QATAR UNIVERSITY

COLLEGE OF ENGINEERING

OPTIMAL SIZING OF HYBRID RENEWABLE ENERGY SYSTEMS: AN APPLICATION FOR REAL DEMAND IN QATAR REMOTE AREA

BY

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ABSTRACT

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Title: Optimal Sizing of Hybrid Renewable Energy Systems: An application for Real Demand in Qatar Remote Area

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Renewable energy (RE) sources are becoming popular for power generations due to advances in renewable energy technologies and their ability to reduce the problem of global warming. However, their supply varies in availability (as sun and wind) and the required load demand fluctuates. Thus, to overcome the uncertainty issues of RE power sources, they can be combined with storage devices and conventional energy sources in a Hybrid Power Systems (HPS) to satisfy the demand load at any time. Recently, RE systems received high interest to take advantage of their positive benefits such as renewable availability and CO_2 emissions reductions. The optimal design of a hybrid renewable energy system is mostly defined by economic criteria, but there are also technical and environmental criteria to be considered to improve decision making. In this study three main renewable sources of the system: photovoltaic arrays (PV), wind turbine generators (WG) and waste boilers (WB) are integrated with diesel generators and batteries to design a hybrid system that supplies the required demand of a remote area in Qatar using heuristic approach. The method utilizes typical year data to calculate hourly output power of PV, WG and WB throughout the year. Then, different combinations of renewable energy sources with battery storage are proposed to match hourly demand during the year. The design which satisfies the desired level of loss of power supply, CO_2 emissions and minimum costs is considered as best design.

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At the end, I would like to dedicate my thesis to my parents who have made me what I am today by their significant time each single day.

Above all, I am thankful to Allah who has giving me this good life to meet good people and beautiful opportunities in my life

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List of Abbreviations and Symbols

A_{PV}	**PV panel area [m^2]**
A_{WG}	**Wind turbine rotor swept area [m^2]**
C_I	**Investment cost [€/KW]**
C_p	**Power coefficient**
CRF	**Capital recovery factor**
C_{fuel}	**Fuel cost [€/year]**
C	**Constant weighting parameter**
$CO2_{emis}$	**System CO_2 emission [kg/year]**
D	**Hourly energy demand [kWh]**
E_{PV}	**Energy produced by PV panels [kWh]**
E_{WG}	**Energy produced by wind turbines [kWh]**
E_{bat}	**Power charged or discharged from batteries [kWh]**
E_g	**energy generated from renewable sources**
E_l	**Load demand**
EF	**Emission factor [kg/lit]**
EOT	**Equation of time [min]**
$fuel_{cons}$	**Diesel generator fuel consumption [lit/hr]**
FC_G	**Hourly fuel consumption (l/hr)**
HW	**Heating value of waste component**
HPS	**Hybrid power system**
I_T	**Total solar radiation on tilted surface [kWh/m^2]**
$I_{b,tilt}$	**Beam radiation [kWh/m^2]**
$I_{d,tilt}$	**Sky diffuse radiation [kWh/m^2]**
$I_{r,tilt}$	**Ground reflected solar radiation [kWh/m^2]**
$I_{b,n}$	**Direct normal irradiance [kWh/m^2]**
i	**interest rate [%]**
LLP	**Loss of load probability [%]**
LST	**local standard time**
L_{local}	**local longitude [Degree]**
L_{local}	**local longitude [Degree]**
NPC	**Net present cost**
OM	**Operation and maintenance cost $/Kw**
P_{n-DG}	**Diesel generator nominal output power [kW]**
P_{PV}	**PV panel capacity [kW]**
P_{WG}	**Wind turbine capacity [kW]**
$P_{WG,r}$	**Wind turbine rated power [kW]**
P_{bat}	**Battery capacity [kWh]**
P_{Dis}	**Diesel generator capacity [kW]**
P_G	**Output power of diesel**
R	**Replacement cost $/Kw**
RES	**Renewable energy sources**
S	**Salvage value $/Kw**
SOC	**Battery state of charge [%]**
SOC_{min}	**SOC lower limit [%]**
SOC_{max}	**SOC upper limit [%]**
SEF	**Specific emission factor (kg/ton)**
$shortage$	**Unmet load during time step *t* [kWh]**
T	**Project life time [year]**
V	**wind speed [m/s]**
V_c	**Cut-in wind speed [m/s]**
V_r	**Rated wind speed [m/s]**
V_f	**Cut-off wind speed [m/s]**
WTE	**Waste boiler energy Kwh/ton**
η_{pv}	**PV panel efficiency [%]**
η_{inv}	**Efficiency of inverter**
η_b	**Charge efficiency of battery bank**
ρ	**Air density [kg/m^{-3}]**
ρ	**Reflection index**
χ	**Sun zenith angle [Degree]**
ζ	**Plate azimuth angle [Degree]**
δ	**Solar declination angle [Degree]**
λ	**Latitude [Degree]**
α	**Solar angle [Degree]**
ϕ	**Tilt angle from the horizontal surface [Degree]**
φ	**Uniform random number**
σ	**Self-discharging coefficient of the battery**
δ	**Inflation rate**
μ_{PV}	**Escalation rate of PV**
μ_W	**Escalation rate of wind**
$\propto_{pv}$	**PV initial cost $/Kw**
$\propto_w$	**Wind initial cost $/Kw**
$\propto_{waste}$	**Waste initial cost $/Kw**
β_{pv}	**PV annual OM**
β_w	**Wind annual OM**
β_{waste}	**Waste annual OM**
λ_{PV}	**PV resale price**
λ_w	**Wind resale price**
λ_{waste}	**Waste resale price**

Chapter 1: Introduction

1.1. Overview

Recently, the issue of global warming has been raised due to the interest in reducing gas emissions (GHG) as a cause of overloaded human activities including electricity generation from conventional resources such as natural gas, oil, and coal. In addition, the Kyoto Protocol (which was adopted on December 11, 1997) recognized that developed countries are responsible of increasing gases emitted into the atmosphere because of more than 150 years of industrial activities [1]. Thus, many researches have stimulated the interest to increase the concern of the development of clean energy by looking for sustainable sources of energy.

Renewable energy sources (RES) like solar, wind, biomass and others provide sustainable and environmentally friendly alternatives from nature. These natural sources are used for electricity generation, water and air heating/cooling, transportation, in addition to supplying rural off grid areas with energy services. However, using renewable resources alone cause some technical and economic challenges. First, as they are unpredictable, uncontrollable, and intermittent, RES cannot be used solely to provide power generation continuously. Furthermore, renewable technologies are more expensive than conventional generators especially if used in conjunction with storage devices to enhance system reliability. Finally, the energy supplied from renewable sources are affected by their installed locations.

To overcome these challenges, integrating several types of RES with some storage devices and conventional sources (such as diesel generator) can be a viable solution. Each resource should be utilized in a way to complement each other due to differences in seasonal and daily resource availability. This type of integrated system referred as

"Hybrid Power System". As well as stand-alone renewable sources have challenges, hybrid systems have economic and technical challenges. These challenges are:

I. The multiple components utilized in hybrid system generally make them expensive to build.
II. Not all the components are fully developed, it is risky to invest in them for long-term.
III. Implementing hybrid system can create market opportunities to apply for technologies that are not mature yet.
IV. The system has limited scalability with the currently used technologies to be applied for small power production facilities, so applying for large areas can be high challenged. Table 1 summarizes the advantages and disadvantages of hybrid systems.

Table 1: advantages and disadvantages of hybrid system

S.NO.	Advantage	Disadvantage
1	Each renewable source has its strengths during certain period which enable to overcome the weakness of the others.	Although, most hybrid renewable systems are highly location dependent.
2	In standalone hybrid system, construction of power plant does not need a grid connection.	Integration of more than one source cause to have a complex system.
3	Although hybrid system makes the system reliable and stable during the year.	Most renewable sources used are solar and/or wind in addition with others

Due to the above reasons, hybrid power systems (HPS) are required to be optimally designed to be cost effective, reliable, and environment friendly systems. Many approaches have been studied for hybrid systems from simple ones as analytical approaches to more complicated methods as meta-heuristic techniques. Classical optimization methods are not able to tackle the optimization problem of HPS due to its complexity to be represented mathematically as such systems have high dimensional space or non-linear nature. In addition, simulation model used to evaluate the performance of complex systems, but using simulation models alone cannot obtain an optimal solution. Therefore, combination between optimization and simulation models is preferable.

1.2. Motivation:

Qatar is an oil and gas rich nation, with the third largest gas reserves and one of the highest gross domestic products (GDP). Statistics showed that, electricity demand has grown rapidly in the last few years (increased by 17%) and it is likely to expand in next coming years due to heavy industries and energy intensive areas, in addition to its successful bid to host the 2022 FIFA world Cup. Moreover, Qatar has one of the highest emissions per capita in the world, and there is a recent growing interest to find alternatives and sustainable sources of energy like solar and wind. The country aims to become the world's leading exporter of renewable energy sources. In addition to [2]:

- Qatar aims to install 1.8 GW of solar capacity by 2022
- Qatar aims to generate 20% of its energy from renewable
- Qatar promises a carbon-neutral 2022 FIFA World Cup
- 80% of Qatar’s total water desalination could soon be powered by solar energy

- Achieving environmental sustainability is a key pillar of the Qatar National Vision 2030

Figure 1, depicts how the amount of CO_2 emissions has increased since 2000 until 2012. However, in 2013 the amount has decreased due to the increasing concern of the gases emissions risks. While electricity consumption has been raised rapidly in line with Qatar's population growth and overloaded activities.

In this thesis, a combination of three renewable sources: solar panels, wind turbines, and waste boilers will be integrated to design a hybrid system which feeds required demand in remote areas in Qatar.

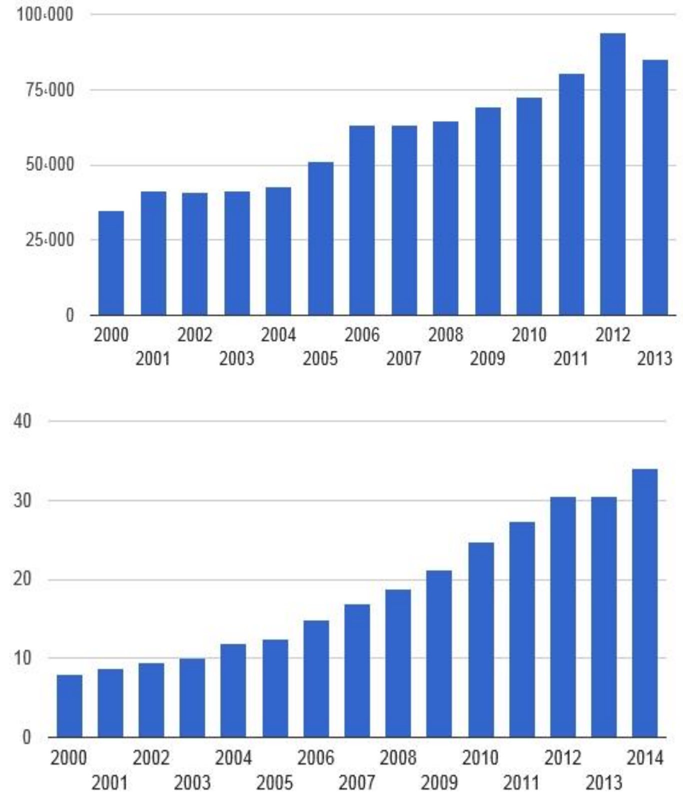

Figure 1 Qatar carbon dioxide (CO_2) emissions & Electricity Consumption (Billion kilowatt-hours)

Source: **TheGlobalEconomy.com, the World Bank.**

1.3. Objectives

The objective of this thesis is to develop an approach that can be used to optimize the sizing of a hybrid renewable energy system to supply the energy demand in remote area which is not connected with the grid, taking into consideration the following:

- Design criteria are annual net present total cost (NPC), CO_2 emissions and unmet load. These three criteria will help the decision maker to select best solution based on target parameters.
- The hourly variations of solar irradiation, wind speed and waste combustion by collecting actual data at Qatar. As no studies, has been published using actual data to design hybrid model in Qatar to the best of our knowledge.
- Solutions obtained shall not violate the technical and operational constrains of the system.
- The optimization model shall be applicable while giving fairly accurate results.

1.4. Data Collection:

During this thesis, a significant amount of time and effort are put in collecting data, the following were used in the thesis:

- Solar irradiation, wind speed data, specifications of solar panels and wind turbines obtained from Kahramaa (Qatar General Electricity and Water Corporation).
- Waste combustion, waste boiler specifications with its total costs obtained from Keppel Seghers Company in Qatar.

For confidentiality reason, the data obtained can’t be published on this study.

1.5. Thesis Outline

Beyond the scope of chapter 1, this thesis contains 5 more chapters divided by the steps that should be followed.

Chapter 2 reviews the literature addressing the HPS design problem, including design objectives, renewable energy system types, and design approaches. Simulation and optimization modules used in this study are discussed in chapter 3 in addition to the proposed heuristic algorithm. Then, the suggested methodology will be applied using real data and demand in remote area in Qatar in chapter 4. Finally, discussing results with summarized conclusions and future research are presented in chapters 5 and 6.

Chapter 2: Literature Review

Hybrid renewable energy systems have been proved to be the most suitable and favorable option to supply electricity in certain distances or in large areas at the lowest economic costs and maximum environmental and social benefits. In the last decades, researches regarding HPS grown dramatically due to the global interest in the development of renewable energy resources that contribute to the improvement of the environment. Different methodologies have been applied for this purpose. In this chapter, the work reviewed is mapped per different criteria such as system types, design objectives, and algorithms used.

2.1. Design Objectives:

2.1.1. Single Objective Designed System: Cost Minimization

Cost minimization is the most repeated and considered objective when designing HPS. Total costs considered for HPS are the one- time costs (i.e. capital) and the recurring costs (i.e. operational costs). Some researches calculate the total costs by using Net Present Cost (NPC) formula or Levelized Cost of Energy (LCE). The second option is preferable to be used because it measures the system economic feasibility. In Kost et al. [3] examined different technologies options to achieve the optimal annual cost effective designed system for supplying power for an Industrial company in German. The annual costs consist of operation and expenses costs where the last was calculated using annuities, while operation costs depend on the energy generated by different technologies. Since the system is grid connected, so grid cost was calculated as the difference between annual costs for electricity purchase mines the annual revenues for selling electricity to the grid. The authors studied the existing optimization model in order to extend it with renewable energy resources under technical and economic constrains. The model is described by a mixed-integer problem in which decision variables are set for the size of hybrid energy system. The model was applied at different scenarios to study the best option under different performances. It was concluded that, with grid-connection, the system prefers to use PV system for electricity supply since the roof of the company is covered with PV panels.

On the other hand, to avoid electricity consumption from the grid, the model will use both PV and wind systems which need to be supported for the fluctuations in the stand-alone system, by integrating energy storage, diesel generator, and a thermal generation such as biomass plant. In this case, the total annual costs were strongly increased comparing with the use of local electricity supply from the grid. Finally, the authors analyzed the effects of the input data on the model results by changing the technology costs and the costs for electricity purchase from the grid which has the highest impact on the objective function. It was observed that; grid connections costs have less influence.

Also, the study conducted by Fahmy et al. [4] verified the possibility of designing a hybrid renewable energy system to power a small scale of desalination unit and tourism motel in Egypt. The authors proposed four different hybrid power systems with backup systems and compared between them with respect to the total net present cost (NPC) and levelized cost of energy to find the best one which can feed the required electricity for both applications. First, they knew the daily consumed electrical energy for the desalination unit and tourism motel in summer and winter seasons. Then, a site was selected based on some criteria like availability of ground water, potential of solar radiation and wind speed, demand for fresh water, and the non-availability of electric grid. For the selected site a weather data such as monthly solar radiation and monthly average wind speed was collected. A simulation of the model was carried out on NREL and HOMER software to find the optimal design that gives minimum costs for the suggested power systems. Results showed that PV-wind-battery system provided most economical solutions under resources and load conditions with sufficient required energy for the desalination unit and tourism motel compared when using PV-wind-fuel cell system. This is because to the high capital cost of fuel cell system and electrolyser compared to battery. In reference [5] proposed an optimal hybrid energy generating system including wind, photovoltaic, and battery that feeds a power for a remote area in the North West of Iran. The aim of the study was to design a standalone system with minimum costs for 20 years of operation. The economic analysis costs involved net present costs and customer's dissatisfaction costs which were calculated as electricity interruptions. Data like hourly solar radiation, hourly wind speed, and load was collected and measured in the region for a one year period. The authors then used a Particle Swarm Optimization algorithm to find the optimal solution under different scenarios which are PV-battery systems, wind-battery systems, and PV-wind-battery systems. It was noticed that, because the region has fluctuations in wind more than the solar radiation, they added more battery storages to the wind-battery systems to avoid any unmet load which therefore increased the total costs. PV-battery system has lower total costs than PV-wind-battery systems; this is because the peak load in the region is near to the peak load of PV generation compared with the peak of wind generation. Furthermore, since the climate is always cold, so the electricity demands in summer is not more than demand in the winter. This helped them to decrease the number of required battery storages which therefore let the designed system to be more economical. To sum up, the authors focused to find the optimum minimum costs hybrid systems without taken into considerations the reliability indexes like generator failures and renewable power availability which might affect the power supplied.

2.1.2. Other Objectives:

Besides cost minimization objective, some studies focused on other objectives such as:

a. Maximizing System Reliability: system reliability can be enhanced by minimizing the chance of not providing a power from HRS. This can be achieved by minimizing the Loss of Power Supply Probability (LPSP), which defied as the ratio of all the losses power supply values over the total load required during that period. Yang & Zhou [6] has developed a novel approach for designing a hybrid solar-wind system with battery bank to maximize the system reliability by minimizing the probability of loss power supply. The authors basically developed three models: mathematical model for the hybrid system, economic model based on levelized cost of energy concept, and reliability model based on loss of power supply concept. This system was applied for a telecommunication station on a remote island in Shanwei of Guangdong province, China which demanded a 1000 W power load. Thus, the system was optimized according to the desired reliability value. Based on this requirement, the authors run and simulate the model in the HSWSO program to find the optimal capacity sizes of different components of the proposed system. They considered the system sizes which gave the desired LPSP and minimum LCOE.

While some researches aimed to minimize unmeet load which is defined as the amount of not served the energy in certain time. For example, in reference [7] authors have developed a particle swarm optimization algorithm for multisource hybrid power generation systems. The proposed system was designed under different scenarios. For example, hybrid system linked with grid connections without considering the system uncertainties such as equipment failures, time dependent source of energy, and load variations. Then, a time series models was developed to reflect the stochastic characteristics. Finally, a sensitivity analysis was analyzed to study the system performance under different parameters.

b. Maximizing System Efficiency: it is represented as a function of conversion devices efficiencies and measures the amount of dumped energy. This is calculated by dividing the total supplied power to the load by total energy provided by all generators. Li et al. [8] performed the feasibility study of PV energy systems with different energy storage technologies, such as fuel cells, hydrogen tanks, batteries, and electrolyzers to ensure the continuous power flow. They developed three hybrid energy systems to be compared. The system with highest efficiency and minimum costs will be chosen. The results showed that, the proposed PV/FC/Battery system is the best, because it requires less PV modules comparing with the single storage systems. Thus, ensuring the lowest costs. Furthermore, this system ensures the continuity of power supply, in case if the solar system cannot cover the required load, the storage systems will handle the problem.

c. Minimizing Line Losses: loss minimization can be achieved through proper selection of system's types and sizes. Atwa et al. [9] proposed an optimal system by allocating different types of renewable distributed generation units that gives the minimum annual energy loss. The model was formulated as mixed integer nonlinear programming with one objective and four constrains. The proposed model was applied to a rural distribution system with different scenarios for different combinations of renewable distributed generation units. Results showed that, regardless of the combinations of RDG units, the model gave a significant reduction in annual energy loss.

