176	176.00	176.00
1-Jan	1400	178	178.00	178.00
1-Jan	1500	191	191.00	191.00
1-Jan	1600	208	208.00	208.00
1-Jan	1700	241	241.00	241.00
1-Jan	1800	253	253.00	253.00
1-Jan	1900	253	253.00	253.00
1-Jan	2000	250	250.00	250.00



	A	B	C	D	E
1			TRNC	Scaled Load	Scaled Load
2		Units	MWh	Scenario I	Scenario II
3					
4	DATE	HOUR			
5	1-Jan	0000	188	188.00	188.00
6	1-Jan	0100	182	182.00	182.00
7	1-Jan	0200	170	170.00	170.00
8	1-Jan	0300	160	160.00	160.00
9	1-Jan	0400	157	157.00	157.00
10	1-Jan	0500	156	156.00	156.00
11	1-Jan	0600	160	160.00	160.00
12	1-Jan	0700	155	155.00	155.00
13	1-Jan	0800	166	166.00	166.00
14	1-Jan	0900	179	179.00	179.00
15	1-Jan	1000	184	184.00	184.00
16	1-Jan	1100	186	186.00	186.00
17	1-Jan	1200	180	180.00	180.00
18	1-Jan	1300	176	176.00	176.00
19	1-Jan	1400	178	178.00	178.00
20	1-Jan	1500	191	191.00	191.00
21	1-Jan	1600	208	208.00	208.00
22	1-Jan	1700	241	241.00	241.00
23	1-Jan	1800	253	253.00	253.00
24	1-Jan	1900	253	253.00	253.00
25	1-Jan	2000	250	250.00	250.00



SCENARIO I

DATE	TIME	famagust	nicosia	lefke	girne	guzelyurt	Solar	TRNC Water Systen	TRNC Sewage	TOTAL
1-Jan	0000	0.40801	0.40801	0.40801	0.40801	0.40801	0	0	0	2.04005
1-Jan	0100	0.673477	0.673477	0.673477	0.673477	0.673477	0	0	0	3.367386
1-Jan	0200	0.354863	0.354863	0.354863	0.354863	0.354863	0	0	0	1.774315
1-Jan	0300	0.129323	0.129323	0.129323	0.129323	0.129323	0	0	0	0.646616
1-Jan	0400	0.038318	0.038318	0.038318	0.038318	0.038318	0	0	0	0.19159
1-Jan	0500	0.188256	0.188256	0.188256	0.188256	0.188256	0	0	0	0.941282
1-Jan	0600	0.529708	0.529708	0.529708	0.529708	0.529708	0	0	0	2.64854
1-Jan	0700	1.141532	1.141532	1.141532	1.141532	1.141532	71.22188	0	0	76.92954
1-Jan	0800	2.102585	2.102585	2.102585	2.102585	2.102585	239.0619	0	0	249.5748
1-Jan	0900	3.264081	3.264081	3.264081	3.264081	3.264081	379.2799	0	0	395.6003
1-Jan	1000	5.082921	5.082921	5.082921	5.082921	5.082921	457.6172	0	0	483.0318
1-Jan	1100	3.264081	3.264081	3.264081	3.264081	3.264081	476.5222	0	0	492.8426
1-Jan	1200	2.102585	2.102585	2.102585	2.102585	2.102585	428.1643	0	0	438.6772
1-Jan	1300	1.141532	1.141532	1.141532	1.141532	1.141532	326.8021	0	0	332.5097
1-Jan	1400	0.673477	0.673477	0.673477	0.673477	0.673477	205.9752	0	0	209.3426
1-Jan	1500	0.306544	0.306544	0.306544	0.306544	0.306544	72.94355	0	0	74.47627
1-Jan	1600	0.129323	0.129323	0.129323	0.129323	0.129323	1.582916	0	0	2.229533
1-Jan	1700	0.129323	0.129323	0.129323	0.129323	0.129323	0	0	0	0.646616
1-Jan	1800	0.129323	0.129323	0.129323	0.129323	0.129323	0	0	0	0.646616
1-Jan	1900	0.129323	0.129323	0.129323	0.129323	0.129323	0	0	0	0.646616
1-Jan	2000	0.188256	0.188256	0.188256	0.188256	0.188256	0	0	0	0.941282