2.1.3. Multi Objectives Designed System:

Some researchers had multi objectives to be analyzed and solved simultaneously, such as minimizing both costs and CO_2 emissions. While some objectives inherently conflicting like minimizing costs and maximizing system reliability. In this case, the researchers tried to find the best trade-off between these contradicting objectives. Suchitra et al. [10] designed a PV-diesel system with battery to meet a particular load curve with solar irradiation data of Chennai, India. The authors aimed to design the system with minimum total net present cost and pollutant emissions. A mathematical model was developed for each component of the system with its relevant data. Then, a multi objective genetic algorithm using -Dominating Sorting procedure for populations (NSGA-II) was used for optimizing the system programmed using MATLAB. The type of PV panel and battery was studied as well as the number of PV modules, number of batteries, and diesel generator runtime. Results showed the required numbers of parameters for the system which gave the minimum net present cost and the emission of CO_2. Thus, the system is reliable and can supply high quality power to the load. The authors, at the end recommended to add few more renewable resources like wind, biomass, and storage devices such as fuel cell which will help to reduce the probability of unmet load.

Also, Kraj et al. [11] assessed the long-term performance of a hybrid wind-solar-biomass system for supplying power at Fernando de Noronha island in Brazil. A diesel generator and storage components was integrated to the hybrid system to be used as a backup device for electrical energy generation. They applied a multi-objective optimization model using the evolutionary algorithm, SPEA (Strength Pareto Evolutionary Algorithm) implemented in MATLAB. The model simulated real data for solar, wind and biomass, diesel backup and storages parameters. The objective was to minimize costs, maximize system reliability and maximize renewable energy generation to meet the required load. Results showed that, having multi renewable energy systems will increase the RE ration and thus decrease the diesel fuel dependence. Furthermore, HRES can stabilize the electricity supply of remote locations through complimentary combinations of energy systems with the most economical solution. Finally, in reference [12] authors analyzed the technical, environmental, and economic feasibility of using wind/solar system along with diesel and battery systems to feed energy demands of Telecommunication Center in Catalonia, Spain. The authors analyzed the models at different scenarios through HOMER software. Required data for the study was collected from RETScreen and PVsyst software that provide meteorological data to be introduced on the energy model in HOMER. To study the performance of the proposed system, they applied sensitivity analysis which helps to understand the affects and viability of the designed system under different changes in inputs. Results showed that for economic criteria PV-diesel-battery system is the optimal one. While PV-wind-diesel-battery system showed as optimal solution for the environmental criteria, no optimal solution for technical criteria. Furthermore, the authors realize the system that combines multi criteria; PV-diesel-battery system is the best optimal solution. To sum up, a PV-wind-diesel system was simulated under different criteria to provide high reliability and high quality of electrical energy for telecommunication infrastructure and services. Chedid et al. [13] also designed a PV-wind-diesel system applied to hypothetical site in Lebanon. The model considered two objectives which are minimum costs and emissions. They solved each of the objectives separately using Linear Programming and compare it when using a multi objective problem by the ε-constraint and the goal attainment methods. The results of minimizing costs only using liner programming showed wind power was used rather than solar power and batteries because it is less expensive and the addition of wind turbines was limited by wind resource contribution constraints. While when minimizing the emissions only, the model takes less diesel units and solar panels rather than wind turbines was used to compensate for energy loss. However, when considering two objectives on the same time the total costs was higher than minimizing cost as only one objective due to higher installation of PV panels. Emissions objective was affected too because more diesel units were added.

2.2. Renewable Energy System Type:

2.2.1. Renewable Energy System Size:

Hybrid Renewable energy sources have proven its capabilities to provide power for different applications from single building to large areas. For example, Diaf et al. [14] designed a PV/wind hybrid system to be installed at Corsica Island in France to provide 300 W for the residential households. Authors in reference [15] designed the HRES to supply power for the entire island with a demand of 23 Kw. Vafaei [16] focused to design wind-hydrogen energy system to provide the power for remote community in northern Ontario Canada, with the goal of minimizing the total costs. On the other hand, some studies only tested the availability of the system to achieve the optimum combinations and sizes within the desired criteria. In reference [17], the author developed a mathematical model for hybrid wind-PV-tide generation system then using

MATLAB to find the optimum sizes. To test the availability of the methodology, authors used the field data which was acquired from sets of experiments. Results proved that the proposed method can find the optimal combinations and sizes with consistency. These examples show that HPS can be built in virtually any size to serve the desired application, and that regardless of their size; the design of HPS has to be optimized in order to operate reliably and economically.

2.2.2. Device Combinations:

Solar energy is the most available source that has been used in many RES applications. It is free and non-pollutant source. Some studies only used solar system to provide the desired energy with backup systems. In references [18] & [19] the authors used one type of renewable energy resource which is a solar system with one storage device (fuel cell) to complement the fluctuating solar energy to satisfy the growing load. The system was designed to supply power in the city of Brest in France and for rural village in India respectively. The proposed system was optimized and simulated through HOMER software and it was basically focused on the economical performances concept. Results analysis showed that the combination of the solar photovoltaic and fuel cell supported the desired load.

Furthermore, Rashid et al. [20] designed the photovoltaic system with two different configurations for fuel cell, one included the fuel cell with electrolyser unit to produce energy using hydrogen, and the other one included fuel cell with battery. The two configurations were optimized using Particle Swarm Optimization Algorithm. The one with optimum configuration in terms of efficiency and costs was selected to provide reliable supply power during 20 years' system life.

On the other hand, due to uncertainties of RES some researchers used more than one source to feed the electric power. In references [21] & [22] they developed a PV-wind hybrid system with one fuel cell storage device. They preferred to use fuel cell due to its high efficiency, long life, and lowest cost comparing with other storage system. While, some researchers combine more than two RES in order to provide more efficient system in terms of its reliability. Akella et al. [23] integrated PV-wind-biomass system with hydrogen tank to feed a power for rural area in India. The model was optimized using LINDO software. The results indicated that, the optimized model has been found as the best choice to provide the desired energy in that area. About 16.81% is the contribution of the renewable energy sources to the total energy demand.

2.2.3. Grid vs. Non-Grid Connectivity Configurations

In case of unavailability of grid, standalone systems are designed combining different renewable energy resources. To overcome the uncertainties of these resources a back-up system such as battery storage device, diesel generator, and fuel cell are integrated. This system has been applied in many studies for rural areas where the extension to grid connections is almost impossible, such application as remote village, islands industrial companies, and telecommunication centers. Sen [24] Designed an optimal hybrid system combining of a mix of renewable energy resources to satisfy the electrical needs in remote village in India. The authors used HOMER to find the optimal design. They made a comparison between off-grid option and grid extension. They concluded that a hybrid combination of renewable generators at off-grid location is cost effective comparing with grid connection. Furthermore, it is more sustainable, techno-economically viable and environmentally sound than the second option. Gupta et al. [25] developed the same study using LINDO software. The objective of their study is to prove that power can be generated by making use of different RES such as wind, solar, micro hydro, and biomass without the need of grid connections. Results have supported the desired objective and provide feasible and reliable solutions.

However, Chedied & Rhman [26] studied their proposed system in conjunction with the grid. Because of this, they considered the emission as another variable that had to be minimized in the objective function through assuming a cost associated with other RES components' costs. Thus, by running out the optimization model (LP technique) the correct size of RES was selected to supply power for DGs in grid linked system. Some studies made a comparison between grid and off grid connections. Al-Ammar et al. [27] studied the designed RES with off/grid connections under different scenarios. They noticed that the system preferred to use grid rather than RS such as solar system and this leads to have fluctuations in total annual costs. While in the stand-alone system, the total annual cost is increasing as minimum renewable fraction is increasing too. In conclusion, stand-alone systems will have fewer emissions than grid connected systems.

2.3. System Design Approach:

2.3.1. Analytical Approach:

In some researches, the authors used simple analytical techniques to find a simple and closed optimum solution for the designed hybrid renewable energy system. Habib et al. [28] proposed a wind- PV system to supply a constant load of 5 Kw. The optimization procedure was based on calculating the percentage of power produced by each energy source. The authors used the average wind speed and solar radiation to calculate percentage contribution of each resource. Because the availability of the renewable sources is critical, they calculated the required total energy that will be stored on daily, monthly, and annually basis to overcome this problem. Finally, to find the optimal solution, different combinations were determined to calculate and compare their costs, the one with least total capital cost was selected. In conclusion, this approach can be applied for simple stand-alone PV-wind-battery system where no operating strategy is required. Furthermore, the accuracy level of this type of approach is minimum, since many assumptions are usually made to simplify the proposed system.

On the other hand, some researchers found the optimal sizes of the hybrid system by increasing the number of one energy source while putting the second one constant until they achieve the desired level which supplies the required load. In references [29] & [30], the authors set an initial number for PV modules, while the number of wind turbines was gradually increasing until a balance is achieved for the demand with least cost system configuration. For the storage device, the capacity is determined by calculating the difference between supplied power from the hybrid system and the desired load. While Markvart [31] employed a simple graphical construction of PV surface area and wind speed curves to find the optimal sizes of PV and wind generators. The author assumed a constant demand. The point between the two curves is assumed to be the optimum solution.

2.3.2. Simulation Based Optimization:

Most of the studies designed the HRS optimization model uses simulation based techniques. This approach helps the researchers to study the performance of the system under different conditions within the desired criteria. Furthermore, it is recommended to be applied for simple systems where all the possible solutions can be tested to find the sizes of HRS considering the optimum criteria, which is called design space approach. Dalton et al. [32] used the same technique to find the optimum sizes of the HRS components to supply power for a hotel located in a subtropical coastal area of Queensland, Australia. The authors used HOMER and HYBRIDS software tools to compare different generator combinations which are: RES only, diesel generators only, and RES/diesel hybrid combinations. Results showed that all combinations are good to support the required load. The RES is technically feasible and economically viable as replacement for conventional energy supply. Similar approaches were used in references [33] and [34]. On the other hand, when the proposed components of HRS have non-liner characterizes with large number of variables in the optimization problem, a large smarter search technique will be used to get the best solution from very large numbers of feasible solutions.

Seeling & Hochmuth [35] used a Genetic Algorithm for determining the size and operation control of hybrid-PV systems. They divided the algorithm into main and sub-algorithm which dealing with components sizing and operation optimization respectively. Thus, the algorithm found the optimum system based on decision variables and constrains of the designed system. Other evolutionary algorithms such as Strong Pareto Evolutionary Algorithm which was used by Rodriguez et al. [36] in combination with linear programming to find the optimum RES which has the best trade-offs between several objectives. While Celli et al. [37] combined the genetic algorithm with a ε –constrained method for optimal sizing of DG resources into existing distribution network. The methodology was planned to find the best solution that gives minimum costs, loss of power supply and maximum desired load.

Particle Swarm Optimization is another stochastic optimization technique similar to genetic algorithm. It shares GA by initiating a random solution from the population and then searching for the optimum by updating generations. However, PSO has potential solutions called particles that fly through the problem space by following optimum particles. Thus, it differs from GA which has evolution operators such as crossover. Sharafi & Elmekkawy [38] proposed a novel approach for optimizing the size of HRES. They used PSO after developing the mathematical model by ε –constraint. The approach has been applied to tackle the multi-objective optimization problem. The main advantage of the proposed approach was its simplicity which leads to computational efficiency results. PSO was used in [39] and [40] to determine the optimal sizes of different HRES and in [42] to find the optimal design of standalone PV-wind with hydrogen system. While Ekren & Banu [41] performed Simulated Annealing (SA) algorithm for optimizing the sizes of their proposed system to feed a power for a campus area in Turkey.SA considered as heuristic approach uses a stochastic gradient to search for the global optimization. The authors noticed that SA algorithm gave efficient results satisfying the desired demand with minimum total cost.

2.3.3. Constrained Optimization:

Unlike simulation based methods, constrained optimization methods are free rule techniques. In this approach, the problem is formulated in a set of equations include the decision variables that represent the required output from the designed system within its required objective. The model then is solved using different solver software like LINDO. Akella et al. [42] design a hybrid energy system consisting of PV-wind-biomass with micro hydro generation unit by using Linear Programming method. The proposed system was able to satisfy the annual energy demand at minimum cost. Chedid et al. [26] also used LP in their designed hybrid system to meet the load requirements in minimum cost and in reliable and environmentally manner. For multi objectives optimization problems, some studies converted the multi objectives to a single problem by using ε –constraint method. In this method, one objective is treated as constant with its maximum value of ε such that it can be solved by LP [42]. Linear Programming approach enforced to approximate the analyzed curves to be linear, which is not always the case. Kumar &Gao [43] used Integer Non-Linear Programming model the optimum sizes of generation units in the hybrid system. In reference [44] the authors used the same approach for a multi objectives problem. Other constrained optimization algorithm used in the literature is the Mixed Integer Quadratic Programming [45], the Mixed Integer Programming model [46], and the multidimensional direct algorithm [47]. In conclusion, constrained optimization problem can be used to achieve better heuristic solutions. Table 2, summarizes the advantages and disadvantages of different optimizations approaches.

2.4. Applications in GCC Countries:

In recent years, the interest in renewable energy sources has increased significantly in the Middle East. They contribute to concerns regarding global warming and the consumption of fossil fuels. Countries who have extensive consumption of energy like Saudi Arabia and United Arab Emirates have taken the steps for developing new strategies for renewable energy resources. Mousa et al. [47] studied hybrid solar/wind systems and assessed their feasibility to power remote locations including Weather Station, Home, and Village that are not grid connected. The system was designed to find the optimal parameters for the number of PV models, number of wind turbines, height of wind turbine, and the diameter of rotor turbine. The goal was to minimize the costs including investment and maintenance costs for the components of the system.

The model was solved using GAMS for mathematical programming and optimization. In order to study the performance of the system, the authors used generated weather data that is typical of Middle Eastern countries of UAE and Oman to calculate the power output from the system and compare it with the required demand. Results demonstrate that, the system is reliable and can supply high quality power to the load. It was concluded that, there is a complementary relationship between the two sources, such that when one of the sources supplied low energy due to the weather conditions, the other source can supply high energy and covered the required load.

While, Mokheimer et al. [48] presented a hybrid system model that included battery bank and inventor along with solar and wind power to feed electricity for water desalination system in Saudi Arabia. The battery bank was used as backup system to charge it when the power generated is higher than the required demand, while the inventor was used to convert the generated energy to AC power. They developed a simulation models for the system to calculate optimized combinations of PV panels, wind turbines, and battery bank parameters for a given required load. The model was running for 2 load demand cases, one for 12h/day, and the other for 24h/day. It was concluded that for 24h demand loading, the number of parameters was higher comparing with 12h demand loading.

The feasibility and ability to use hybrid power system to provide village with its need of electricity in Saudi Arabia was assessed by Al-Ammar et al. [27]. The proposed system included renewable energy generators, diesel generator, battery bank, and convectors. Each component their initial cost, cost of fusel fuel, component life time, annual interest rate, and annual load was collected to be used as inputs for HOMER software. The designed system was studied under different scenarios which are; solar-grid connected without constraints, solar-wind-grid connected without constraints, solar-wind-grind connected with constraints, diesel-solar-wind without grid and constraints, and diesel-solar-wind without grid and with constraints. The optimal design was solar with grid connection, and it was concluded that there is no contribution from wind due to its low speed. Thus, the authors compared between solar-grid connected and solar-diesel generator systems. When the system connected to the grid, it will prefer to use it rather than the solar energy generated. That is way there is a fluctuation in total annual costs. While the hybrid system increases its annual costs as renewable fraction increases. To conclude, the authors prefer to use solar-grid combination due to the minimum annual costs and emissions.

Qatar also has started to take into consideration the importance of RES for the environmental and social development. Ben [49] proposed a standalone hybrid renewable energy system for a remote location in the state of Qatar using the Levelized Cost of Energy Approach. The objective is to find the sizes of the hybrid system to provide the load requirement of 1.2 Kw. Data from solar radiation, wind speed, demand load was collected to be carried out on MATLAB simulation model, in addition with backup batteries and diesel generator. Each component of the system was analyzed and tested against the proposed model. The results showed that, power from wind is very limited comparing with the wind characteristics, while solar radiation can supply high power during the highest required load. Therefore, the analysis considered varying the installed capacities of photovoltaic and battery to generate the ideal case. It was observed that, the minimum LCOE for such a combination is at 3.2 Kw of installed PVpower with an efficiency of 13.65% and 0.828 KAh of installed battery capacity with 0.2934 $/kwh LCOE. Finally, a sensitivity analysis was done to study the effects of the components' costs and lifetime on the LCOE. It was concluded that, the LCOE calculated for the best combination of PV models and battery is still higher compared with global standards.

Table 2 advantages and disadvantages of different optimization techniques

S.NO.	Optimization Technique	Advantages	Disadvantages
1	Analytical Technique	-Easy to implement. -Calculation time is short.	-Not applicable in complex systems.
2	Particle Swarm Optimization	-Search based on the speed of the particle. -Applicable for large space to search for optimal solution.	-Not easy to find the optimal solution due to difficulty to find the problem of scattering
3	Heuristic Algorithms	-Useful for complex problems. -Can find near optimal solutions	-Difficult to be used in stochastic data. -Difficult to find optimal solution.

2.5. Conclusion Remarks:

It is clear from the reviewed studies; renewable energy resources are able to provide the desired energy under some criteria. It was noticed that, most RE sources used in almost all the reviewed articles is solar energy. Then wind turbine is the second most used option. Other resources as biomass, geothermal, tidal, etc. are very rare to be used. Moreover, when the system is stand-alone without any grid connections, storage device has to be integrated and usually as battery banks. Most studies modeled single cost minimization objective and simulate the proposed system using HOMER software.

Finally, few studies provide future research directions to enhance the system. Table 3 shows a summary of the reviewed articles. However, there are some limitations and issues need to be addressed:

- Some studies have not considered sensitivity analysis, as it is an important analysis to study the performance of the system under different circumstances.
- Most studies proposed stand alone or grid connected models, but not both. In some situation, a micro grid is required for both models to operate especially if the connection with the main grid is intermittent.
- The studies which consider the usage of storage devices did not consider uncertainty factors such as generator failures in order to be included in the system reliability indexes.
- For minimizing the greenhouse gases emissions such as CO_2, the authors considered only direct operational emissions (i.e. during the operation of the diesel generator). An emission from the systems' components during the manufacture, transport, and installation was most neglected.
- In simulation based methods, the models which have storage devices in the RES was considered as free models, and an enumerative search methods were used where all different combinations are examined. This is impractical since the number of combinations might increase beyond certain limits. On the other hand, some studies considered heuristic methods which are sensitive to the selection of the algorithm parameters and easily get stuck in local optimal solution.

This thesis distinguished from other researches on:

- In Gulf region and especially in Qatar, there is very limited work in RE and integrating more than once source to design reliable system.
- Using real data for PV panels, wind turbines and waste boilers, in addition to real demand at Qatar in the developed models.
- Since waste treatment in Qatar is based on combustion, so the decision maker can integrate waste boilers as renewable source with specified amount of CO_2 emissions produced , since most studies only considered solar panels and wind turbines.
- In most studies, either different specifications for system's components or different system types are studied. In this study, different sizes (capacities) for system's components will be considered to study different designed systems performance using combination of simulation and heuristic techniques.

Table 3 summary of reveiwed articles

References	Application	PV	WT	FC	Biomass	Hydropower	Diesel	Other	Optimization Model & Objective	Optimization Techniques	Grid Connections	Future Research Directions
Kost et al. [3]	Industrial company in German	•	•		•		•		Single-mixed-integer problem with min. annual costs	-	With grid: only PV Without grid: PV, wind, diesel and Biomass	-
Yang & Zhou [6]	station on a remote island in Shanwei, China	•	•					Battery	Multi-objective-minimizing costs and maximize system reliability	Simulation model using HSWSO program	No grid connections	-
Suchitra et al. [10]	Remote area in Chennai, India.	•					•	Battery	Multi objective genetic algorithm using -Dominating Sorting procedure with min. NPC and CO_2	MATLAB program	No grid connections	Integrate more RE sources such as wind, Biomass and FC to reduce probability of unmet load

Gupta et al. [24]	**Remote rural area in India**	●		‹	●	●	**Battery, Biogas**	**Single mixed integer linear mathematical programming model (time-series) to min. costs**	**C++ program**	**No grid connections**	**-**
Fahmy et al. [4]	**Small scale of desalination unit and tourism motel in Egypt**	●	●	‹			**Battery**	**Single model to minimize costs**	**Simulation model using NREL and HOMER software**	**No grid connections**	**-**
Mousa et al. [47]	**small-size reverse osmosis desalination plant**	●	●					**Single model to minimize costs**	**GAMS program**	**No grid connections**	**-**
Jahanbani, Fatemeh, and Riahy [5]	**Remote area in the North West of Iran**	●	●				**Battery**	**Single model to minimize costs**	**Particle Swarm Optimization algorithm**	**No grid connections**	**System reliability shall be considered such**

												as to measure the uncertainty factors of storage failures and power availability
Ekren & Banu [41]	**campus area in Turkey.**	•	•					**Battery**	**Single model to minimize costs**	**Simulated Annealing (SA) algorithm**	**No grid connections**	**-**
Ben [49]	**Remote area in Qatar**	•	•					**Battery**	**Single model to minimize levelized costs of energy**	**MATLAB program**	**No grid connections**	**-Alternative option for grid connections.** **-different sets of PV panels and wind turbines for assessing the performance.** **-integrate more storage systems**

											as FC and hydrogen generator
Al-Ammar et al. [27]	Remote Village at Saudi Arabia	•	•			•	Battery	Multi-Objective to minimize costs and emissions	HOMER software	With grid: only PV Without grid: PV, wind, diesel	-
Belfkira, R. et al [46]	-	•	•				Battery	Multidimensional direct algorithm to min. costs and unmet load	MATLAB program	No grid connections	-
Kraj et al. [11]	Supplying power at island in Brazil	•	•	•		•		Multi-objective optimization model to minimize costs, maximize system reliability and maximize renewable	MATLAB program	No grid connections	-

Akella et al. [42]	**Jaunpur block of Uttaranchal state of India**	●	●	●	●			**Single LP model to minimize costs**	**LINDO software**	**No grid connections**	**-**
Sharafi & Elmekkawy[38]	**Tested on hypothetical case study**	●	●	‹		●	**Electrolyzer& hydrogen tank**	**Multi-objective using ε –constraint method to min. costs, unmet load and fuel emission**	**Particle Swarm Optimization algorithm and C++ program**	**No grid connections**	**-detailed analysis for heat and electricity load separately. -load shifting within the proposed system. -analysis of uncertainty of RE sources**
Martínez et al. [12]	**Telecommunication station in Catalonia**	▪	▪			▪	**Battery**	**Multi-objective to min. costs, CO_2 emissions and max. system reliability**	**HOMER software**	**No grid connections**	**-**

Hakimi [39]	residential area		▪	'	Electrolyzer	Single objective model to min. costs	Particle Swarm Optimization algorithm	No grid connections	-
Nowdeh et al. [22]	Case study	▪	▪	▪		Multi-objective to min. costs and max. reliability	PSO algorithm and MATLAB	No grid connections	-
Wang& Singh [7]	-	▪	▪		Battery	Multi-objective to min. costs, CO_2 and max. reliability	PSO algorithm	No grid connections	Integrate more renewable energy sources
Khemariya, Manish &Mittal [19]	Rural village in India	▪		▪	Battery	Single objective to min. costs	HOMER software	No grid connections	-
Lim& Hwan [17]	-	▪	▪		Tidal	Single objective-LP model to min. costs	MATLAB program	No grid connections	-

Chapter 3: Proposed Methodology

3.1. Problem Description

Figure 3, shows the proposed system which will be used to supply demand at rural area in Qatar. The system is composed of PV panels, wind turbines, and waste boilers as an optional source to be integrated. Batteries will be used to store extra energy generated from the RE sources over the required load at any hour and hence this energy can be used in case of renewable sources cannot meet requested load. Finally, diesel generators will be used if the available energy from the RE sources and the batteries cannot meet the required load. It is worth mentioning that, if the proposed sizing of all sources of energy cannot meet the demand a shortage of load supply will occur. Based on Qatar's geographical and climate characteristics, climate data shows the global horizontal irradiance (GHI) which is useful to use photovoltaic panels is averaged to 0.54 Kwh/m2/day, and the average direct normal irradiance (DNI) for concentrating solar panel is 5.6 Kwh/m2/day. Therefore, Qatar has abundant solar irradiation which should be integrated in the hybrid system. In addition, the yearly average wind power density in Qatar is 59 W/m_2 occurring between March and June. Thus, the average wind speed is 4.58 m/s at 10 m height with direction of north to north-west over the year. In this study, hourly data for solar irradiation and wind speed are used in the proposed methodology.

In this proposed system, we basically have three scenarios that might happen:

- Scenario [A] the produced power from RE sources higher than demand: in this case the excess energy will be stored in the storage systems (i.e. the batteries).

If there is still remaining energy after installing in both storage systems, the energy will be dumped and therefore wasted.

- Scenario [B] the produced power from RE sources cannot meet demand: in case the system energy from batteries will be used first. If the demand is still higher, diesel generator will be used as emergency system.
- Scenario [C] the produced power from RE sources are equal to the required demand: here neither battery bank nor diesel generator will be used.

3.2. Proposed approach

This study attempts to design hybrid system using simulation-based heuristic method. Simulation used as an effective tool due to the system's mathematical models complexity. However, using simulation alone does not obtain an optimal solution. Therefore, optimization methods are used with simulation to not violate constrains and have an accurate reliable system. Due to the complex features of the system, linear programming approach cannot be applied. Therefore, a simple heuristic algorithm as shown in figure 5 has been proposed to generate possible solutions that meet required demand. The algorithm starts with generating initial solutions from 10% fraction capacity of renewable sources. Then, this fraction changed (increased) and study the performance of the designed systems. Basically, the system has five decision variables which represent the capacity required from each three-renewable source in addition to battery banks and diesel generators capacities. Each generated solution should be checked if it meets constrains that represent the maximum capacity that each component can store/ provide energy. Otherwise, it will not be considered as possible solution. Finally, solutions are selected based on three criteria; minimum shortages (LLP), minimum CO_2 emissions, minimum total costs (NPC).

In general, the following steps were used in the study to generate possible solutions:

I. Hourly energy output from renewable energy sources is calculated by the simulation module.

II. Different iterations were generated and within the same iteration, different combinations of renewable sources are used to match hourly load. In case of energy deficit during several consecutive hours a storage device is required to supply demand.

III. The capacity of battery is determined by calculating the maximum excess energy for each 10 consecutive hours during the year.

IV. If storage systems cannot meet demand, diesel generator is used to overcome the shortages. Any excess demand still remaining is considered as shortages.

V. Loss of load probability (LLP), CO_2 and total net present cost (NPC) of 20 years is calculated for each combination.

VI. Then, optimal combination is selected based on desired LLP, CO_2 and minimum NPC.

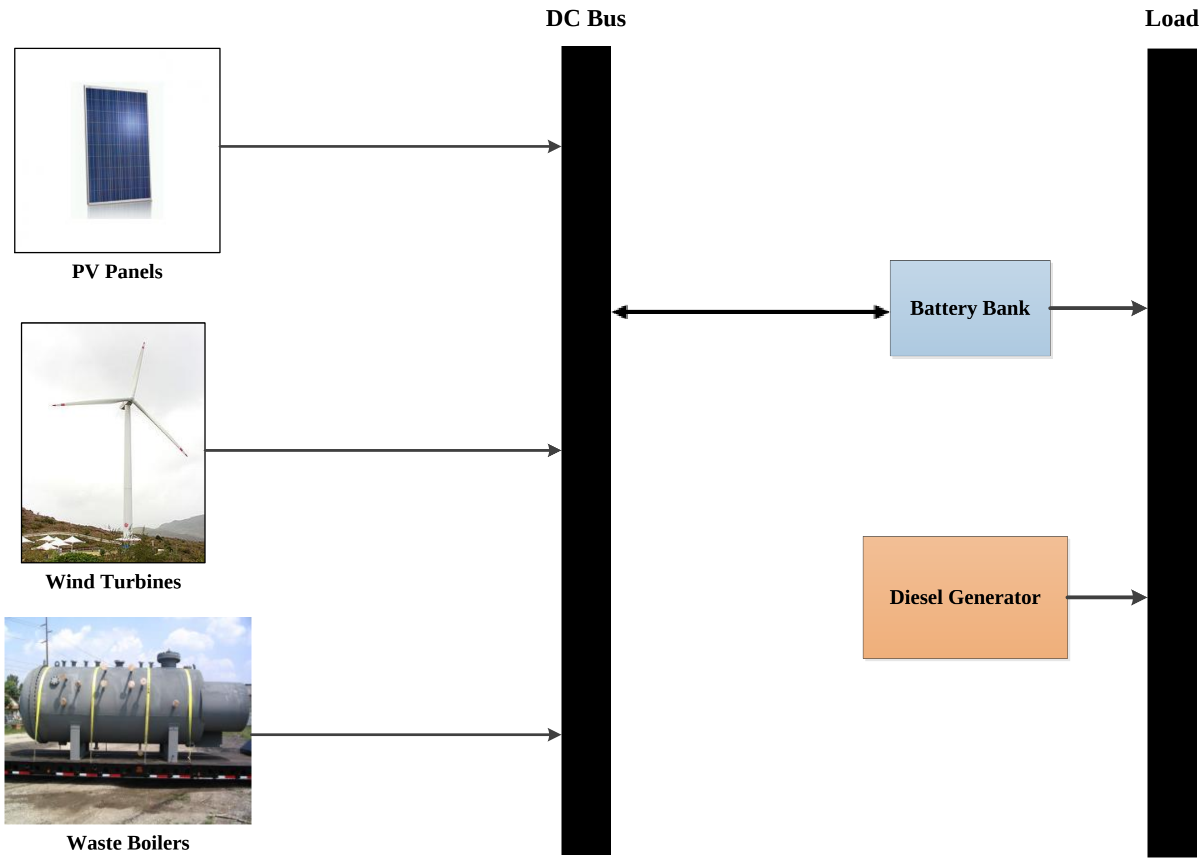

Figure 3 hybrid renewable energy system proposed

3.3. Simulation Module

The simulation model is applied to check the feasibility of each proposed solution. In this study, the simulation runs to calculate the power obtained from each component, CO_2 emission, and unmet load yearly. Then, the values will be investigated to check if they met the constructed constrains and therefore determine energy capacity from each component of the proposed solution. The simulation model is based on the hourly time interval analysis of electricity demand, solar radiation, wind speed, and burned wastes. The PV model converts the total solar radiation on the horizontal surface to energy output. Similarly, wind model converts the hourly wind velocity to the energy output. Wastes are burned to be converted to power and storage devices are added to cover the shortages or to store the excess energy generated from the renewable resources. The diesel model uses the fuel consumption curve data to calculate the output and it is used as an emergency component. The components' mathematical models which are used in the study are summarized below:

3.3.1. Mathematic Model of Photovoltaic Panels

Photovoltaic panels convert the sun light into electricity. The produced energy can be calculated by [38]:

$$E_{PV}(t) = \eta_{PV} A_{PV} I_T(t) \quad (1)$$

Where:

- $E_{PV}(t)$ is the energy produced by PV panels at any time t
- η_{PV} is the PV models efficiency assumed to be 7%
- A_{PV} is the PV panels area (m2)
- $I_T(t)$ is the hourly total solar radiation on tilted surface

Total solar radiation can be identified by considering two main components, which are: tilt angle of ϕ from the horizontal surface to tilt surface, azimuth angle ξ which determines how many degrees the surface of the modules diverges form the exact direction of south and it is the sum of components consisting of beam ($I_{b,tilt}$) , sky diffuse ($I_{d,tilt}$) , and ground reflected solar radiation ($I_{r,tilt}$) :

$$I_T = I_{b,tilt} + I_{d,tilt} + I_{r,tilt} \quad (2)$$

Or can be expressed as:

$$I_T = I_{tilt} = I_{b,n} \left[cos(\theta) + C\, cos^2\left(\frac{\phi}{2}\right) + \rho\, (cosX + C) sin^2(\frac{\phi}{2})\right] \quad (3)$$

Where:

- $I_{b,n}$ is direct normal irradiance on a surface perpendicular to the sun's rays
- θ is the angle between the tilted surface and the solar rays
- C is diffuse portion constant for calculation of diffuse radiation
- ρ is the reflection index
- X is the zenith angle which is the angle between the sun light and vertical

To calculate angle θ by:

$$cos(\theta) = [cos\phi\, cosX + sin\phi\, sinX\, cos(\xi - \zeta)] \quad (4)$$

Where ζ stands for plate azimuth angle

The below equations are used to calculate azimuth angle ξ and zenith angle X:

$$cosX = sin\delta\, sin\lambda + cos\delta\, cos\lambda\, cos\alpha \quad (5)$$

$$tan\xi = \frac{sin\,\alpha}{sin\lambda\, cos\alpha - cos\lambda\, tan\delta} \quad (6)$$

Where:

- δ is solar declination angle
- λ is latitude per degree
- α is solar angle

Each angle can be determined by:

$$\delta = 23.44\, sin\left[360\,(\frac{d-80}{365.25})\right] \quad (7)$$

$$\alpha = \frac{360}{24}\,(t-12) \quad (8)$$

$$t = LST + EOT - 4L_{local} + \, 60\, t_{zone} \quad (9)$$

$$B = \frac{360(\,n-81)}{364} \quad (10)$$

$$EOT(min.) = \, -(9.87\, sin2B - 7.53cosB - 1.5sinB) \quad (11)$$

Where d is number of days when January 1st is equal to one, t is the solar time calculated by knowing local standard time (LST) or real time, time for irregularity of the earth speed around the sun (EOT), L_{local} is local longitude (degrees East >0, degrees West<0) and t_{zone} is the time zone difference compared to GMT (degrees East >0, degrees West<0).

3.3.2. Mathematic Model of Wind Turbine:

Wind power is generated through converting wind kinetic energy into electrical energy. The power output varies with the wind velocity which has typical characteristics modeled by Weibull distribution shown in figure below.

Thus, the total power generation P_w is the area under the curve. The cut-in speed V_c is the speed at which the turbine starts to operate, while the cut-out speed V_o is the speed at which wind turbine shuts down to avoid damage. The wind velocity produces power from cut-in speed until rated speed V_r and then constant power until cut-out speed. This power from wind turbine can be calculated as [61]:

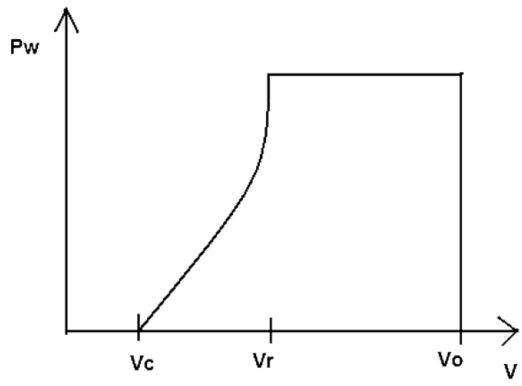

Figure 4 Weibull Distribution

$$E_w = \begin{cases} P_w = 0 & v < v_c \\ P_w = \frac{1}{2}\, C_p \rho\, A\, v^3(t) \Delta t & v_c < v < v_r \\ P_w = P_r & v_r < v < v_o \\ P_w = 0 & v > v_o \end{cases} \qquad (12)$$

Where :

- P_w is the power generated from wind turbine
- C_p is the power coefficient of performance (obtained from manufacturer firm)
- ρ air density
- A is the cross sectional area of the rotor
- v is the wind velocity at time t
- P_r is the rated power

3.3.3. Mathematic Model of Waste Boiler:

Due to the large increase of wastes as a result of human activities, and their effects on environment and public health. It has increased the awareness to develop scientific methods for safe disposal of wastes. Therefore, recovery of energy from wastes can play vital role in mitigating the problem. These wastes are created every day and can be replenished. Waste power generated from converting amount of waste burned into electricity. Power produced can be calculated as [65]:

$$WTE = \frac{Heating\ Value\ (i)(2000\frac{lb}{ton})}{Heat\ rate} \quad (13)$$

Where:

- WTE: is the energy generated as electricity from the combustion of the waste (Kwh per ton)
- Heating Value: is the heating value of the waste component.
- Heat Rate: is a measure of the efficiency of the plant. The number of fuel needed to generate 1 Kwh (btu/kwh).

3.3.4. Mathematic Model of Battery:

At any hour, battery state depends on the previous state of charge, total energy generation and energy consumption at the time *t*. When the total output from renewable resources are greater than the energy demand, the battery bank is in charging state and it can be described by [66]:

$$SOC_t = -\sigma\ x\ SOC_{b_t} + (\frac{Eg(t) - El(t)}{\eta_{inv}})\ \eta_b \quad (14)$$

On the other hand, when the energy load is greater than the energy generated from renewable sources, the battery bank is in discharging state and it can be described by [66] :

$$SOC_t = -\sigma\ x\ SOC_{b_t} + \left(\frac{El(t)}{\eta_{inv} - Eg(t)}\right) \quad (15)$$

At any hour, battery storage capacity is subject to the following constraint:

$$SOC_{bmin.} \leq SOC_b(t) \leq SOC_{bmax.} \qquad (16)$$

Where:

- $El(t), Eg(t)$ represent the load demand at any time (t) and the total energy generated by PV, wind turbine, and waste boiler respectively.
- η_{inv}, η_b are the efficiency of inverter and charge efficiency of battery bank.
- σ is self-discharging coefficient of the battery.
- SOC_b is the maximum energy that can be stored in the battery.
- $SOC_{bmin.}$, $SOC_{bmax.}$ are the maximum and minimum allowable storage capacity.

In this study discharging state $SOC_{bmin.}$=30% and $SOC_{bmax.}$=100%

3.3.5. Mathematic Model of Diesel Generator:

Diesel generator is used as a backup system when the battery bank is discharged to its allowable depth. The generator uses fuel to generate power which depends on the rating and actual power. Manufactures provide the fuel consumption curve which help to calculate the fuel consumption at any load supplied by generator, which can be calculated as [38] :

$$\mathrm{FC_G} = \mathrm{a\,P_G} + \mathrm{b\,P_{R-G}} \qquad (17)$$

Where:

- FC_G is the hourly fuel consumption (l/h)
- P_G , P_{R-G} are output and rated power of diesel generator respectively
- a, b are the coefficients of the fuel consumption curve respectively. Typical values are a= 0.246 (l/Kwh) and b= 0.08145 (l/Kwh). These values fit well with the given consumption at rated power and even for low power generators

3.3.6. Mathematic Model of CO_2 Emission:

Since diesel generator is used in the HRE system, thus, the number of Kg produced CO_2 will be calculated each time interval during the year[38]:

$$CO2_{emission} = \sum_{t=1}^{8760} fuel_{cons}(t) \times EF \qquad (18)$$

where:

- EF: is the emission factor for the diesel generator which depends on the type of the fuel and diesel generator, here it is considered as 2.4-2.8 kg/lit rang.

In addition, the incineration of municipal waste involves the generation of climate-relevant emissions including CO_2 (carbon dioxide), N2O (nitrous oxide), NOx (oxides of nitrogen) NH3 (ammonia) and organic C, measured as total carbon. In this study, only carbon dioxide will be considered. To calculate the emission, it depends on the type of waste being disposed of (for example: plastics) and it is calculated as [63]:

$$CO2_{emission} = \sum_{t=1}^{8760} waste\ produced(\text{ton}) \times \text{SEF} \qquad (19)$$

Specific emission factor (kg/ton) is considered to be 2 for plastic waste types.

3.3.7. Mathematic Model of Unmet Load (LLP):

The system must supply the required energy at each time. In case if the total energy produced by RE components is less than the demand, the system will use storage components for supplying. If this is not enough, then shortages will happen to the proposed system. Therefore, the module is aimed to minimize the unmet load. This can be calculated as[61]:

$$\text{LLP} = \frac{\sum_{t=1}^{8760} \text{shortage (t)}}{\sum_{t=1}^{8760} \text{D (t)}} \qquad (20)$$

Where:

- D(t): is electricity demand
- Shortage (t): is the unmet load during the time t

3.4. Optimization Module

To obtain an optimal solution of the problem, optimization algorithm is necessary to be developed and implemented. The optimization problem is composed of decision variables, objective functions and constrains. In this case, simulation modeling is used to calculate the amount of energy supplied from each component of the proposed sizing of the HRE system. In addition, the amount of loss of load percentage (LLP) and CO_2 emission are calculated for the candidate system design too. While the optimization module is used for two reasons. First, it sends the proposed system design (sizing) to the simulation model. Second, it checks if the proposed solution satisfies the constrains and objectives.