SCENARIO II

DATE	TIME	famagust	nicosia	lefke	girne	guzelyurt	Solar	TRNC Water Sy	TRNC Sev
1-Jan	0000	0.40801	0.40801	0.40801	0.40801	0.40801	0	0	
1-Jan	0100	0.673477	0.673477	0.673477	0.673477	0.673477	0	0	
1-Jan	0200	0.354863	0.354863	0.354863	0.354863	0.354863	0	0	
1-Jan	0300	0.129323	0.129323	0.129323	0.129323	0.129323	0	0	
1-Jan	0400	0.038318	0.038318	0.038318	0.038318	0.038318	0	0	
1-Jan	0500	0.188256	0.188256	0.188256	0.188256	0.188256	0	0	
1-Jan	0600	0.529708	0.529708	0.529708	0.529708	0.529708	0	0	
1-Jan	0700	1.141532	1.141532	1.141532	1.141532	1.141532	71.22188	0	
1-Jan	0800	2.102585	2.102585	2.102585	2.102585	2.102585	239.0619	0	
1-Jan	0900	3.264081	3.264081	3.264081	3.264081	3.264081	379.2799	0	
1-Jan	1000	5.082921	5.082921	5.082921	5.082921	5.082921	457.6172	0	
1-Jan	1100	3.264081	3.264081	3.264081	3.264081	3.264081	476.5222	0	
1-Jan	1200	2.102585	2.102585	2.102585	2.102585	2.102585	428.1643	0	
1-Jan	1300	1.141532	1.141532	1.141532	1.141532	1.141532	326.8021	0	
1-Jan	1400	0.673477	0.673477	0.673477	0.673477	0.673477	205.9752	0	
1-Jan	1500	0.306544	0.306544	0.306544	0.306544	0.306544	72.94355	0	
1-Jan	1600	0.129323	0.129323	0.129323	0.129323	0.129323	1.582916	0	
1-Jan	1700	0.129323	0.129323	0.129323	0.129323	0.129323	0	0	
1-Jan	1800	0.129323	0.129323	0.129323	0.129323	0.129323	0	0	
1-Jan	1900	0.129323	0.129323	0.129323	0.129323	0.129323	0	0	
1-Jan	2000	0.188256	0.188256	0.188256	0.188256	0.188256	0	0	

R111 =R$2-T110

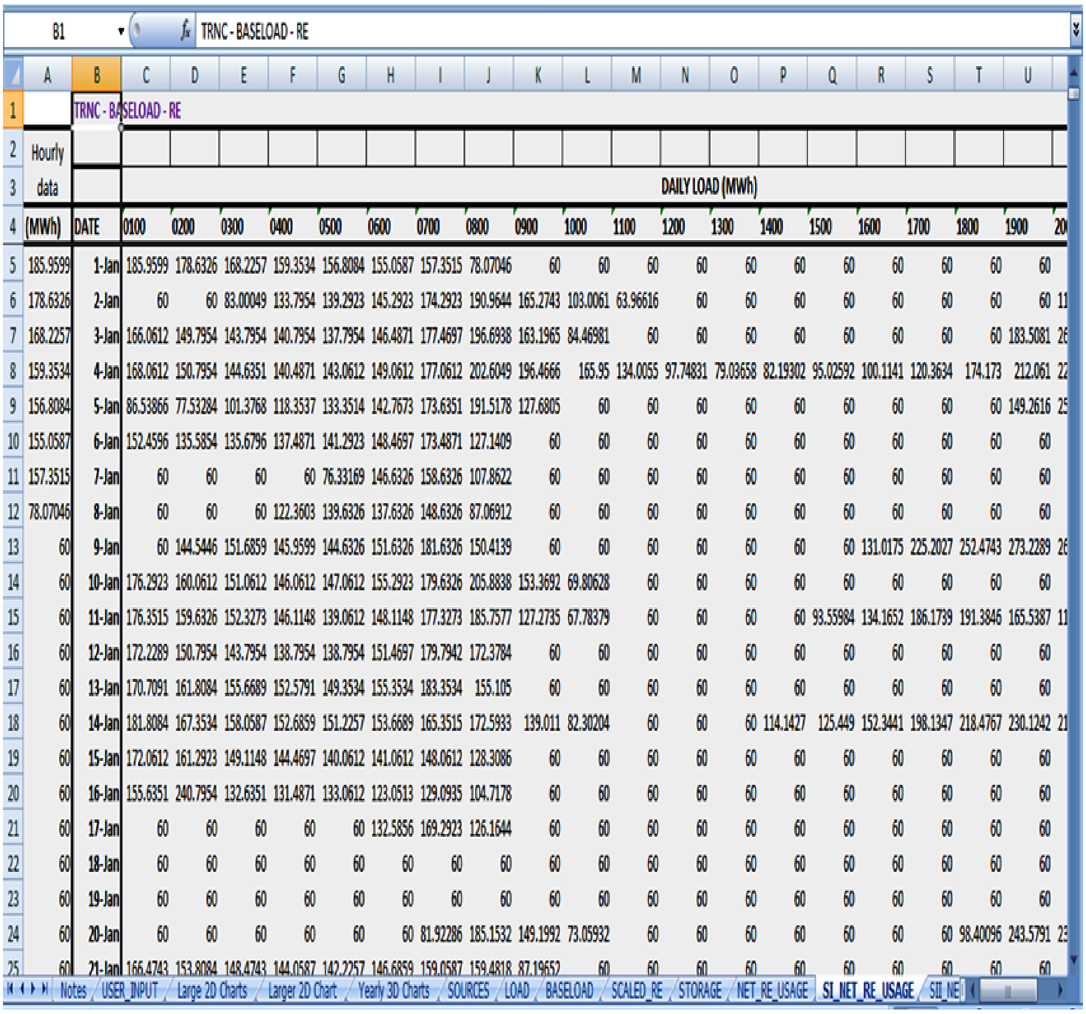
	A	B	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1			C	y	Rate		SCENARIO I									SCENARIO II						
2							8,000	MWh Nameplate		8,000	MW Capacity			if(LoadLessRE>baseload):		8,000	MWh Nameplate		7,200	MWh Actual		
3			1	90%	100%		Space Available	STspace = Nameplate - Stenergy	Stored Energy	STenergy= STenergy(-1) +STload -STused	Usable Energy	STusable= Efficiency * Stenergy	Used Energy	STused = MIN((LoadLessRE-Baseload), STusable),		Space Available		Stored Energy		Usable Energy		Us Ener
4	DATE	HOUR	MW/MWh	%	%									STused =0;								
5	1-Jan	0000					8,000.0		-		-		-			8,000.0		-		-		-
6	1-Jan	0100					8,000.0		-		-		-			8,000.0		-		-		-
7	1-Jan	0200					8,000.0		-		-		-			8,000.0		-		-		-
8	1-Jan	0300					8,000.0		-		-		-			8,000.0		-		-		-
9	1-Jan	0400					8,000.0		-		-		-			8,000.0		-		-		-
10	1-Jan	0500					8,000.0		-		-		-			8,000.0		-		-		-
11	1-Jan	0600					8,000.0		-		-		-			8,000.0		-		-		-
12	1-Jan	0700					8,000.0		-		-		-			8,000.0		-		-		-
13	1-Jan	0800					8,000.0		143.6		129.2		-			8,000.0		83.6		75.2		-
14	1-Jan	0900					7,856.4		420.2		378.2		-			7,916.4		300.2		270.2		-
15	1-Jan	1000					7,579.8		779.2		701.3		-			7,699.8		599.2		539.3		-
16	1-Jan	1100					7,220.8		1,146.0		1,031.4		-			7,400.8		906.0		815.4		-
17	1-Jan	1200					6,854.0		1,464.7		1,318.3		-			7,094.0		1,164.7		1,048.3		-
18	1-Jan	1300					6,535.3		1,681.2		1,513.1		-			6,835.3		1,321.2		1,189.1		-
19	1-Jan	1400					6,318.8		1,772.6		1,595.3		-			6,678.8		1,352.6		1,217.3		-
20	1-Jan	1500					6,227.4		1,772.6		1,595.3		56.5			6,647.4		1,352.6		1,217.3		116
21	1-Jan	1600					6,227.4		1,709.8		1,538.8		145.8			6,647.4		1,223.1		1,100.8		205
22	1-Jan	1700					6,290.2		1,547.8		1,393.0		180.4			6,776.9		994.5		895.0		240