3.4.1. Decision variables

They are defined as the installed capacity of each component in HRE system:

P = [Ppv, Pw, Pbat, PDis, Pwasteboiler]

Where Ppv is the capacity of the PV panels (kw), Pw is the capacity of wind turbine (kw), Pwaste is the capacity generated from wastes, Pbat is the capacity of batteries installed (kwh) and PDis is the capacity of the diesel generator (kw).

3.4.2. Objective functions

In this study, net present cost (NPC) is used for the cost analysis of the hybrid renewable energy recourses. The analysis consists of calculating the present worth of all the expenses over the life span of each component. It includes the capital cost (C), operation and maintenance cost (OM), replacement cost (R) and the salvage value (S). NCP is formulated as follows [68]:

$$NCP = C + OM + R - S \qquad (21)$$

The capital cost of the investment is obtained by:

$$C_{comp} = \propto_{comp} \; P_{comp} \qquad (22)$$

Where $\propto_{comp}$ is the initial cost of each component.

With an annual operation and maintenance cost of β_{comp} in $/Kw/year, the total OM cost during the year is:

$$OM_{comp=}\beta_{comp}\, P_{comp}\, \sum_{j=1}^{N}(\frac{1+\mu_{comp}}{1+i})^{i} \qquad (23)$$

Where N is the project lifetime, i is the interest rate and μ_{comp} is the escalation rate.

Since the project lifetime is equal to the largest component's life time and in most cases, it is equal to PV panels lifetime. In our case, since lifetime of PV panels and wind turbine are equal, so the lifetime of the project will 20 years and the cost of replacing these components is zero. Other components have less time and therefore, will be replaced. Finally, the net present value of the total income from the resale is:

$$S_{comp} = \lambda_{comp}\, P_{comp}\, (\frac{1+\delta}{1+i})^{N} \qquad (24)$$

Where λ_{comp} is the resale price per unit and δ is the inflation rate.

For the battery bank storage system, the operation and maintenance cost as well as salvage value are neglected. Finally, fuel cost of the diesel generator during the year calculated as:

$$total\ C_{fuel} = fuel_{cons.yr} \text{ x } C_{costfuel}\ x\ inflaction\ rate \qquad (25)$$

Where $C_{costfuel}$ is the fuel cost per liter. Table 4 summarizes the used parameters in proposed system. For PV panels, wind turbines and waste boilers specifications and their costs obtained from two government utilities in Qatar during data collection process. While battery banks and diesel generators obtained from reference [58].

3.4.3. Constrains:

System constrains are designed to ensure the system is working under limited and desired criteria. In our case, the designed constrains are:

$$E_{PV}(t) + E_{WG}(t) + E_{Dis-load}(t) + E_{bat-load}(t) + E_{FC-load}(t) + \text{shortage}\ (t) \geq D(t) \qquad (26)$$

$$E_j(t) \leq P_j \times \Delta t \qquad (27)$$

$$SOCmin. \leq SOC(t) \leq SOCmax. \qquad (28)$$

$$0 \leq P_j \leq P_{max,j} \qquad (29)$$

$$E_j(t) \geq 0 \qquad (30)$$

For every component in the system, the energy produced or entered each time E_j should be less than its capacity P_j (equation 27). The first constrain (equation 26) is to balance the energy produced by each component and the demand. Batteries can supply energy to the load until lower limit of SOC_{min} and can be charged until SOC_{max} is reached (equation 28). Finally, decision variables and energy flows should be always positive, negative values are not accepted in this case (equation 30).

3.5. Heuristic Algorithm:

Applying a mathematical programming to the hybrid energy systems to obey constrains and target values would be complicated due to the stochastic nature of the system and its scale. Therefore, heuristic approaches are used as simple and fast tool to provide reasonable solution which supports proposed designs. Cormen etl. Al [64] defines heuristic algorithm as an algorithm that follows the problem-solving heuristic of making locally optimal choice at each stage, with the hope to find a global solution. In many problems, heuristic algorithm does not in general generate an optimal solution, but nonetheless may produce locally optimal (near optimal) solutions that approximate global optimal in a reasonable time. The heuristic main structure is composed of two phases (1) construction phase, and (2) local optimization. The "construction phase" refers to the construction of an initial solution by different iterations. In each iteration, the algorithm investigates designed systems feasibility.

In the second phase, optimal structure is exhibited by a problem if an optimal solution to the problem contains optimal solutions to the sub problems within it. Therefore, local points are selected based on target parameters improvement. If no improving is possible on one/more of these parameters in the next iteration, the algorithm investigates the remaining parameters for improvement. Otherwise, the algorithm maintains the same current solution set and therefore it terminates Fig[5]. In general, heuristic algorithm has five components [64]:

- Candidate set from which the solution is created
- A feasibility function to decide if a candidate can contribute to the solution
- An objective function to assign a value to a solution
- A selection function to choose the best candidate to be added to the solution

- A solution function to indicate when we have discovered a complete solution

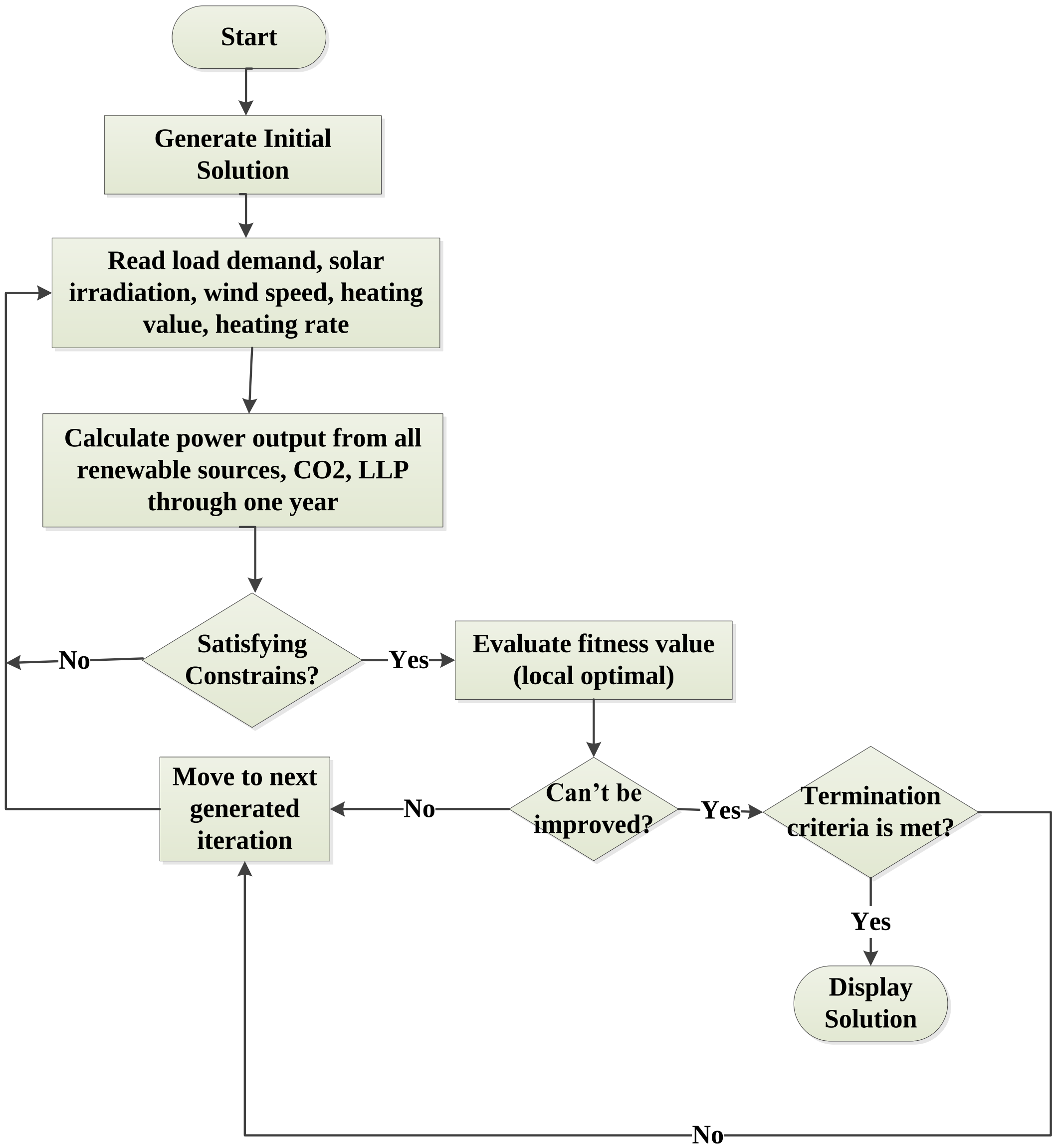

Figure 5 flow chart of the proposed methodology

Table 4 parameters used in the study

Interest t rate (i)	**0.1**
Project lifetime (N)	20
Inflation rate (δ)	0.04
Escalation rate (μ_{PV}, μ_W)	0.075
PV initial cost ($\propto_{pv}$)	1605 $/Kw
OM of PV(β_{pv})	36.047 $/Kw
PV resale price (λ_{PV})	901.18 $/Kw
PV lifetime	20 years
Wind turbine initial cost ($\propto_w$)	1708.788 $/Kw
OM of wind turbine (β_w)	34.175 $/kw
Wind turbine resale price (λ_w)	512.63 $/kw
Wind turbine lifetime	20 years
Power coefficient (Cp)	0.59
Air density (ρ)	1.225 kg/m3
Initial cost of waste boiler ($\propto_{waste}$)	4620 $/kw
OM of Waste boiler (β_{waste})	136 $/kw
Replacement cost of pv & wind turbine	zero
Number of replacement of pv, wind turbine & waste boiler	0,0, 1
Waste boiler resale price (λ_{waste})	6.825 $/kw
Battery acquisition cost	2420.417 $/kw
OM of battery	108.78 $/kw
Battery lifetime	15 years
Battery charge efficiency η_{bc}	0.9
Battery discharge efficiency η_{bd}	1
Diesel acquisition cost	2453.7 $/kw
OM of diesel	0.23 $/kw
Fuel Cost	1.27 $/ L

Chapter 4: Application of the Proposed Methodology using a Case Study from Qatar

4.1. Description of the Case Study

The developed methodology was applied using solar radiation, wind speed, and waste combustion collected for one year in Qatar. Then, the collected data were simulated to produce energy from each component. From the data obtained, the maximum solar irradiation is during June which is the hottest month in Qatar and can generate 443.34 wh/m_2. While, maximum wind speed is achieved during March 5.54 m/s. The daily and monthly solar irradiation on the horizontal surface and wind speed data at 10 m height are plotted in figures 6 and 7 respectively.

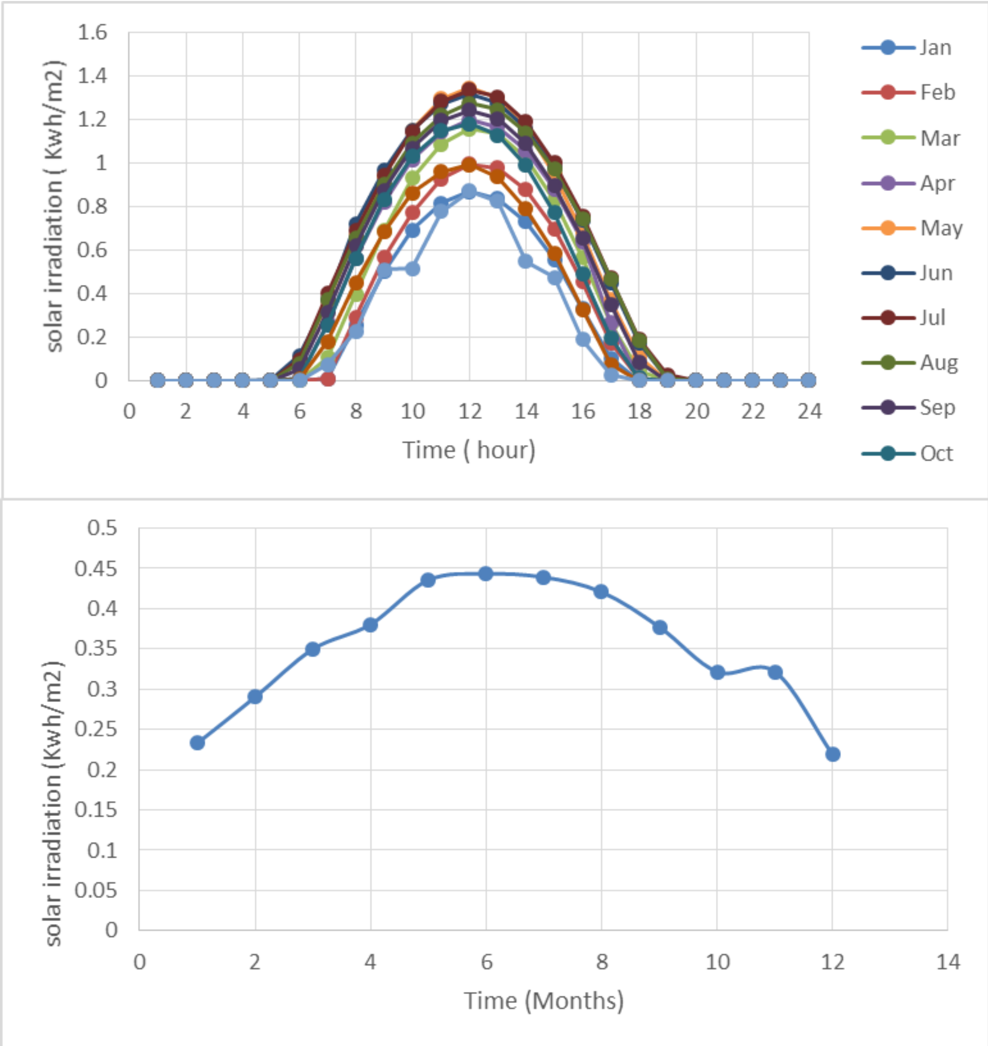

Figure 6 average hourly and monthly solar irradiation

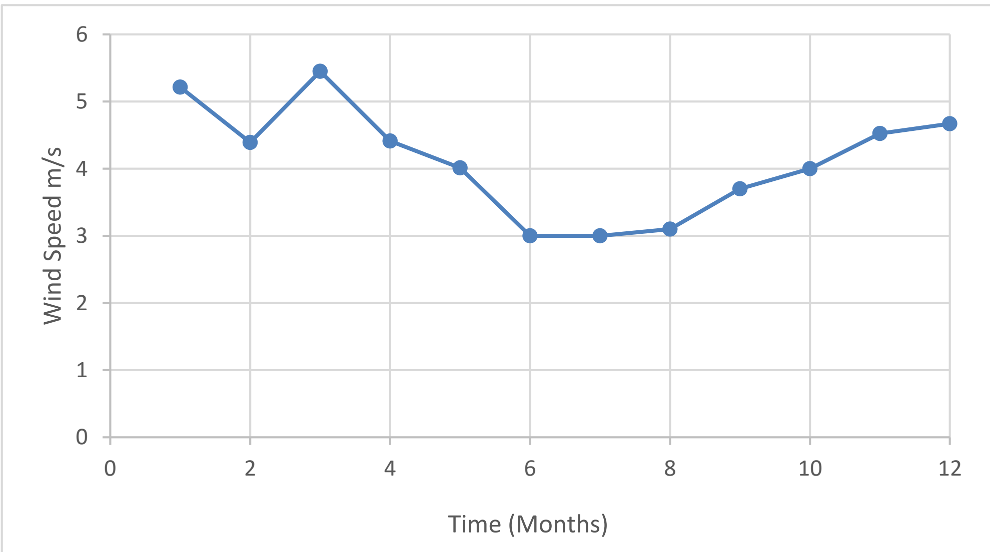

Figure 7 average monthly wind speed at 10 m height for one year

4.2.Load Profile

Since Qatar is small country and therefore the geographical characteristics do not vary across the region, hence a remote area is assumed that has ten households that consume on average 34,000 Kw each and one Mosque that consumes 35,136 Kw per year.

In order to estimate hourly load during the year. First hourly load of January is estimated and then used as basis for load estimation for other 11 months. Then, each month has its outdoor temperature, so it is divided by the outdoor temperature of January and this factor is multiplied by January demand. Therefore, resulting the demand for each month. The load for 1 year is depicted in Figure8.

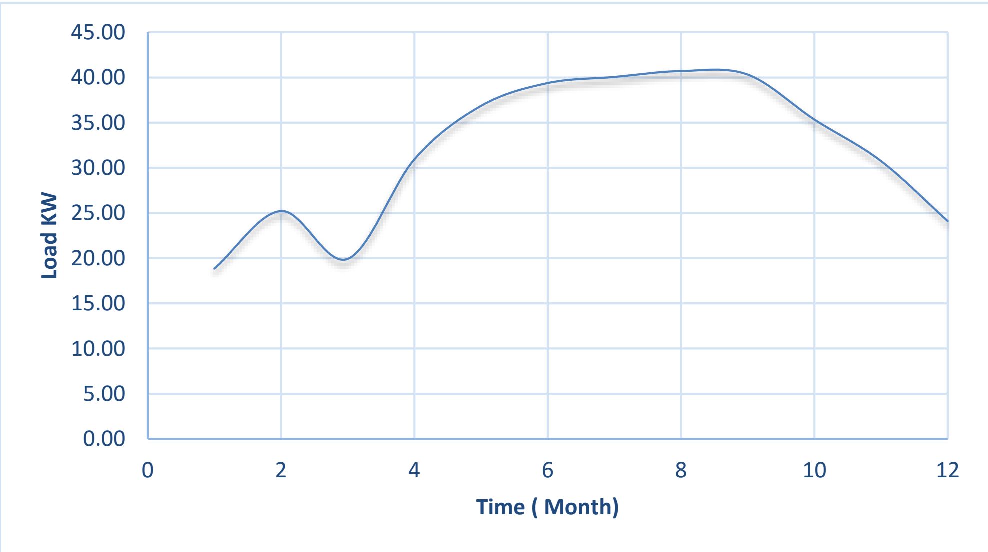

Figure 8 load profile for one year

4.3. Components Characteristics

The specifications of the components used to design and optimize hybrid PV/wind/waste/diesel/battery are presented in Table 5. For PV panels, wind turbines and waste boilers specifications and their costs obtained from two government utilities in Qatar during data collection process. While battery banks and diesel generators obtained from reference [58].

Table 5 specifications of PV panels, wind turbines, waste boilers, battery and DG

Component	Type and Specifications	Power	Area
PV panel	SHARP polycrystalline solar panel, NDL235Q1 model	235 W	1.63 m2
Wind turbine	AEOLOS vertical-axis wind turbine, Aeolos-V1 KW model. Cut-in, rated and cut-off speeds of 1.5, 10, 25 m/s, respectively	1 KW	3.14 m2
Waste Boiler	From Keppel Seghers company	the heating value for each boiler is 7,500 kJ/Kg to 9,000 kJ/kg and generate maximum of 21 tons of waste per hour	-
Battery	Lead acid battery with nominal capacity of 200 Ah	9.6 Kwh	-
Diesel Generator	-	Rated output power 5.5 KVA	-

Chapter 5: Results and Discussions

The proposed methodology has been applied using Matlab, Simulink, and spreadsheets. Multiple iterations have been considered starting from 10% capacity supplied by renewable sources including PV panels, wind turbinaes and waste boilers until provided capacity of 100%. At each iteration, different system designs obtained and each individual design determined the net present cost, amount of CO_2 emissions, loss of load probability, number of batteries required to supplied system and finally the amount of capacity from diesel generators. A total of 132591 combinations have been designed considering the local optimal at each iteration. Basically, four scenraios were examined in detailed from these combinations; PV/wind turbines/waste boilers in addition to battery banks and diesel generators (the size of PV fixed), PV/wind turbines/waste boilers in addition to battery banks and diesel generators (the size of wind turbine fixed), PV/wind turbines/waste boilers in addition to battery banks and diesel generators (the size of waste boiler above 100), and PV/wind turbines only in addition to battery banks and diesel generators.