Notes / USER_INPUT / Large 2D Charts / Larger 2D Chart / Yearly 3D Charts / SOURCES / LOAD / BASELOAD / SCALED_RE / STORAGE / NET_RE_USAGE / SI_NET_RE_USAGE / SII_NE

L5 =IF(K5>0,1,0)

	A	B	D	E	F	G	H	I	J	K	L	M	N	O	P
1			LoadNetRE =	STload =	TotalLoad =	NetLoad0 =	REused =	UnmetLoad =	REused0 =	Curtailed0 =		NetLoadB =	REusedB =	CurtailedB =	Daily Overgeneration
2			Load-RE	if(LoadNetRE> 0): 0, MIN(STspace,-LoadNetRE);	Load + STload	TotalLoad - (RE + STused)	if (Supply>Load): Load- (STused+Baseload), RE;	Load - (STused + REused + Baseload)	if(NetLoad0<0): TotalLoad, RE;	if(NetLoad0<0): -NetLoad0, 0;		NetLoad0 - Baseload	if(NetLoadB>0): RE, (TotalLoad - (Baseload +	if(NetLoadB<0): -NetLoadB, 0;	= sum of 24 hours of CurtailedB
3			SCENARIO I	load from	Total Load	LD-RE	renewables	load	RE Used	MWH curtailed	hours curtailed	Scenario I	RE Used	MWH curtailed	Daily MWh hour
4	DATE	HOUR	LOAD - RE	Storage	for graph	+-ST	for graph	for graph	From zero	from Zero	from zero	load-RE-Baseload	from baseload	from baseload	Overgeneration fron
5	1-Jan	0000	185.96	-	188.00	186.0	2.0401	125.96	2.040	-	0	125.96	2.04	-	
6	1-Jan	0100	178.63	-	182.00	178.6	3.3674	118.63	3.367	-	0	118.63	3.37	-	
7	1-Jan	0200	168.23	-	170.00	168.2	1.7743	108.23	1.774	-	0	108.23	1.77	-	
8	1-Jan	0300	159.35	-	160.00	159.4	0.6466	99.35	0.647	-	0	99.35	0.65	-	
9	1-Jan	0400	156.81	-	157.00	156.8	0.1916	96.81	0.192	-	0	96.81	0.19	-	
10	1-Jan	0500	155.06	-	156.00	155.1	0.9413	95.06	0.941	-	0	95.06	0.94	-	
11	1-Jan	0600	157.35	-	160.00	157.4	2.6485	97.35	2.649	-	0	97.35	2.65	-	
12	1-Jan	0700	78.07	-	155.00	78.1	76.9295	18.07	76.930	-	0	18.07	76.93	-	
13	1-Jan	0800	(83.57)	143.57	309.57	60.0	106.0000	-	249.575	-	0	-	249.57	-	
14	1-Jan	0900	(216.60)	276.60	455.60	60.0	119.0000	-	395.600	-	0	-	395.60	-	
15	1-Jan	1000	(299.03)	359.03	543.03	60.0	124.0000	-	483.032	-	0	-	483.03	-	
16	1-Jan	1100	(306.84)	366.84	552.84	60.0	126.0000	-	492.843	-	0	0.00	492.84	-	
17	1-Jan	1200	(258.68)	318.68	498.68	60.0	120.0000	-	438.677	-	0	-	438.68	-	
18	1-Jan	1300	(156.51)	216.51	392.51	60.0	116.0000	-	332.510	-	0	-	332.51	-	
19	1-Jan	1400	(31.34)	91.34	269.34	60.0	118.0000	-	209.343	-	0	-	209.34	-	
20	1-Jan	1500	116.52	-	191.00	60.0	74.4763	-	74.476	-	0	-	74.48	-	
21	1-Jan	1600	205.77	-	208.00	60.0	2.2295	-	2.230	-	0	-	2.23	-	