Before determing designed systems, three calculations were done:

- Calculated the capacity of diesel generators as the only source of supplying demand: in this case 26 DGs are required with total of 114.4 Kw with 186901Kg of carbon dioxide emissions per year . Then, different percentages from 10% to 100% from this total capacity was calculated. Therefore, if 10% fraction of capacity are supplied from renewable sources, 90% will be supplied from diesel generators. CO_2 emissions considered as percentage are a result of dividing amount of CO_2 in Kg per year from designed hybrid system by amount of CO_2 in Kg per year from diesel generators only.

- Capacity of battery banks were calculated based on the maximum value of consecutive 10 hours of excess energy from renewable sources.
- Model verification were done throguh two steps:
  - Simplied model: where her each component is considered to be installed in an individual test so the resulting data of the model is evaluated.
  - Other software: comparing the results obtained from matlab with spreadsheets which were the same in this case.
- Model validation were done throguh changing the input parametrs of the proposed algorithm. In this case from 10% untill 100% fraction of RES to determine the effect on the model's behavior of output and designed objectives.

5.1. PV/Wind Turbines/Waste Boilers with Storage Systems and Diesel Generators (PV size fixed):

It was noticed that, from 10% capacity of RES until 60% no battery bankes were obtained. This is because the total amount of renewable capacity sources is allways less than the demand. Therefore, the system used the diesel genertors to avoid or reduce shortages. While from 70% untill 100% of RES, due to the increas of supplied capacity, batteries were used in order to sotre excess energy and to feed load during shortage times and it was increased gradually as showing in figure 9.

Despite the increased capacity of renewable sources, LLP was increased too. The reason is due to decreased capacity percentage of diesel generators, and the lack of battery banks avaliability from 10% to 60% fraction of RES. Even if the number of batteries at 100% capacity of renewable sources are 114 and above, batteries capacity can not supply load during all hours. Excess energy can be stored in some hours and then used in later hours when required. Thus, there is possiblity to have energy dificit. The figure below shows LLP percentage versus percentage used of renewable sources.

On the other hand, CO_2 decreased as the reduction of diesel generator capacity and low number of used waste boielrs. In this case, the size of waste boiels were from 2 to 50. Finally, net present costs of the designed systems increased as renewable capacity increased due to the fact renewable sources are highly expensive.

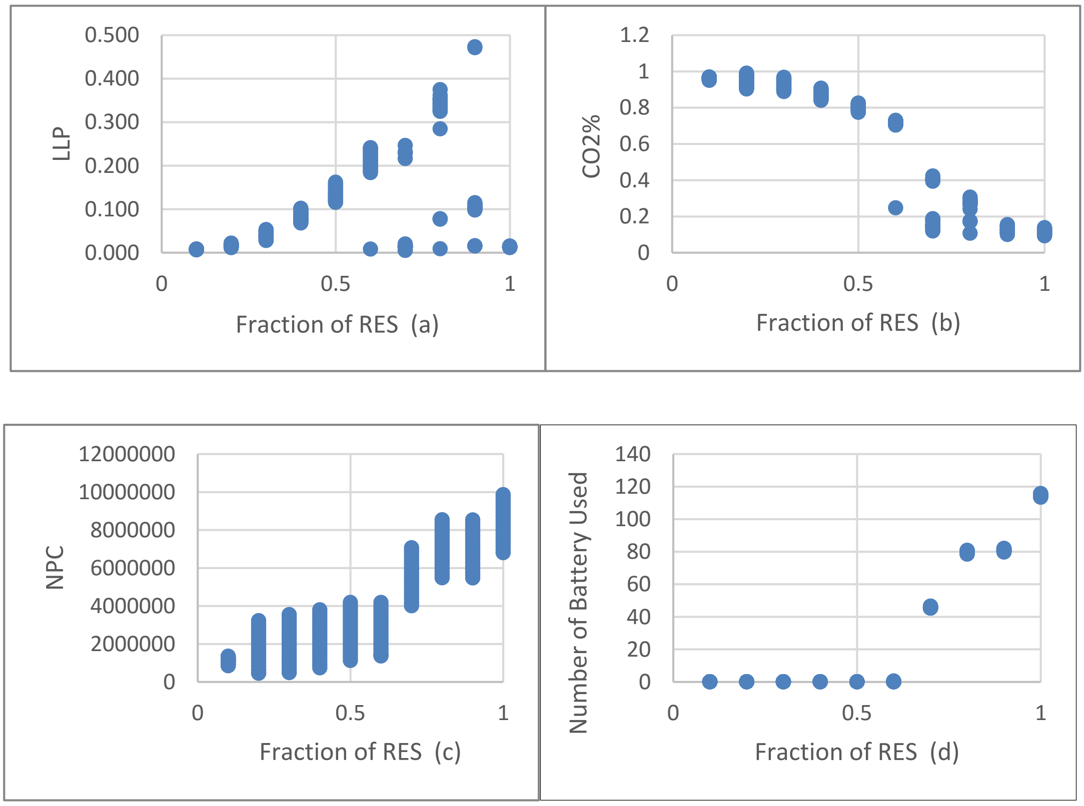

Figure 9 different percentage capacities of RES under fixed PV sizes (a) LLP (b) CO2 emissions (c) NPC (d) number of batteries used

5.2.PV/Wind Turbines/Waste Boilers with Storage Systems and Diesel Generators (Wind Turbines size fixed):

Similar to the first case, the results obtained indicated that LLP and CO_2 percentages are not affected with fixed size of wind turbines at each iterations. Althgouh, the values of LLP increased more than 50% as a result of reduced number of batteries obtained (less than 20) because of reduced amount of capacity provided. Therefore, Net present cost was reduced by small percentages. The figures below depicted the above discussions.

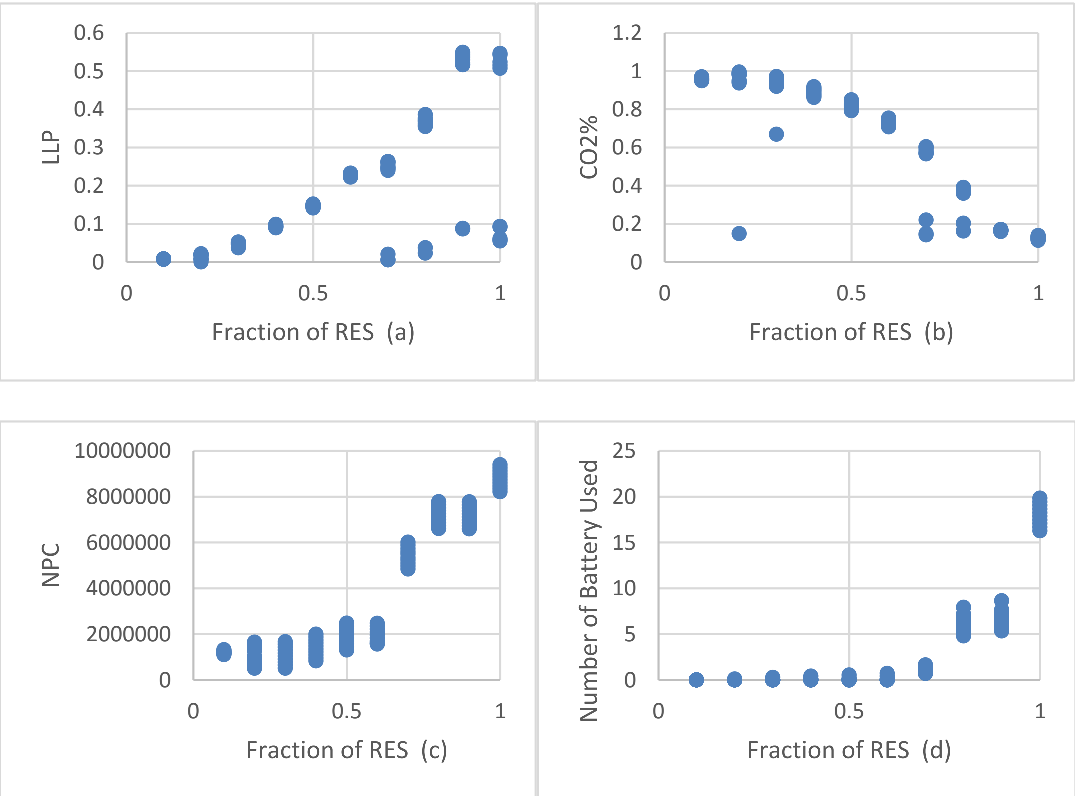

Figure 10 different percentage capacities of RES under fixed wind turbine sizes (a) LLP (b) CO2 emissions (c) NPC (d) number of batteries used

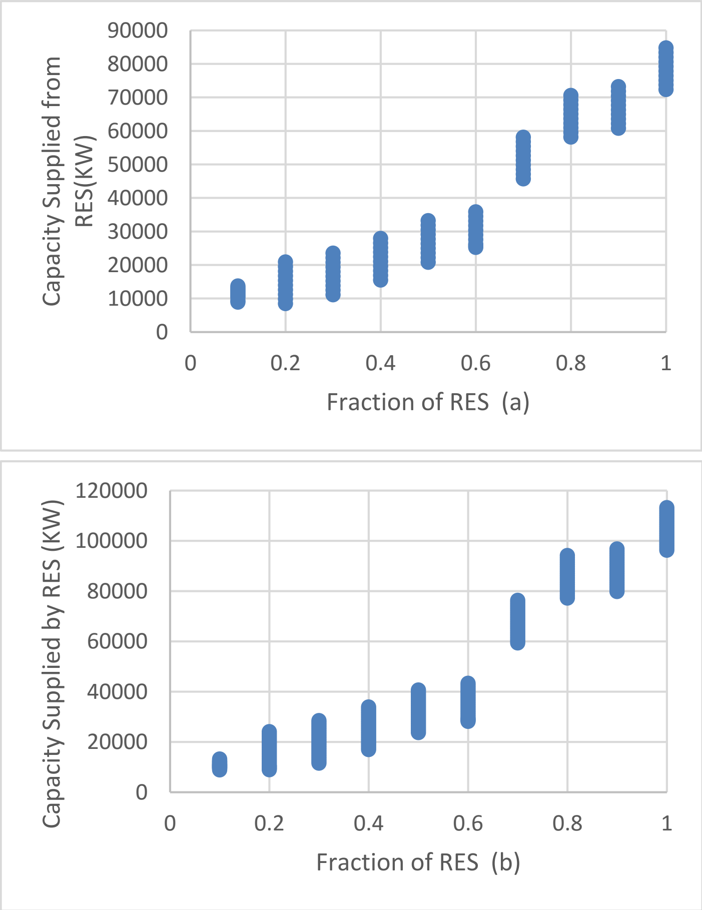

Figure 11 total capacity supplied RES in kw under different percentage capacities (a) with fixed wind turbine sizes (b) with fixed PV sizes

5.3.PV/Wind Turbines/Waste Boilers with Storage Systems and Diesel Generators (Waste Boilers size above 100):

Conversely, CO_2 emissions have increased as the increase of provided capacity percentage of renewable sources. This indicates that, the use of waste boilers as a source to supply demand can have negitve effect on environmental in addition to the increased amount of net present cost. While loss of load probability values have been decreased compared with the first two scenarios, as a maximum value of 1.2% to 0% percentages due to the large amount of excess energy from renewable sources. As a result, we noticed that designed systems in this case have high costs.

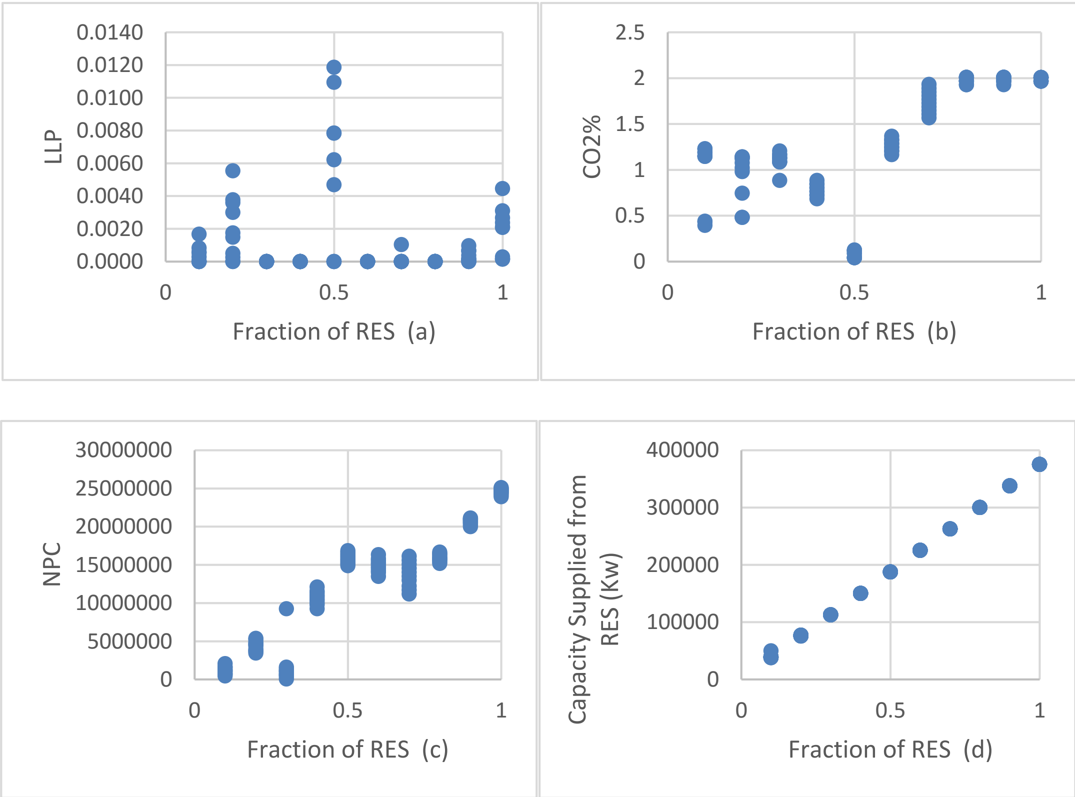

Figure 12 different percentage capacities of RES under high size of waste boilers (above 100) (a) LLP (b) CO2 emissions (c) NPC (d) total capacity supplied from RES

5.4. PV/wind turbines only in addition to battery banks and diesel generators:

As a result of removing waste boilers, CO_2 emissions decreased to maximum value of 87% compared with other scenarios. The amount of capacity provided is the highest, since the sizes of PV panels and wind turbinas increased and therefore, NPC of designed systems increased too. loss of load probabilty decreased when 60% fraction of RES is provided and therefore required battery banks increased.

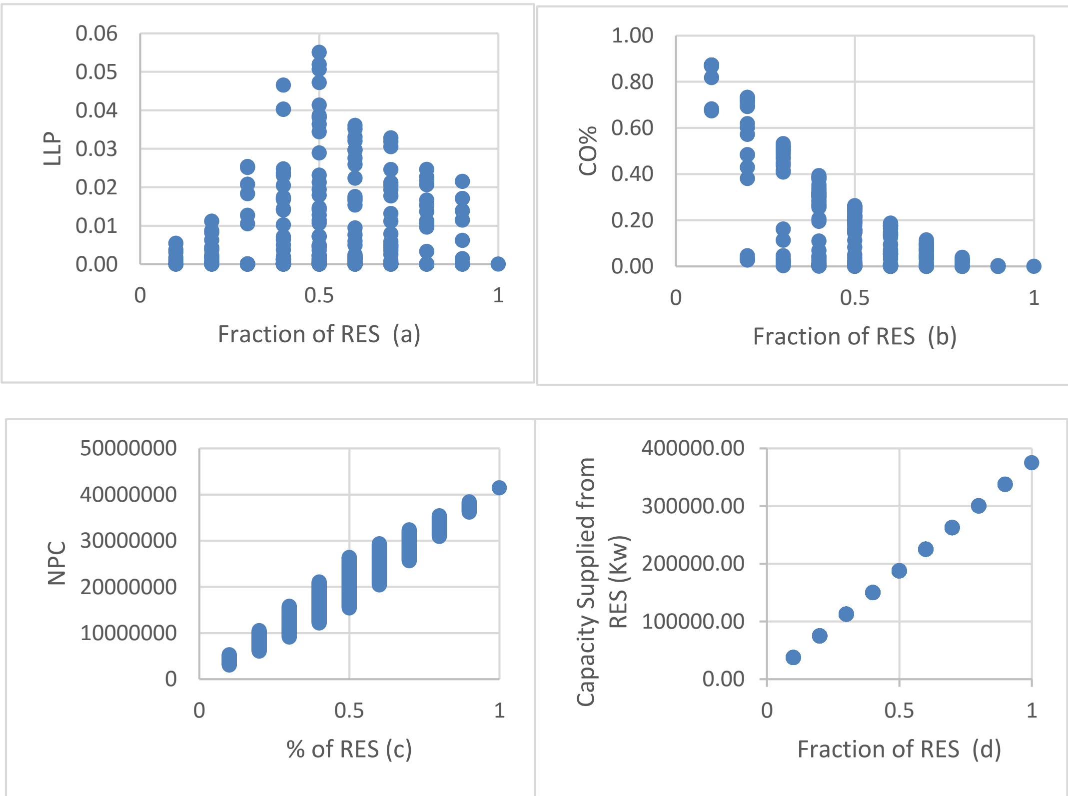

Figure 13 different percentage capacities of RES using PV panels and wind turbines only (a) LLP (b) CO2 emissions (c) NPC (d) total capacity supplied from RES

In addition to the above cases, minimum LLP, CO_2, and NPC were considered for each iteration as shown on tables 6 to 8. On table 6, best scenarios of minimum LLP were determined for each capacity percentage of RES. In this case, LLP values are equal to zeros as a result of using large capacity of DGs or large number of batteries. Therefore, decision maker can select one of these solutions if only interested on minimum shortages of suppling demand. While table 7 presents best scenarios of minimum carbon dioxide emissions for each capacity percentage of RES. It was noticed that, at 10% fraction of RES, CO_2 was highest (0.67%) as a result of using only one renewable source with very low size (23 of wind turbines) and large capacity of diesel generators. Then, the emission was decreased due to the increase capacity of RES and decrease capacity of DGs. It is best when the system is only supported by PV panels and wind turbines at 100% capacity. Finally, table 8 shows best solutions at each iteration for minimum net present cost. The relation now is positive between total cost and capacity of RES, as the percentage increased, the cost increased too. Therefore, worst scenario obtained when the system is supplied by renewable sources only.

To sum up, it the following points are concluded:

I. Loss of probability values are affected by three factors; capacity of diesel generator, number of battery banks, and capacity of renewable sources. Any increase of any one of these factors, help reducing shortages.

II. Increasing the size above 100 for waste boilers as leads significantly to increasing the CO_2 emissions. Therefore, either the decision maker determined the required amount of emissions produced from boilers which are not violate pollution emission standards or remove it from hybrid system.

III. Net present cost is highly affected by the provided capacity of renewable sources.

IV. At low fractions of renewable sources (from 10% until 50%) battery banks required could be zero or low which indicated no more excess energy from RES.

The tables below consider the best scenarios at each iteration for minimum LLP, CO_2, and NPC.