Notes / USER_INPUT / Large 2D Charts / Larger 2D Chart / Yearly 3D Charts / SOURCES / LOAD / BASELOAD / SCALED_RE / STORAGE / NET_RE_USAGE / SI_NET_RE_USAGE / SII_NE

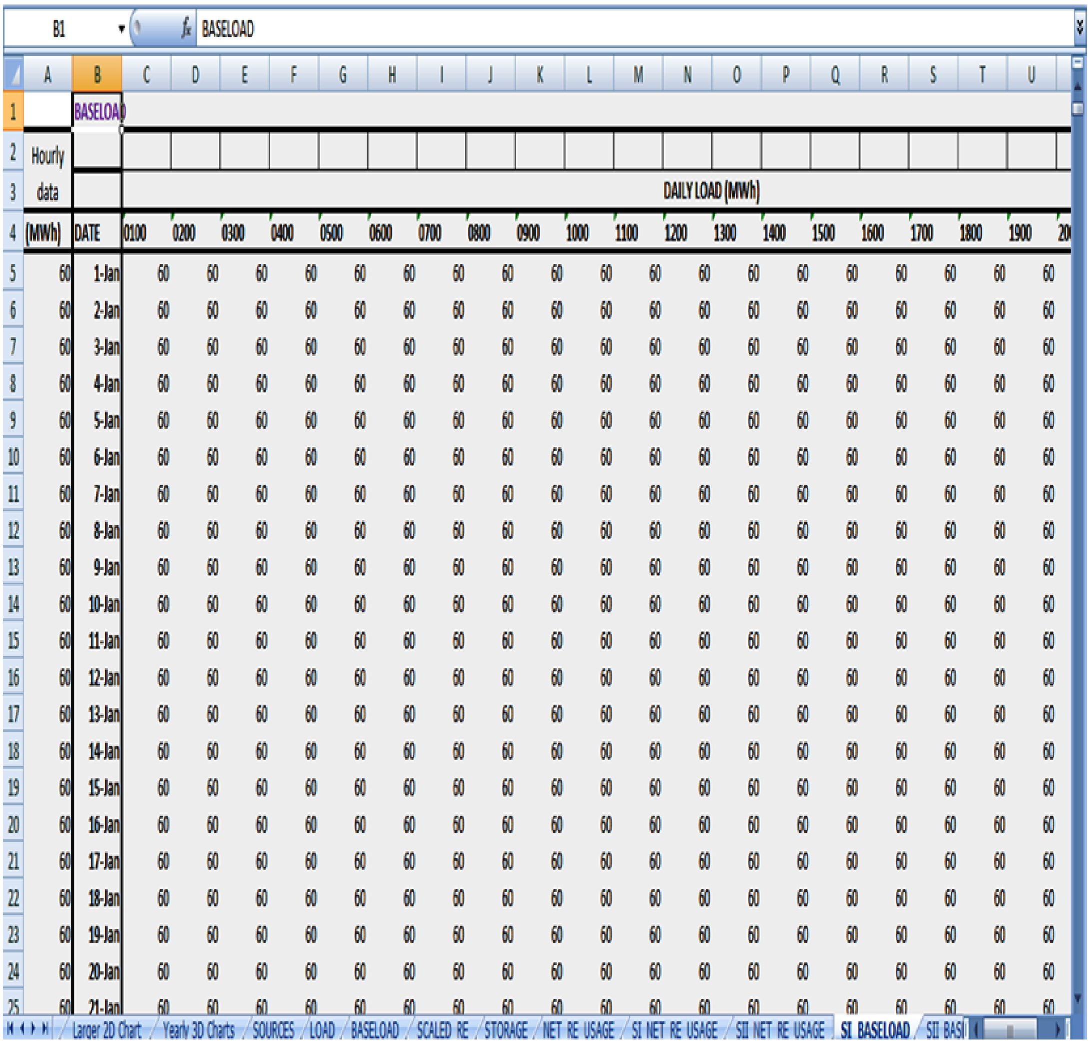


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	
1		TRNC - BASELOAD - RE																				
2	Hourly																					
3	data													DAILY LOAD (MWh)								
4	(MWh)	DATE	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	20
5	185.9599	1-Jan	185.9599	178.6326	168.2257	159.3534	156.8084	155.0587	157.3515	78.07046	60	60	60	60	60	60	60	60	60	60	60	
6	178.6326	2-Jan	60	60	83.00049	133.7954	139.2923	145.2923	174.2923	190.9644	165.2743	103.0061	63.96616	60	60	60	60	60	60	60	60	11
7	168.2257	3-Jan	166.0612	149.7954	143.7954	140.7954	137.7954	146.4871	177.4697	196.6938	163.1965	84.46981	60	60	60	60	60	60	60	60	183.5081	26
8	159.3534	4-Jan	168.0612	150.7954	144.6351	140.4871	143.0612	149.0612	177.0612	202.6049	196.4666	165.95	134.0055	97.74831	79.03658	82.19302	95.02592	100.1141	120.3634	174.173	212.061	22
9	156.8084	5-Jan	86.53866	77.53284	101.3768	118.3537	133.3514	142.7673	173.6351	191.5178	127.6805	60	60	60	60	60	60	60	60	60	149.2616	25
10	155.0587	6-Jan	152.4596	135.5854	135.6796	137.4871	141.2923	148.4697	173.4871	127.1409	60	60	60	60	60	60	60	60	60	60	60	
11	157.3515	7-Jan	60	60	60	60	76.33169	146.6326	158.6326	107.8622	60	60	60	60	60	60	60	60	60	60	60	
12	78.07046	8-Jan	60	60	60	122.3603	139.6326	137.6326	148.6326	87.06912	60	60	60	60	60	60	60	60	60	60	60	
13	60	9-Jan	60	144.5446	151.6859	145.9599	144.6326	151.6326	181.6326	150.4139	60	60	60	60	60	60	60	131.0175	225.2027	252.4743	273.2289	26
14	60	10-Jan	176.2923	160.0612	151.0612	146.0612	147.0612	155.2923	179.6326	205.8838	153.3692	69.80628	60	60	60	60	60	60	60	60	60	
15	60	11-Jan	176.3515	159.6326	152.3273	146.1148	139.0612	148.1148	177.3273	185.7577	127.2735	67.78379	60	60	60	60	93.55984	134.1652	186.1739	191.3846	165.5387	11
16	60	12-Jan	172.2289	150.7954	143.7954	138.7954	138.7954	151.4697	179.7942	172.3784	60	60	60	60	60	60	60	60	60	60	60	
17	60	13-Jan	170.7091	161.8084	155.6689	152.5791	149.3534	155.3534	183.3534	155.105	60	60	60	60	60	60	60	60	60	60	60	
18	60	14-Jan	181.8084	167.3534	158.0587	152.6859	151.2257	153.6689	165.3515	172.5933	139.011	82.30204	60	60	60	114.1427	125.449	152.3441	198.1347	218.4767	230.1242	21
19	60	15-Jan	172.0612	161.2923	149.1148	144.4697	140.0612	141.0612	148.0612	128.3086	60	60	60	60	60	60	60	60	60	60	60	
20	60	16-Jan	155.6351	240.7954	132.6351	131.4871	133.0612	123.0513	129.0935	104.7178	60	60	60	60	60	60	60	60	60	60	60	
21	60	17-Jan	60	60	60	60	60	132.5856	169.2923	126.1644	60	60	60	60	60	60	60	60	60	60	60	
22	60	18-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	
23	60	19-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	
24	60	20-Jan	60	60	60	60	60	60	81.92286	185.1532	149.1992	73.05932	60	60	60	60	60	60	60	98.40096	243.5791	23
25	60	21-Jan	166.4743	153.8084	148.4743	144.0587	142.2257	146.6859	159.0587	159.4818	87.19652	60	60	60	60	60	60	60	60	60	60	