Table 6 Best Scenarios at each percentage capacity of RES for Min. LLP

Fraction of RES	PV size	WT size	Min. LLP	NCP $	CO_2 Kg/year	DG Kw /year	Num. of Batteries	CO2%	RES total capacity Kw/year
10%	26	5	0	5.E+06	162899	103	0	0.9	37513.5
20%	49	11	0	9.E+06	8566	92	16	0.1	75027.0
30%	81	11	0	1.E+07	3014	103	61	0.0	112540.5
40%	114	11	0	2.E+07	1312	69	113	0.0	150054.0
50%	162	0	0	3.E+07	200	57	189	0.0	187567.5
60%	32	114	0	2.E+07	18	46	333	0.0	225081.0
70%	65	114	0	3.E+07	8	34	339	0.0	262594.5
80%	97	114	0	3.E+07	2	23	367	0.0	300108.0
90%	130	114	0	4.E+07	2	11	423	0.0	337621.5
100%	162	114	0	4.E+07	0	0	480	0.0	375135.0

Table 7 best scenarios at each percentage capacity of RES for Min. CO_2

Fraction of RES	PV size	WT size	LLP	NCP $	Min. CO_2 Kg /year	DG Kw /year	Num. of Batteries	CO2 %	RES total capacity Kw/year
10%	0	23	0.01	3.E+06	125899	103	29	0.67	37513.5
20%	52	9	0.00	1.E+07	5042	92	19	0.03	75027.00
30%	94	2	0.00	2.E+07	564	103	74	0.00	112540.5
40%	88	30	0.00	2.E+07	101	69	108	0.00	150054
50%	23	98	0.00	2.E+07	37	57	278	0.00	187567.5
60%	32	114	0.00	2.E+07	18	46	333	0.00	225081
70%	88	98	0.00	3.E+07	5	34	297	0.00	262594.5
80%	97	114	0.00	3.E+07	2	23	367	0.00	300108
90%	130	114	0.00	4.E+07	2	11	423	0.00	337621.5
100%	162	114	0.00	4.E+07	0	0	480	0.00	375135

Table 8 best scenarios at each percentage capacity of RES for Min. NPC

Fraction of RES	PV size	WT size	LLP	Min. NCP $	CO2 Kg/year	DG Kw/year	Num. of Batteries	CO2 %	RES total capacity Kw/year
10%	0	23	0.01	3.E+06	125899	103	29	1	37514
20%	0	46	0.01	6.E+06	112383	92	94	1	75027
30%	0	68	0.03	9.E+06	77348	80	174	0	112541
40%	0	91	0.04	1.E+07	57546	69	253	0	150054
50%	3	112	0.00	2.E+07	6837	57	325	0	187568
60%	32	114	0.00	2.E+07	18	46	333	0	225081
70%	65	114	0.00	3.E+07	8	34	339	0	262595
80%	97	114	0.00	3.E+07	2	23	367	0	300108
90%	130	114	0.00	4.E+07	2	11	423	0	337622
100%	162	114	0.00	4.E+07	0	0	480	0	375135

5.5. Optimal Solutions:

In the previous section, we noticed that how at each criteria we obtained different solutions. Therefore, we developed a decision support tool where the decision maker can assess all possible solutions based on different objectives at any chosen level of renewable sources. For example, if the decision maker is only interested on increasing capacity provided from renewable sources, so all three types are recommend to be used. While if he/she is interested on decreasing amount of gases emissions, so either we determine a specific amount produced from waste boiler or removed it and produced energy from PV panels and wind turbines.

Here we have two examples:

Best solution from all types of renewable when LLP% and CO_2 are zero with minimum costs: in the case, the decision maker is interested to obtain best solution with minimum costs and emissions and no shortages. Considering first solutions with LLP% is zero, we obtained 64 solutions. Then, solutions with minimum emissions of CO_2% less than 1% is selected and they are 4 solutions. Finally, the one which has minimum NPC is selected which is shown in the table below:

Table 9 best solution when all types of renewable are used with LLP% & CO_2% zero

PVsize	WTsize	WBsize	LLP	CO2 kg	CO2%	NPC$	DG Kw /year	Num. of Batteries
0	112	14	0	7540.73	0	14884919.55	57.2	350

Therefore, 50% is supplied from renewable and 50% from diesel units.

Best solution from PV with wind turbines only when LLP% and CO_2 are zero with minimum costs: From the obtained results, it was considered the PV panels with wind turbines designed systems only with a total number of 260 solutions. These solutions are feasible, but one should be selected based on requested targets. The priority given to LLP values, where we ensure that system supplies load all the times and avoid any shortages. From the solutions obtained, the values of LLP ranges from zero to maximum value of 6%. Therefore, only solutions with zero LLP was taken first, which are 170 solutions (appendix c). Then, from the last solutions, second priority was considered for CO_2 emissions which have values from 0% until 67%. Thus, only systems with zero percentage of CO_2 was considered and obtained 64 designed systems with zero percentage of LLP and CO_2 emissions. Finally, the one with minimum value of net present cost is considered as the optimum solution. The table below depicted the best solution obtained.

Table 10 the best solution obtained from PV and wind turbines with LLP% & CO_2% zero

PV size	WT size	LLP	CO2 kg	CO2%	NPC	DG Kw /year	Num. of Batteries
10	84	0	217.7672	0	12796811.78	68.64	230

The best solution supplied 40% capacity from renewable sources and 60% from diesel generators.

5.6. Summary of findings:

The algorithm developed is general which can help the decision maker to apply different data or components specifications and study all possible solutions obtained. Also, the results obtained in this thesis considered as reflection or extension comparing with other previous researches, as we concluded that increasing the capacity of renewable will lead to increase total costs of the system while it improves system reliability and efficiency. In addition, one can claim that why to use wastes combustion to generate electricity although it produces amount of CO_2 emissions. In this case the following justifications may be stated:

- Wastes are considered as one types of renewable sources, since it is replenished and it is created every day with enormous amount as result of human activities. Therefore, a scientific methods are developed in order to have safe disposal of wastes and recovery of energy from wastes considered as one of these methods.
- Flirting process can be included within waste combustion in order to dispersed clean gases into the atmosphere.
- Or considering the amount of emissions from wastes combustion which meet emissions pollution standards.

Finally, costs obtained from different solutions ranges from 10$M to maximum 40$M. costs are high because we used five components to supply high value of demand (more than 371 Kw/year) and this resulted in increasing the size of renewable up to 400Kw per year. In addition, a study was done in KSA (27) where the hybrid system is composed of PV panels, wind turbines, batteries and diesel units to supply 6000Kw remote village, the obtained total costs is 55$ M.

Chapter 6: Conclusion and Future Research

6.1. Summary and Conclusions

Renewable energy sources are considered as viable alternatives for off- grid services including remote areas without the need to build infrastructure for grid connections. Power supplied from renewable sources can help developed countries to reach its goals in providing clean, reliable, and affordable energy. Therefore, a strong need to design alternative systems have been increased in the last few years, due to globalization, population increase, new technologies inventions, and electricity consumption in both industries and urban sectors.

The big challenge of using renewable technologies is the fluctuations of power generation. Each type of renewable source has its characteristics in power generation. For example, PV panels can best supply power during summer seasons, while in cloudy days the power will go down. As a result, researches integrated more than one type of renewable sources in addition to storage systems and it is called "hybrid renewable system".

Over the next twenty years, GCC will experience a rapid growth on economic and electricity consumption in the world. Therefore, GCC countries are interested now on developing hybrid renewable systems as an alternative for supplying demand.

As discussed on chapter 2, different design approaches are implemented on hybrid renewable systems, from simple and easy algorithms to complex ones. Hybrid renewable systems can differ on their system size, type, approaches, and system's objectives. Studies which considered system's objective/s only, the most considered objective is total costs consisting of capital, maintenance, replacement costs for each component proposed. Hybrid systems that are developed based on PV panels (in addition to storage systems) have lowest costs comparing with hybrid systems consisting of PV panels with other renewable sources. Some researchers studied the performance of hybrid systems in case of grid connections, and noticed lowest costs obtained when proposed systems used grid with PV panels. While multi objectives hybrid system are solved using trade-off between contradicting objectives.

Chapter 3 presented the main contribution of this thesis in using real data and discussed a heuristic approach for designing a hybrid system for 20-year period of operation consisting of three renewable sources integrated with battery banks and diesel generators for supplying real demand at Qatar. The objective is to design a reliable, environmental and economic system. Therefore, the system which has minimum value of loss of load probability, CO_2 emissions, and net present cost is considered as optimal (local optimal) solution. The main advantage of using heuristic algorithm is its simplicity for determining all possible designed systems especially for complex real systems.

Then chapter 4 discussed results obtained based on proposed methodology. First, a data was collected including solar irradiation, wind speed, amount of wastes combustion, models specifications and demand which helped to apply and study a real system in Qatar. Then, the data has been used to build and run mathematical model for each component within the hybrid system. Simulink in MATLAB was used for this purpose and the results obtained are hourly energy in Kw/hr for PV panels, wind turbines, waste boilers, battery banks, and diesel generators. The model was verified using Excel too.

The importance of using optimization is to ensure that the designed system obtains valid results based on decision maker’s objectives and specifications. In this case, three main objectives were considered; unmet load (loss of load probability), CO_2 emissions, and net present cost of the system. In addition, technical constrains were built to ensure that the system is supplying demand from renewable sources with storage systems to the required demand hourly during the year. In case if supplied energy is greater than the demand, excess is stored in battery banks. An excess more than the capacity of batteries is considered as dumped energy. While, if the supplied energy from renewable sources is less than demand, so batteries used first for supporting. Then, any excess demand is supplied from diesel generator. Other constrains are; the energy supplied or stored is maximum to component's capacity, and all values used in the system are positive.

Unless other optimization techniques, heuristic algorithm enables the decision maker to evaluate and study all possible solutions. Initial solutions generated at the beginning when considering 10% supplied capacity from renewable sources. The different scenarios were calculated using MATLAB coding. In this case about 66 solutions for different designed systems obtained that can supply demand according to required constrains. Therefore, each time the percentage of supplied capacity increased different and more solutions are obtained. Using 10% until 100% fraction of renewable energy sources, a total of 132,591 solutions with different values of LLP, CO_2 emissions, and NPC were resulted. The following were concluded:

- With fixed size of PV panels different capacities of wind turbine with waste boiler, CO_2 emissions has been increased. While LLP and NPC has been increased. Loss of load probability increased due to the reduction of diesel capacity.
- Similar to the first case, with fixed size of wind turbines different capacities of PV panels with waste boilers, CO_2 has been decreased. While, LLP and NPC has been increased. Although, in this case power generated from renewable

sources are less comparing with the fixed PV size. Therefore, number of batteries and NPC are less.

- With high size of waste boilers and different capacities of PV panels with wind turbines, CO_2 has gradually increased in addition of using diesel generators. While system's reliability has been decreased.
- With PV panels and wind turbines only, the designed systems have been improved on their reliability, system's environmentally, and system's costs.

Finally, It is the most important and difficult part to select the local optimal solution from large number of solutions. Therefore, determined criteria are used to facilitate the decision of choosing near optimal solution. Since there are three criteria, so optimal solution is selected through three phases. At different objectives set, different solutions will be obtained. For example, when all types of renewable are considered with zero LLP% and CO_2%, the local optimal solution is when supplying 50% from renewable and the remaining supported from diesel generators. While considering PV with wind turbines only will give the local optimal solution when the system supplies 40% from renewable sources and 60% from diesel generator with 10 PV panels and 84 wind turbines.

6.2. Suggestions for future work

For future research, the hybrid system can be assessed its performance under different conditions. Such as:

- Different sets/specifications of PV panels, wind turbines as an important analysis to study the performance of the system
- Alternative option for grid connections
- Alternative options for storage devices as H tank, fuel cell, and electrolyzer
- Changing capacities of battery banks and diesel generators
- Considering emissions in addition of direct emissions (for example from diesel generators) from system's component during the manufacture, transport, and installation was most neglected
- Measuring uncertainty factors of storage failures as part of system reliability
- Considering filtering process in the process of waste combustion in order to produce clean gas into the atmosphere
- Using meta-heuristic algorithm (such as genetic algorithm) to compare it with the proposed approach. As GA is better in finding global solutions.

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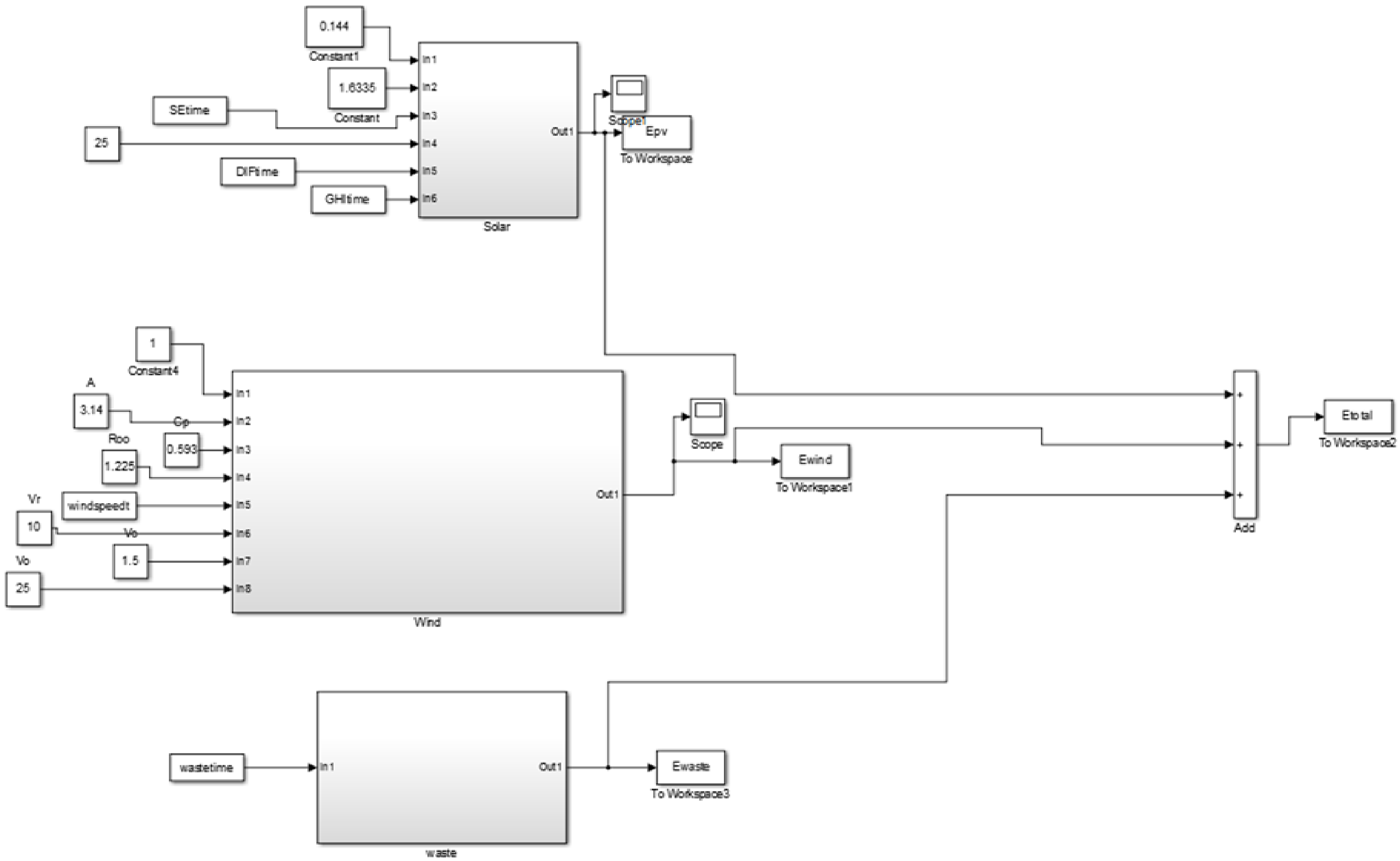
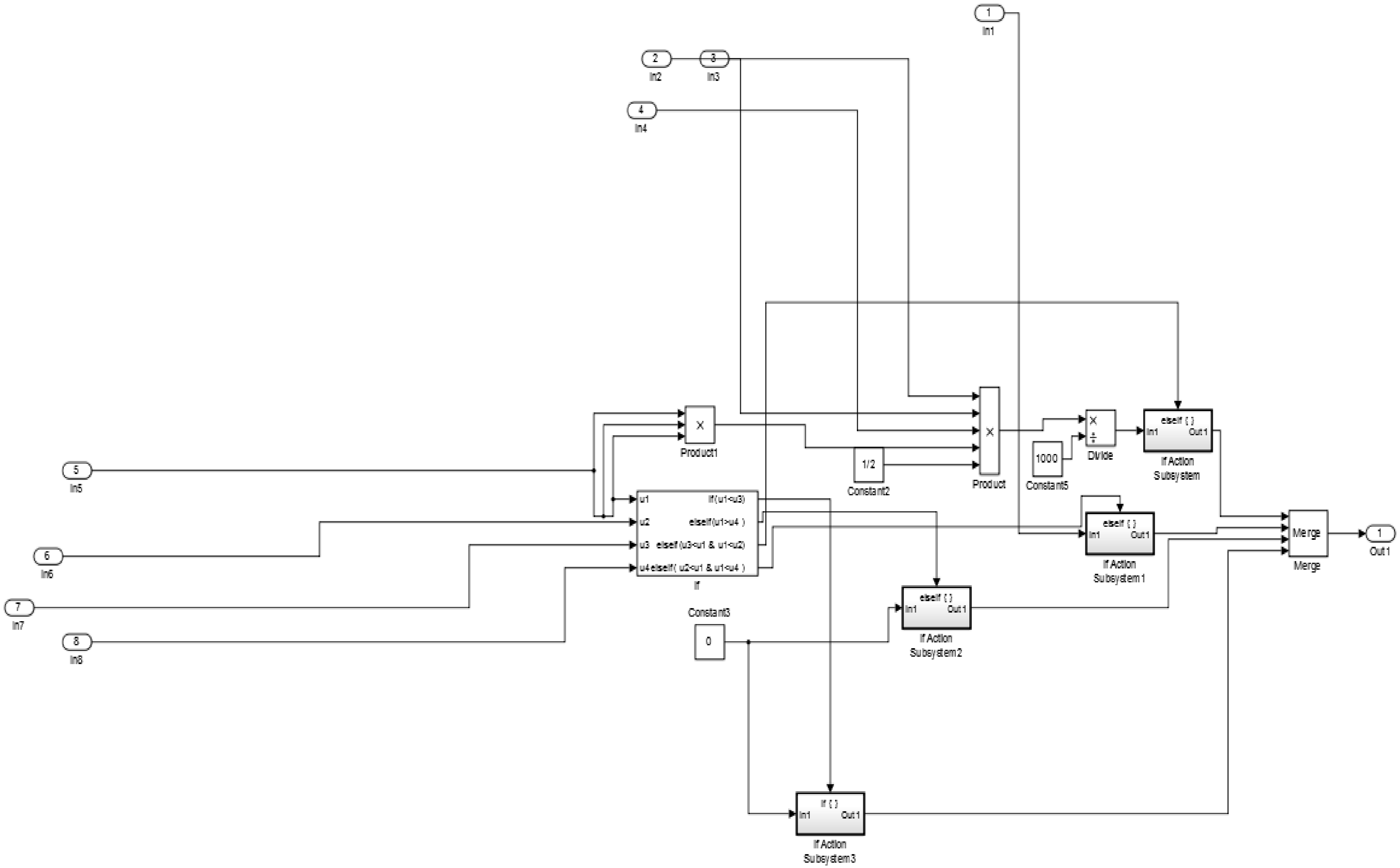
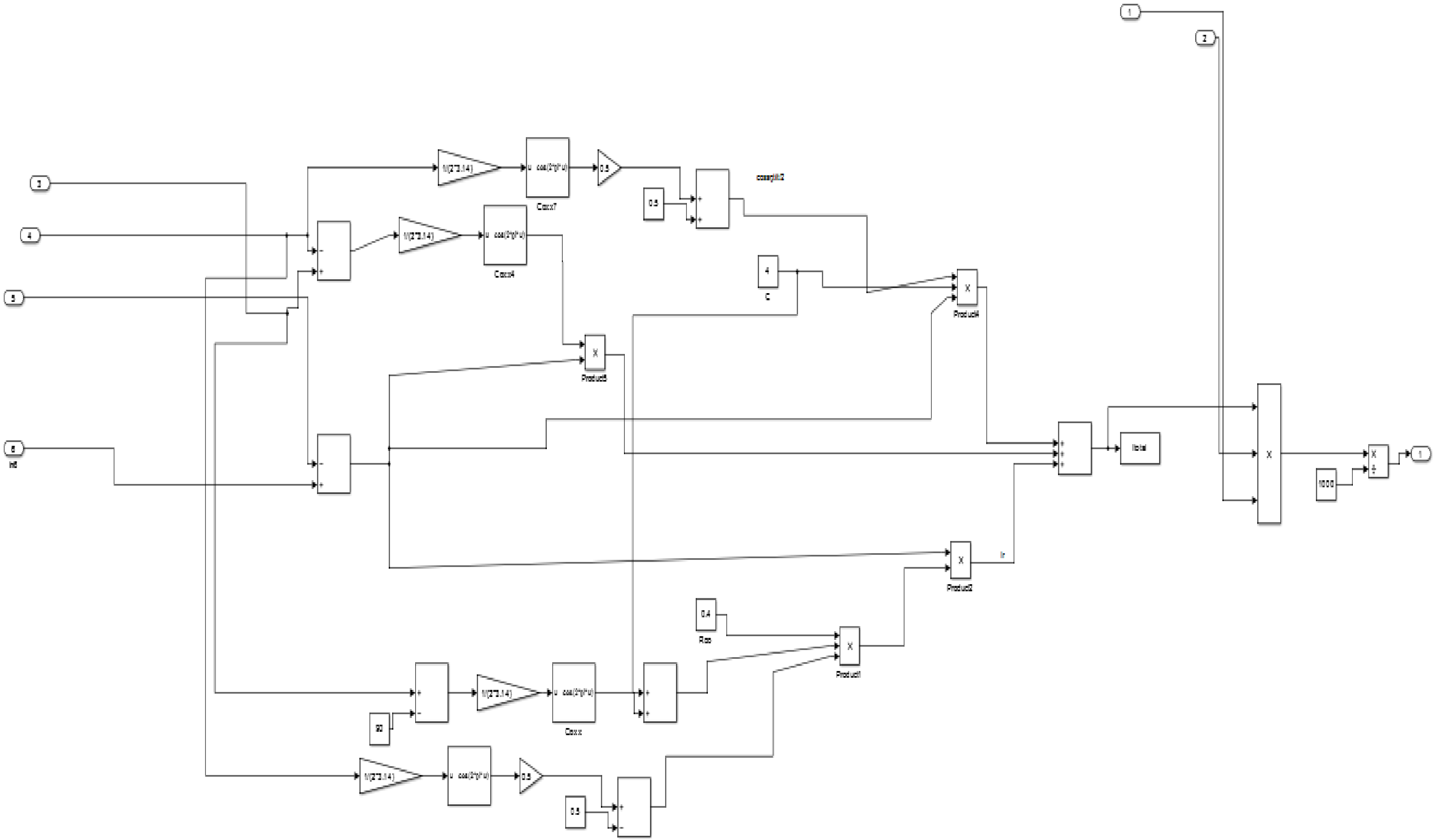
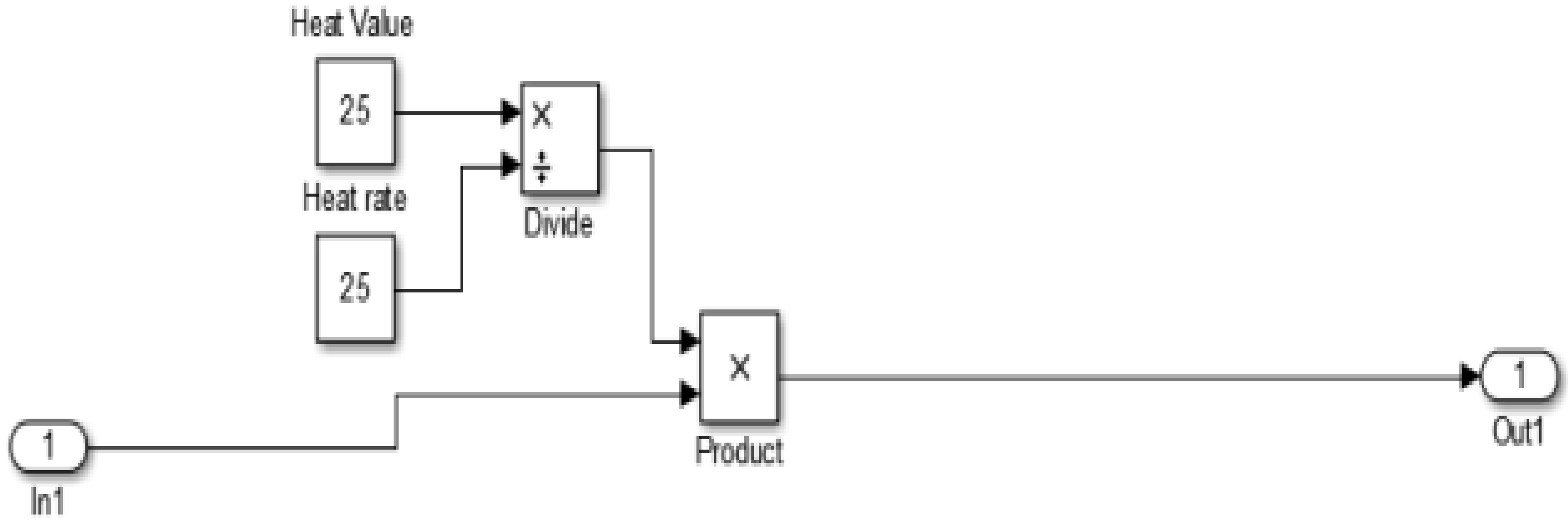
Appendix A : Mathematical Model of System's Components

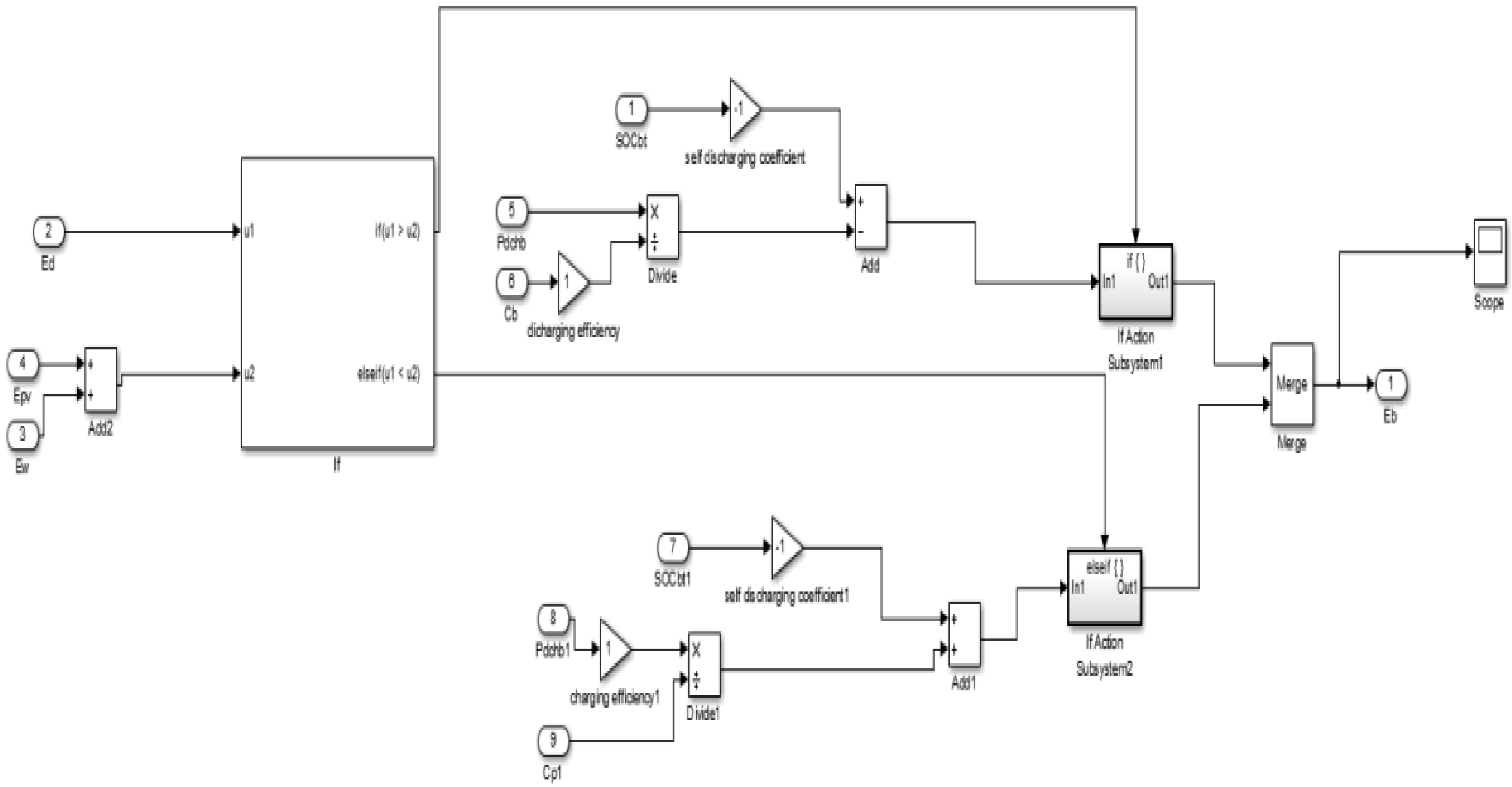


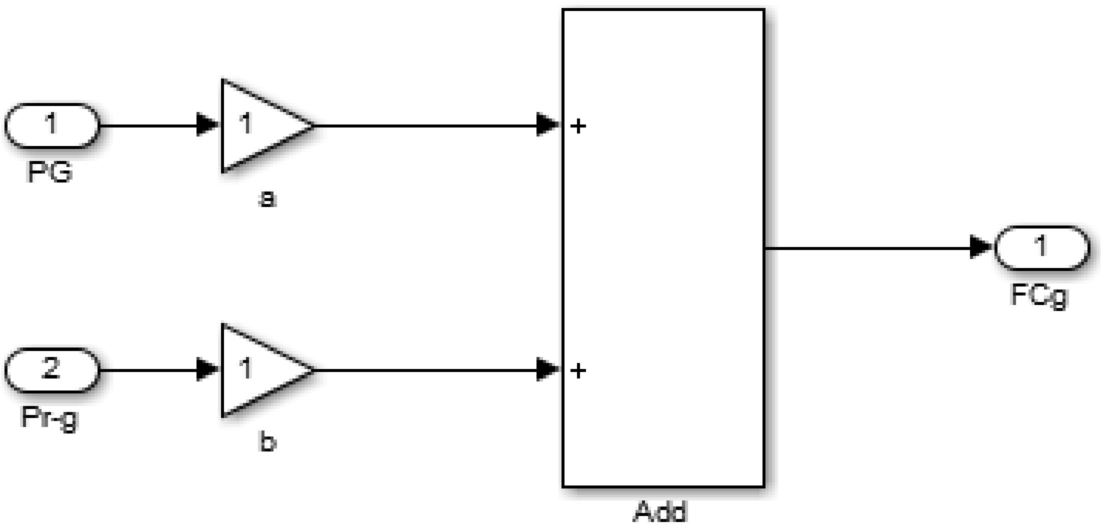

In1
In2
In3
In4
In5
In6
In7
In8
Product1
Product
Constant2
1/2
1000
Constant5
Divide
elseif { }
In1
Out1
If Action Subsystem
If Action Subsystem1
u1
u2
u3
u4
if(u1<u3)
elseif(u1>u4)
elseif (u3<u1 & u1<u2)
elseif(u2<u1 & u1<u4)
If
Constant3
0
If Action Subsystem2
if { }
If Action Subsystem3
Merge
Out1



1/(2*3.14)
Cosx7
0.5
Cosx4
C
Product4
Product5
In6
ltotal
Product2
Ir
0.4
Ro
Product1
92
Cosx
1000


Heat Value
25
Heat rate
25
Divide
Product
1
In1
1
Out1


2
Ed
u1
if(u1 > u2)
4
Epv
3
Ew
Add2
u2
elseif(u1 < u2)
If
1
SOCbt
-1
self discharging coefficient
5
Pdchb
6
Cb
1
dicharging efficiency
Divide
Add
if { }
In1
Out1
If Action Subsystem1
Merge
Merge
1
Eb
Scope
7
SOCbt1
-1
self discharging coefficient1
8
Pdchb1
1
charging efficiency1
Divide1
9
Cp1
Add1
elseif { }
In1
Out1
If Action Subsystem2


1
PG
1
a
2
Pr-g
1
b
+
+
Add
1
FCg

Appendix B: MATLAB Coding

```
load datajan2017.mat

Ewaste=evalin('base','Ewaste');

%UNTITLED2 Summary of this function goes here

%   Detailed explanation goes here

%Epv=evalin('base','Epv');

%Ewind=evalin('base','Ewind');

%Ewaste=evalin('base','Ewaste');

%waste=evalin('base','waste');

%%%for test purpose, waste equal zeros

%mysize=8760;

%Ewaste=zeros(mysize,1);

%waste=zeros(mysize,1);

%%% end test

%Demand=evalin('base','Demand');

%G=evalin('base','G');

%t=evalin('base','t');

%load Energydata.mat

%load Energydataten.mat

%Demandperyear=6192380;

Demandperyear=375135;

percRE=100;

percDemand=Demandperyear.*percRE/100;

%%oldCpv=3605;

Cpv=1605;

%%COMpv=36.047;

COMpv=36.047;
```

```
Cwind=1708.788;

COMwind=34.17576;

Cwaste=4620; %%

COMwaste= 136; %%$/year

%CRF:recovery factor

intrest_rate =0.1; %intereset rate Assume 0.4

T=20; %projectlifetim

CRF = [(intrest_rate*(1+intrest_rate)^T)/((1+intrest_rate)^T-1)];

%salvage value for pv,wind

%Spv=512.6364;

Spv=901.1819149;

Sw=512.6364;

S=(1.04/(1+intrest_rate).^(20));

Crepwaste=6.825;

ywaste=1; %no. of replacment of each component

nwaste= 1:ywaste;

Lwaste= 15; % lifetime of each component

Kwaste= sum(1./(1+intrest_rate).^(Lwaste*nwaste));

%mysize=8760;

mysize=8760;

%%%G=10000*ones(mysize,1);

%if kept will be the same as initial case with every iteration

%PSOfinalISA;

%moduleno=1;  %%should come from PSO

%moduleno1=1;   %%should come from PSO

%moduleno2=1;   %% should come from PSO

time=(0:8759)';

%%PV size
```

```
PVcapacity=0.235;

Epvzero=(Epv==0).*0;

Epvrate=(Epv/PVcapacity);

Epvup=(Epv>0);

Epvlower=(Epv<PVcapacity);

Epvbetween=((Epvup & Epvlower).*1);

Epvupper=(Epv>=PVcapacity).*Epvrate;



PVmodule=Epvzero+ Epvbetween+ ceil(Epvupper);

%dataone=ones(mySize,1);

%PVmodule=(PVmodule==0)+PVmodule;

%PVmodule=(Epvzero.*0) + ((Epvlower & Epvup).*1) +
ceil(Epvupper.*Epvrate);

modulesize=timeseries(PVmodule,time);

l=modulesize*PVcapacity;

%l=modulesize;

l=l.Data;

l=sum(l);

%wind size

Wcapacity=1;

%Ewind.Data=Wcapacity*rand(mySize,1);

windturbineszero=(Ewind==0).*0;

turbinerate=(Ewind./Wcapacity);

turbineup=Ewind>0;

turbinelower=Ewind<Wcapacity;

turbinebetween=((turbineup & turbinelower).*1);

turbineupper=(Ewind>=Wcapacity).*turbinerate;

windturbine= windturbineszero+ turbinebetween + ceil (turbineupper);
```

```
%dataone=ones(mySize,1);
windmodule=(windturbine==0)+windturbine;

windturbines1=timeseries(windmodule,time)
%windturbines1=timeseries(windturbines,time)
y=windturbines1*Wcapacity;
%y=windturbines1;
y=y.Data;
ym=sum(y);

Wastecapacity=0.01;

boilerzero=(Ewaste==0).*0;
boilerrate=(Ewaste./Wastecapacity);
boilerup=(Ewaste>0);
boilerlower=(Ewaste<Wastecapacity);
boilerbetween=((boilerup & boilerlower).*1);
boilerupper=(Ewaste>=Wastecapacity).*boilerrate;

boilermodule=boilerzero+ boilerbetween+ ceil(boilerupper);
%dataone=ones(mySize,1);
boilermodule=(boilermodule==0)+boilermodule;

boilermodule1=timeseries(boilermodule,time)
%windturbines1=timeseries(windturbines,time)
z=boilermodule1*Wastecapacity;
%y=windturbines1;
```

```
z=z.Data;

z=sum(z);


x=[l ym z];


%i=percRE/(PVcapacity+Wcapacity+Wastecapacity);

i=percRE;

j=percRE;

k=percRE;



obj=(Cpv+(COMpv/CRF)+(Spv*S))*x(:,1)+(Cwind+(COMwind/CRF)+(Sw*S))*x(:,2)+(Cwaste+(COMwaste/CRF)+(Crepwaste*Kwaste))*x(:,3);

%obj=(Cpv+(COMpv/CRF)+(Spv*S))*l+(Cwind+(COMwind/CRF)+(Sw*S))*ym+(Cwaste+(COMwaste/CRF)+(Crepwaste*Kwaste))*z;

for i=0:100

           for k=0:100

            for j=0:100



            ip=i/100;

            jp=j/100;

            kp=k/100;

             %%temp=(i-1)*11*11 + (j-1)*11 +k;

             %%temp=(i)*10*10 + (j)*10 +k;

             temp= j;



        newPV(i+1,:)=[(ip*Demandperyear)/(PVcapacity*8760) i] ;

        %newPV(i+1,:)=[0 i] ;

        newwind(j+1,:)=[(jp*Demandperyear)/(Wcapacity*8760) j];

       % newwind(j+1,:)=[0 j];
```

```
        newwaste(k+1,:)=[(kp*Demandperyear)/(Wastecapacity*8760) k];
        %newwaste(k+1,:)=[0 k];


        end
    end
end
                for m=1:101
                for n=1:101
                for o=1:101
         temp1=(m-1)*101*101 + (n-1)*101 +o;
         max_sum=m+n+o;
         summ=(m-1)+(n-1)+(o-1);
         scenperce(temp1,:)=[newPV(m) newwind(n) newwaste(o) summ];
         scen(temp1,:)=[newPV(m) newwind(n) newwaste(o)];

         if max_sum>=51  %% to exclude less than 10%


         scen1(temp1,:)=[newPV(n) newwind(m) newwaste(o)];
         Etotal(temp1,:)=newPV(n)+newwind(m)+newwaste(o);




         end


         end
         end
                end


 sumwaste=481057;
```

```
%%exclude CO2 higher than
mysize=length(scen1);

     for i=1:mysize
    Etotal(i,:)=Etotal(i,:);
    %Etotal=Etotal';
  demandyearly=Demandperyear*ones(mysize,1);
  diff(i,:)=demandyearly(i,:)-Etotal(i,:);
  wastage(i,:)=sumwaste*scen1(i,[3]);
     end


%if diff(i,:)<0
%x=scen1;
   %%%%%      obj1=difftrial(x);
     %  CO2waste(i,:)=0.415*wastage(i,:)/0.907185;
      %  CO2(i,:)=CO2waste(i,:);
   %%%%%elseif diff(i,:)>=0
    %%%%%x=scen1;
        %%%%%obj1=difftrial(x);
      %  objtotal(i,:)=obj1(i,:);
       % CO2waste(i,:)=0.415*wastage(i,:)/0.907185;
        % CO2grid(i,:)=1.22*diff(i,:); %%no CO2
         %CO2(i,:)=CO2waste(i,:)+CO2grid(i,:);

         %  objtotal=obj1;
```

```
          %%%%% end
  %assignin('base','obj',obj);
 % assignin('base','obj1',obj1);
% assignin('base','objtotal',objtotal);
% assignin('base','CO2',CO2);
% assignin('base','diff',diff);
% assignin('base','demandyearly',demandyearly)
% assignin('base','Etotal',Etotal)
%  assignin('base','scen1',scen1);
 %  assignin('base','scen',scen);
```