B1 fx TRNC - RENEWABLES

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1		TRNC - RENEWABLES																			
2	Hourly																				
3	data													DAILY LOAD (MWh)							
4	(MWh)	DATE	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
5	185.9599	1-Jan	185.9599	178.6326	168.2257	159.3534	156.8084	155.0587	157.3515	78.07046	0	0	0	0	0	0	0	0	0	0	0
6	178.6326	2-Jan	148.8117	113.3387	123.0609	133.7954	139.2923	145.2923	174.2923	190.9644	165.2743	103.0061	63.96616	0	0	0	0	0	0	38.71245	269.1148
7	168.2257	3-Jan	166.0612	149.7954	143.7954	140.7954	137.7954	146.4871	177.4697	196.6938	163.1965	84.46981	25.46871	0	0	0	0	0	134.4858	221.4767	254.5414
8	159.3534	4-Jan	168.0612	150.7954	144.6351	140.4871	143.0612	149.0612	177.0612	202.6049	196.4666	165.95	134.0055	97.74831	79.03658	82.19302	95.02592	100.1141	120.3634	174.173	212.061
9	156.8084	5-Jan	86.53866	77.53284	101.3768	118.3537	133.3514	142.7673	173.6351	191.5178	127.6805	16.36985	0	0	0	0	0	0	164.8394	228.7673	250.6351
10	155.0587	6-Jan	152.4596	135.5854	135.6796	137.4871	141.2923	148.4697	173.4871	127.1409	0	0	0	0	0	0	0	0	0	0	0
11	157.3515	7-Jan	172.9599	157.6326	151.6326	146.6326	145.6326	146.6326	158.6326	107.8622	0	0	0	0	0	0	0	0	0	0	0
12	78.07046	8-Jan	171.3273	151.2923	125.3273	138.7942	139.6326	137.6326	148.6326	87.06912	0	0	0	0	0	0	0	0	0	0	0
13	0	9-Jan	174.5791	161.3534	151.6859	145.9599	144.6326	151.6326	181.6326	150.4139	32.60701	0.172659	65.78592	49.13524	38.75446	67.5231	111.7477	173.3584	225.2027	252.4743	273.2289
14	0	10-Jan	176.2923	160.0612	151.0612	146.0612	147.0612	155.2923	179.6326	205.8838	153.3692	69.80628	0	0	0	0	0	0	0	0	99.38749
15	0	11-Jan	176.3515	159.6326	152.3273	146.1148	139.0612	148.1148	177.3273	185.7577	127.2735	67.78379	33.00668	43.38543	57.91596	92.91228	101.7703	134.1652	186.1739	191.3846	165.5387
16	0	12-Jan	172.2289	150.7954	143.7954	138.7954	138.7954	151.4697	179.7942	172.3784	44.70304	0	0	0	0	0	0	0	0	0	0
17	0	13-Jan	178.9019	161.8084	155.6689	152.5791	149.3534	155.3534	183.3534	155.105	20.4453	0	0	0	0	0	0	0	0	0	22.70196
18	0	14-Jan	181.8084	167.3534	158.0587	152.6859	151.2257	153.6689	165.3515	172.5933	139.011	82.30204	29.68918	54.60713	81.42302	124.853	125.449	152.3441	198.1347	218.4767	230.1242
19	0	15-Jan	172.0612	161.2923	149.1148	144.4697	140.0612	141.0612	148.0612	128.3086	45.44142	0	0	0	0	0	0	0	0	13.54427	242.4697
20	0	16-Jan	155.6351	240.7954	132.6351	131.4871	133.0612	123.0513	129.0935	104.7178	0	0	0	0	0	0	0	0	0	0	0
21	0	17-Jan	158.4871	140.7954	138.7954	130.7954	129.7954	141.0612	169.2923	126.1644	0	0	0	0	0	0	0	0	0	0	0
22	0	18-Jan	162.6326	147.6326	141.6326	136.6326	139.6326	143.7942	170.3273	121.642	0	0	0	0	0	0	0	0	0	0	0
23	0	19-Jan	160.3273	148.2923	138.4697	132.4871	129.7954	142.0612	170.2923	124.063	0	0	0	0	0	0	0	0	0	0	0
24	0	20-Jan	164.9343	151	146	142	143	149.9761	174.8084	185.1532	149.1992	73.05932	27.18816	0	0	0	0	49.10259	201.117	218.6689	243.5791
25	99.09201	21-Jan	166.4743	153.8084	148.4743	144.0587	142.2257	146.6859	159.0587	159.4818	87.19652	0	0	0	0	0	0	0	0	0	156.1677

Large 2D Charts / Larger 2D Chart / Yearly 3D Charts / SOURCES / LOAD / BASELOAD / SCALED_RE / STORAGE / NET_RE_USAGE / SI_NET_RE_USAGE / SII_NET_RE_USAGE / SI_BA



B1 | BASELOAD

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1		BASELOAD																			
2	Hourly																				
3	data		DAILY LOAD (MWh)																		
4	(MWh)	DATE	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
5	60	1-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
6	60	2-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
7	60	3-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
8	60	4-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
9	60	5-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
10	60	6-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
11	60	7-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
12	60	8-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
13	60	9-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
14	60	10-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
15	60	11-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
16	60	12-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
17	60	13-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
18	60	14-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
19	60	15-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
20	60	16-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
21	60	17-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
22	60	18-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
23	60	19-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
24	60	20-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
25	60	21-Jan	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60

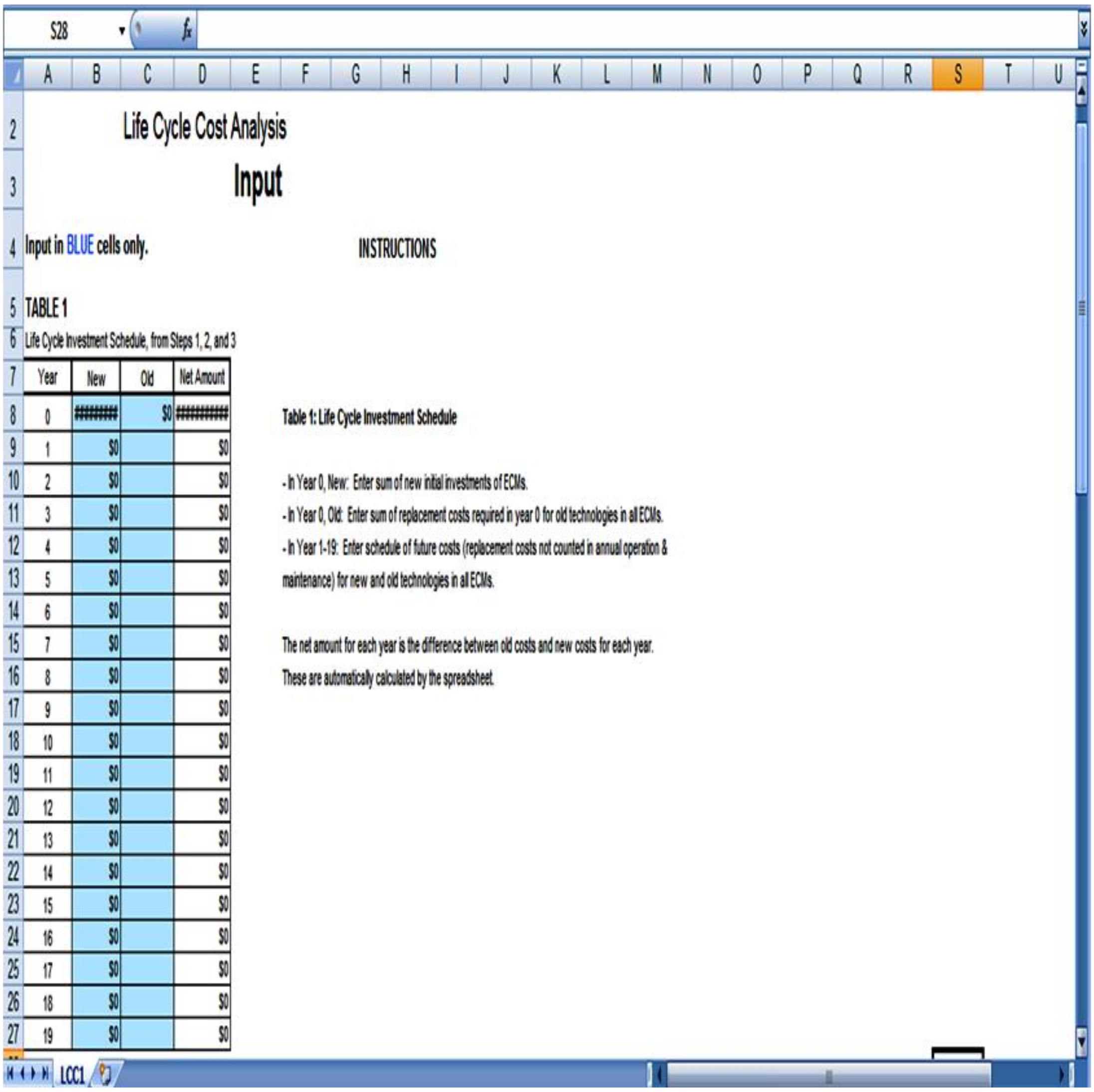
Larger 2D Chart / Yearly 3D Charts / SOURCES / LOAD / BASELOAD / SCALED RE / STORAGE / NET RE USAGE / SI NET RE USAGE / SII NET RE USAGE / SI BASELOAD / SII BASI

AA12

SCENARIO II BASELOAD

Hourly data (MWh)	DATE	DAILY LOAD (MWh) 0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	1-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	2-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	3-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	4-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	5-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	6-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	7-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	8-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	9-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	10-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	11-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	12-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	13-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	14-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	15-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	16-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	17-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	18-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	19-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	20-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	21-Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Yearly 3D Charts / SOURCES / LOAD / BASELOAD / SCALED_RE / STORAGE / NET_RE_USAGE / SI_NET_RE_USAGE / SII_NET_RE_USAGE / SI_BASELOAD / SII_BASELOAD / Sheet1



Life Cycle Cost Analysis

Input

Input in BLUE cells only.

INSTRUCTIONS

TABLE 1

Life Cycle Investment Schedule, from Steps 1, 2, and 3

Year	New	Old	Net Amount
0	########	$0	##########
1	$0		$0
2	$0		$0
3	$0		$0
4	$0		$0
5	$0		$0
6	$0		$0
7	$0		$0
8	$0		$0
9	$0		$0
10	$0		$0
11	$0		$0
12	$0		$0
13	$0		$0
14	$0		$0
15	$0		$0
16	$0		$0
17	$0		$0
18	$0		$0
19	$0		$0

Table 1: Life Cycle Investment Schedule

- In Year 0, New: Enter sum of new initial investments of ECMs.
- In Year 0, Old: Enter sum of replacement costs required in year 0 for old technologies in all ECMs.
- In Year 1-19: Enter schedule of future costs (replacement costs not counted in annual operation & maintenance) for new and old technologies in all ECMs.

The net amount for each year is the difference between old costs and new costs for each year.
These are automatically calculated by the spreadsheet.

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TABLE 2

Table 2: Given Data:

Annual Savings	$125,691	(from Step 3)	- Enter net annual savings (the sum of regular annual savings & expenses).
Discount Rate	4%	(from Step 4)	- Enter discount rate.
Analysis period (years)	20	(from Step 5)	- Choose the number of years for the analysis.
Residual value	#########	(from Step 6)	- Enter sum of residual value of ECM equipment at end of 10 yr service life.

Life Cycle Cost Analysis

Calculations

TABLE 3: Savings Calculations Formula: PV Annual Savings = Annual Savings / (1 + Discount Rate)^{yr} (from Step 7)

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Annual Savings	$0	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,69
PV Annual Savings	$0	$120,856	$116,208	$111,738	$107,441	$103,308	$99,335	$95,514	$91,841	$88,308	$84,912	$81,646	$78,506	$75,486	$72,583	$69,791	$67,107	$64,52
Σ PV Annual Savings	$1,708,175																	

TABLE 4: Investments Formula: PV Life Cycle Investment = Life Cycle Investment / (1 + Discount Rate)^{yr} (from Step 8)

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Net Life Cyle Investments	#########	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$
PV Life Cycle Investments	#########	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$
Σ PV Life Cycle Investments	#########																	

Net Cash Flows (for IRR calculation)	#########	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,69

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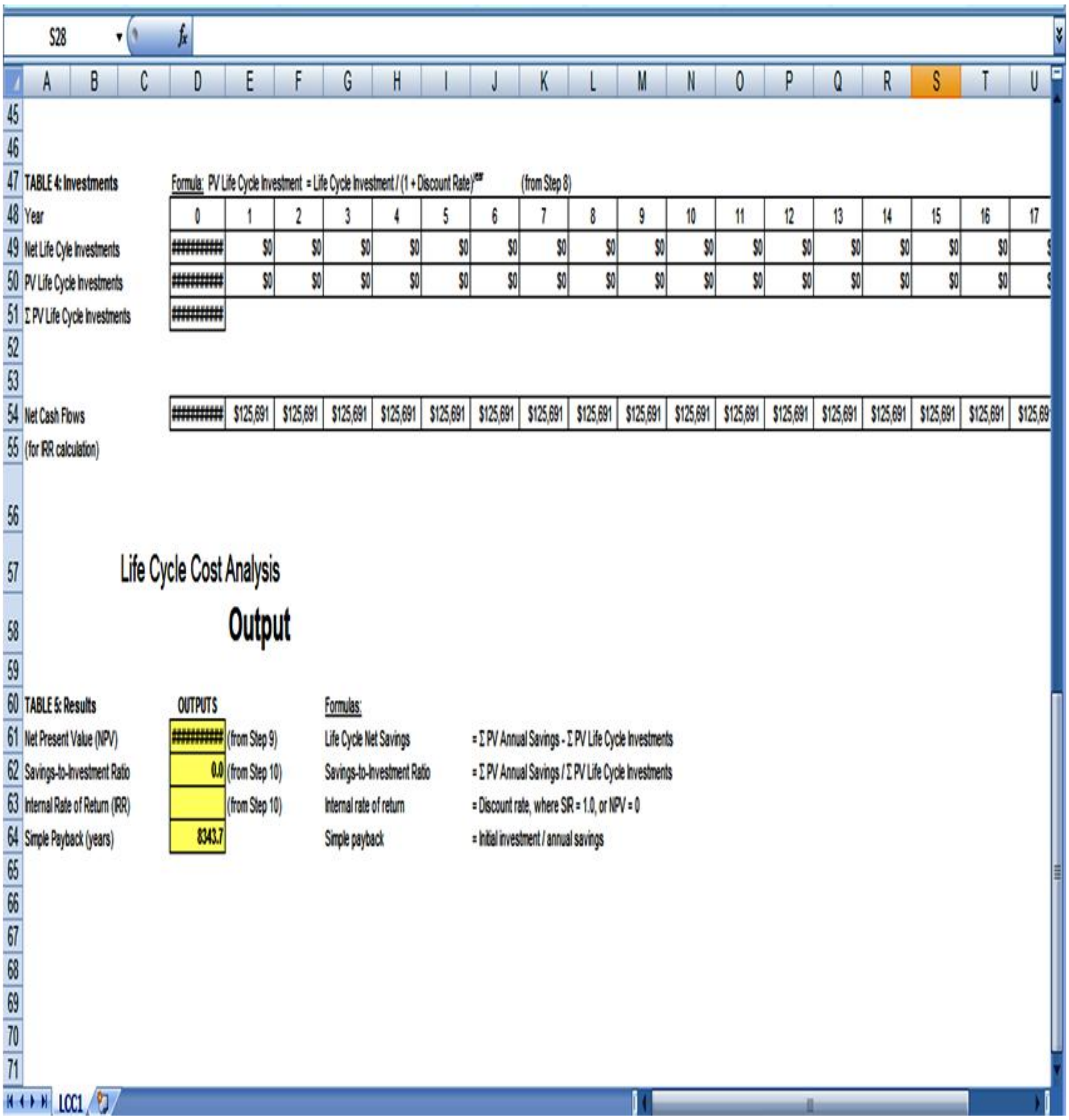

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TABLE 4: Investments — Formula: PV Life Cycle Investment = Life Cycle Investment / (1 + Discount Rate)^{year} (from Step 8)

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Net Life Cyle Investments	##########	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$
PV Life Cycle Investments	##########	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$
Σ PV Life Cycle Investments	##########																	
Net Cash Flows (for IRR calculation)	##########	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,691	$125,69

Life Cycle Cost Analysis

Output

TABLE 5: Results	OUTPUTS		Formulas:	
Net Present Value (NPV)	##########	(from Step 9)	Life Cycle Net Savings	= Σ PV Annual Savings - Σ PV Life Cycle Investments
Savings-to-Investment Ratio	0.0	(from Step 10)	Savings-to-Investment Ratio	= Σ PV Annual Savings / Σ PV Life Cycle Investments
Internal Rate of Return (IRR)		(from Step 10)	Internal rate of return	= Discount rate, where SIR = 1.0, or NPV = 0
Simple Payback (years)	8343.7		Simple payback	= Initial investment / annual savings

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