Appendix C: Obtained Results

% RE	Pv size	Wind size	Waste size	LLP %	NPC$	CO2 Kg /year	DG kg /year	Num. of Battery	CO2%	total Supplied from RE kg/year	Supplied PV kg/year	Supplied Wind kg/year	Supplied Waste kg/year
0.1	1	7	2	0.0	1.E+06	177644	103	0	1.0	13192	1155	11511	526
0.1	2	6	2	0.0	1.E+06	177962	103	0	1.0	12703	2311	9866	526
0.1	3	5	2	0.0	1.E+06	178280	103	0	1.0	12214	3466	8222	526
0.1	4	4	2	0.0	1.E+06	178664	103	0	1.0	11725	4621	6578	526
0.1	5	3	2	0.0	1.E+06	178982	103	0	1.0	11236	5776	4933	526
0.1	6	2	2	0.0	1.E+06	179433	103	0	1.0	10747	6932	3289	526
0.1	7	1	2	0.0	1.E+06	179682	103	0	1.0	10258	8087	1644	526
0.1	8	0	2	0.0	1.E+06	180199	103	0	1.0	9768	9242	0	526
0.1	0	7	3	0.0	1.E+06	178599	103	0	1.0	12300	0	11511	789
0.1	1	6	3	0.0	1.E+06	179051	103	0	1.0	11811	1155	9866	789
0.1	2	5	3	0.0	1.E+06	179369	103	0	1.0	11322	2311	8222	789
0.1	3	4	3	0.0	1.E+06	179687	103	0	1.0	10833	3466	6578	789
0.1	4	3	3	0.0	1.E+06	180005	103	0	1.0	10344	4621	4933	789
0.1	5	2	3	0.0	1.E+06	180456	103	0	1.0	9854	5776	3289	789
0.1	6	1	3	0.0	1.E+06	180772	103	0	1.0	9365	6932	1644	789
0.1	7	0	3	0.0	1.E+06	181089	103	0	1.0	8876	8087	0	789
0.1	0	6	4	0.0	8.E+05	180006	103	0	1.0	10919	0	9866	1052
0.1	1	5	4	0.0	9.E+05	180458	103	0	1.0	10430	1155	8222	1052
0.1	2	4	4	0.0	9.E+05	180709	103	0	1.0	9940	2311	6578	1052
0.1	3	3	4	0.0	9.E+05	181027	103	0	1.0	9451	3466	4933	1052
0.2	1	2	17	0.0	5.E+05	185023	92	0	1.0	8916	1155	3289	4472
0.2	2	2	16	0.0	6.E+05	184123	92	0	1.0	9808	2311	3289	4209
0.2	3	2	15	0.0	8.E+05	183282	92	0	1.0	10701	3466	3289	3946

0.2	4	2	14	0.0	1.E+06	182381	92	0	1.0	11593	4621	3289	3683
0.2	5	2	13	0.0	1.E+06	181419	92	0	1.0	12485	5776	3289	3420
0.2	6	2	12	0.0	1.E+06	180517	92	0	1.0	13377	6932	3289	3157
0.2	7	2	11	0.0	1.E+06	179436	92	0	1.0	14270	8087	3289	2894
0.2	8	2	10	0.0	2.E+06	178355	92	0	1.0	15162	9242	3289	2631
0.2	9	2	9	0.0	2.E+06	177333	92	0	0.9	16054	10398	3289	2368
0.2	10	2	8	0.0	2.E+06	176430	92	0	0.9	16946	11553	3289	2104
0.2	11	2	7	0.0	2.E+06	175585	92	0	0.9	17838	12708	3289	1841
0.2	12	2	6	0.0	2.E+06	174621	92	0	0.9	18731	13864	3289	1578
0.2	13	2	5	0.0	2.E+06	173715	92	0	0.9	19623	15019	3289	1315
0.2	14	2	4	0.0	3.E+06	172631	92	0	0.9	20515	16174	3289	1052
0.2	15	2	3	0.0	3.E+06	171606	92	0	0.9	21407	17329	3289	789
0.2	16	2	2	0.0	3.E+06	170581	92	0	0.9	22300	18485	3289	526
0.2	17	2	1	0.0	3.E+06	169675	92	0	0.9	23192	19640	3289	263
0.2	18	2	0	0.0	3.E+06	168709	92	0	0.9	24084	20795	3289	0
0.2	0	3	17	0.0	4.E+05	184523	92	0	1.0	9405	0	4933	4472
0.2	1	3	16	0.0	6.E+05	183802	92	0	1.0	10297	1155	4933	4209
0.3	1	2	27	0.1	5.E+05	180747	80	0	1.0	11547	1155	3289	7103
0.3	2	2	26	0.1	6.E+05	180014	80	0	1.0	12439	2311	3289	6840
0.3	3	2	25	0.1	8.E+05	179227	80	0	1.0	13331	3466	3289	6576
0.3	4	2	24	0.0	1.E+06	178543	80	0	1.0	14223	4621	3289	6313
0.3	5	2	23	0.0	1.E+06	177753	80	0	1.0	15116	5776	3289	6050
0.3	6	2	22	0.0	1.E+06	177274	80	0	0.9	16008	6932	3289	5787
0.3	7	2	21	0.0	1.E+06	176585	80	0	0.9	16900	8087	3289	5524
0.3	8	2	20	0.0	2.E+06	175789	80	0	0.9	17792	9242	3289	5261
0.3	9	2	19	0.0	2.E+06	174941	80	0	0.9	18685	10398	3289	4998
0.3	10	2	18	0.0	2.E+06	174092	80	0	0.9	19577	11553	3289	4735
0.3	11	2	17	0.0	2.E+06	173189	80	0	0.9	20469	12708	3289	4472
0.3	12	2	16	0.0	2.E+06	172235	80	0	0.9	21361	13864	3289	4209
0.3	13	2	15	0.0	2.E+06	171488	80	0	0.9	22254	15019	3289	3946

0.3	14	2	14	0.0	3.E+06	170687	80	0	0.9	23146	16174	3289	3683
0.3	15	2	13	0.0	3.E+06	169885	80	0	0.9	24038	17329	3289	3420
0.3	16	2	12	0.0	3.E+06	169237	80	0	0.9	24930	18485	3289	3157
0.3	17	2	11	0.0	3.E+06	168536	80	0	0.9	25822	19640	3289	2894
0.3	18	2	10	0.0	3.E+06	167937	80	0	0.9	26715	20795	3289	2631
0.3	19	2	9	0.0	3.E+06	167128	80	0	0.9	27607	21951	3289	2368
0.3	20	2	8	0.0	4.E+06	166057	80	0	0.9	28499	23106	3289	2104
0.4	1	4	35	0.1	7.E+05	169535	69	0	0.9	16940	1155	6578	9207
0.4	2	4	34	0.1	9.E+05	168991	69	0	0.9	17832	2311	6578	8944
0.4	3	4	33	0.1	1.E+06	168400	69	0	0.9	18724	3466	6578	8681
0.4	4	4	32	0.1	1.E+06	168252	69	0	0.9	19617	4621	6578	8418
0.4	5	4	31	0.1	1.E+06	167339	69	0	0.9	20509	5776	6578	8155
0.4	6	4	30	0.1	2.E+06	166559	69	0	0.9	21401	6932	6578	7892
0.4	7	4	29	0.1	2.E+06	165823	69	0	0.9	22293	8087	6578	7629
0.4	8	4	28	0.1	2.E+06	165264	69	0	0.9	23186	9242	6578	7366
0.4	9	4	27	0.1	2.E+06	164568	69	0	0.9	24078	10398	6578	7103
0.4	10	4	26	0.1	2.E+06	163647	69	0	0.9	24970	11553	6578	6840
0.4	11	4	25	0.1	2.E+06	162993	69	0	0.9	25862	12708	6578	6576
0.4	12	4	24	0.1	3.E+06	162471	69	0	0.9	26755	13864	6578	6313
0.4	13	4	23	0.1	3.E+06	161723	69	0	0.9	27647	15019	6578	6050
0.4	14	4	22	0.1	3.E+06	161107	69	0	0.9	28539	16174	6578	5787
0.4	15	4	21	0.1	3.E+06	160488	69	0	0.9	29431	17329	6578	5524
0.4	16	4	20	0.1	3.E+06	159778	69	0	0.9	30324	18485	6578	5261
0.4	17	4	19	0.1	3.E+06	159021	69	0	0.9	31216	19640	6578	4998
0.4	18	4	18	0.1	3.E+06	158352	69	0	0.8	32108	20795	6578	4735
0.4	19	4	17	0.1	4.E+06	157592	69	0	0.8	33000	21951	6578	4472
0.4	20	4	16	0.1	4.E+06	156964	69	0	0.8	33893	23106	6578	4209
0.5	1	7	42	0.2	1.E+06	154233	57	0	0.8	23715	1155	11511	11048
0.5	2	7	41	0.2	1.E+06	153806	57	0	0.8	24607	2311	11511	10785
0.5	3	7	40	0.2	1.E+06	153674	57	0	0.8	25499	3466	11511	10522

0.5	4	7	39	0.2	2.E+06	153200	57	0	0.8	26391	4621	11511	10259
0.5	5	7	38	0.2	2.E+06	152684	57	0	0.8	27284	5776	11511	9996
0.5	6	7	37	0.1	2.E+06	152425	57	0	0.8	28176	6932	11511	9733
0.5	7	7	36	0.1	2.E+06	151937	57	0	0.8	29068	8087	11511	9470
0.5	8	7	35	0.1	2.E+06	151632	57	0	0.8	29960	9242	11511	9207
0.5	9	7	34	0.1	2.E+06	151135	57	0	0.8	30853	10398	11511	8944
0.5	10	7	33	0.1	3.E+06	150522	57	0	0.8	31745	11553	11511	8681
0.5	11	7	32	0.1	3.E+06	150058	57	0	0.8	32637	12708	11511	8418
0.5	12	7	31	0.1	3.E+06	149403	57	0	0.8	33529	13864	11511	8155
0.5	13	7	30	0.1	3.E+06	148708	57	0	0.8	34422	15019	11511	7892
0.5	14	7	29	0.1	3.E+06	148385	57	0	0.8	35314	16174	11511	7629
0.5	15	7	28	0.1	3.E+06	147610	57	0	0.8	36206	17329	11511	7366
0.5	16	7	27	0.1	4.E+06	147058	57	0	0.8	37098	18485	11511	7103
0.5	17	7	26	0.1	4.E+06	146540	57	0	0.8	37990	19640	11511	6840
0.5	18	7	25	0.1	4.E+06	145870	57	0	0.8	38883	20795	11511	6576
0.5	19	7	24	0.1	4.E+06	145347	57	0	0.8	39775	21951	11511	6313
0.5	20	7	23	0.1	4.E+06	144708	57	0	0.8	40667	23106	11511	6050
0.6	1	9	50	0.0	1.E+06	46191	46	0	0.2	29108	1155	14800	13153
0.6	2	8	50	0.2	1.E+06	135629	46	0	0.7	28619	2311	13155	13153
0.6	3	7	50	0.2	1.E+06	136314	46	0	0.7	28130	3466	11511	13153
0.6	4	7	49	0.2	2.E+06	135971	46	0	0.7	29022	4621	11511	12890
0.6	5	7	48	0.2	2.E+06	135655	46	0	0.7	29914	5776	11511	12627
0.6	6	7	47	0.2	2.E+06	135364	46	0	0.7	30806	6932	11511	12364
0.6	7	7	46	0.2	2.E+06	135278	46	0	0.7	31699	8087	11511	12101
0.6	8	7	45	0.2	2.E+06	135064	46	0	0.7	32591	9242	11511	11838
0.6	9	7	44	0.2	2.E+06	134815	46	0	0.7	33483	10398	11511	11575
0.6	10	7	43	0.2	3.E+06	134498	46	0	0.7	34375	11553	11511	11312
0.6	11	7	42	0.2	3.E+06	134237	46	0	0.7	35268	12708	11511	11048
0.6	12	7	41	0.2	3.E+06	133908	46	0	0.7	36160	13864	11511	10785
0.6	13	7	40	0.2	3.E+06	133605	46	0	0.7	37052	15019	11511	10522

0.6	14	7	39	0.2	3.E+06	133417	46	0	0.7	37944	16174	11511	10259
0.6	15	7	38	0.2	3.E+06	133164	46	0	0.7	38837	17329	11511	9996
0.6	16	7	37	0.2	4.E+06	132844	46	0	0.7	39729	18485	11511	9733
0.6	17	7	36	0.2	4.E+06	132397	46	0	0.7	40621	19640	11511	9470
0.6	18	7	35	0.2	4.E+06	132096	46	0	0.7	41513	20795	11511	9207
0.6	19	7	34	0.2	4.E+06	131790	46	0	0.7	42406	21951	11511	8944
0.6	20	7	33	0.2	4.E+06	131357	46	0	0.7	43298	23106	11511	8681
0.7	1	29	40	0.0	4.E+06	34925	34	47	0.2	59366	1155	47688	10522
0.7	2	29	39	0.0	4.E+06	34517	34	46	0.2	60258	2311	47688	10259
0.7	3	29	38	0.2	4.E+06	79053	34	46	0.4	61150	3466	47688	9996
0.7	4	29	37	0.0	4.E+06	32896	34	46	0.2	62042	4621	47688	9733
0.7	5	29	36	0.0	5.E+06	32306	34	46	0.2	62935	5776	47688	9470
0.7	6	29	35	0.2	5.E+06	75735	34	46	0.4	63827	6932	47688	9207
0.7	7	29	34	0.2	5.E+06	76155	34	46	0.4	64719	8087	47688	8944
0.7	8	29	33	0.2	5.E+06	74995	34	46	0.4	65611	9242	47688	8681
0.7	9	29	32	0.0	5.E+06	22811	34	46	0.1	66504	10398	47688	8418
0.7	10	29	31	0.0	5.E+06	22329	34	45	0.1	67396	11553	47688	8155
0.7	11	29	30	0.0	6.E+06	29080	34	45	0.2	68288	12708	47688	7892
0.7	12	29	29	0.0	6.E+06	29206	34	45	0.2	69180	13864	47688	7629
0.7	13	29	28	0.0	6.E+06	28510	34	45	0.2	70073	15019	47688	7366
0.7	14	29	27	0.2	6.E+06	73643	34	45	0.4	70965	16174	47688	7103
0.7	15	29	26	0.0	6.E+06	27429	34	45	0.1	71857	17329	47688	6840
0.7	16	29	25	0.0	6.E+06	27110	34	45	0.1	72749	18485	47688	6576
0.7	17	29	24	0.0	7.E+06	26617	34	45	0.1	73641	19640	47688	6313
0.7	18	29	23	0.0	7.E+06	26083	34	45	0.1	74534	20795	47688	6050
0.7	19	29	22	0.0	7.E+06	25547	34	46	0.1	75426	21951	47688	5787
0.7	20	29	21	0.0	7.E+06	24529	34	46	0.1	76318	23106	47688	5524
0.8	1	40	39	0.4	5.E+06	57319	23	81	0.3	77191	1155	65777	10259
0.8	2	40	38	0.1	6.E+06	32659	23	81	0.2	78083	2311	65777	9996
0.8	3	40	37	0.1	6.E+06	32260	23	81	0.2	78976	3466	65777	9733

0.8	4	40	36	0.1	6.E+06	32096	23	80	0.2	79868	4621	65777	9470
0.8	5	40	35	0.4	6.E+06	55542	23	80	0.3	80760	5776	65777	9207
0.8	6	40	34	0.4	6.E+06	54340	23	80	0.3	81652	6932	65777	8944
0.8	7	40	33	0.3	6.E+06	44822	23	80	0.2	82545	8087	65777	8681
0.8	8	40	32	0.0	7.E+06	20012	23	80	0.1	83437	9242	65777	8418
0.8	9	40	31	0.4	7.E+06	53549	23	80	0.3	84329	10398	65777	8155
0.8	10	40	30	0.4	7.E+06	53606	23	80	0.3	85221	11553	65777	7892
0.8	11	40	29	0.3	7.E+06	53017	23	80	0.3	86114	12708	65777	7629
0.8	12	40	28	0.3	7.E+06	52471	23	79	0.3	87006	13864	65777	7366
0.8	13	40	27	0.3	7.E+06	52093	23	79	0.3	87898	15019	65777	7103
0.8	14	40	26	0.3	8.E+06	51745	23	79	0.3	88790	16174	65777	6840
0.8	15	40	25	0.3	8.E+06	51325	23	79	0.3	89683	17329	65777	6576
0.8	16	40	24	0.3	8.E+06	50871	23	79	0.3	90575	18485	65777	6313
0.8	17	40	23	0.3	8.E+06	50785	23	79	0.3	91467	19640	65777	6050
0.8	18	40	22	0.3	8.E+06	50143	23	79	0.3	92359	20795	65777	5787
0.8	19	40	21	0.3	8.E+06	49651	23	79	0.3	93251	21951	65777	5524
0.8	20	40	20	0.3	9.E+06	49598	23	78	0.3	94144	23106	65777	5261
0.9	1	40	49	0.1	5.E+06	28896	11	82	0.2	79822	1155	65777	12890
0.9	2	40	48	0.1	6.E+06	28345	11	82	0.2	80714	2311	65777	12627
0.9	3	40	47	0.1	6.E+06	27791	11	82	0.1	81606	3466	65777	12364
0.9	4	40	46	0.1	6.E+06	27356	11	82	0.1	82499	4621	65777	12101
0.9	5	40	45	0.1	6.E+06	26850	11	82	0.1	83391	5776	65777	11838
0.9	6	40	44	0.0	6.E+06	24457	11	81	0.1	84283	6932	65777	11575
0.9	7	40	43	0.0	6.E+06	23945	11	81	0.1	85175	8087	65777	11312
0.9	8	40	42	0.0	7.E+06	23419	11	81	0.1	86067	9242	65777	11048
0.9	9	40	41	0.5	7.E+06	26981	11	81	0.1	86960	10398	65777	10785
0.9	10	40	40	0.5	7.E+06	26655	11	81	0.1	87852	11553	65777	10522
0.9	11	40	39	0.1	7.E+06	23751	11	81	0.1	88744	12708	65777	10259
0.9	12	40	38	0.1	7.E+06	23238	11	81	0.1	89636	13864	65777	9996
0.9	13	40	37	0.1	7.E+06	22757	11	81	0.1	90529	15019	65777	9733

0.9	14	40	36	0.1	8.E+06	22219	11	80	0.1	91421	16174	65777	9470
0.9	15	40	35	0.1	8.E+06	21418	11	80	0.1	92313	17329	65777	9207
0.9	16	40	34	0.1	8.E+06	20923	11	80	0.1	93205	18485	65777	8944
0.9	17	40	33	0.1	8.E+06	20580	11	80	0.1	94098	19640	65777	8681
0.9	18	40	32	0.1	8.E+06	20079	11	80	0.1	94990	20795	65777	8418
0.9	19	40	31	0.1	8.E+06	19300	11	80	0.1	95882	21951	65777	8155
0.9	20	40	30	0.1	9.E+06	18632	11	80	0.1	96774	23106	65777	7892
1	1	50	49	0.0	7.E+06	25780	0	116	0.1	96266	1155	82221	12890
1	2	50	48	0.0	7.E+06	25254	0	116	0.1	97158	2311	82221	12627
1	3	50	47	0.0	7.E+06	24728	0	115	0.1	98050	3466	82221	12364
1	4	50	46	0.0	7.E+06	24201	0	115	0.1	98943	4621	82221	12101
1	5	50	45	0.0	7.E+06	23675	0	115	0.1	99835	5776	82221	11838
1	6	50	44	0.0	8.E+06	23149	0	115	0.1	100727	6932	82221	11575
1	7	50	43	0.0	8.E+06	22623	0	115	0.1	101619	8087	82221	11312
1	8	50	42	0.0	8.E+06	22097	0	115	0.1	102512	9242	82221	11048
1	9	50	41	0.0	8.E+06	21571	0	115	0.1	103404	10398	82221	10785
1	10	50	40	0.0	8.E+06	21045	0	115	0.1	104296	11553	82221	10522
1	11	50	39	0.0	8.E+06	20519	0	114	0.1	105188	12708	82221	10259
1	12	50	38	0.0	9.E+06	19992	0	114	0.1	106081	13864	82221	9996
1	13	50	37	0.0	9.E+06	19466	0	114	0.1	106973	15019	82221	9733
1	14	50	36	0.0	9.E+06	18940	0	114	0.1	107865	16174	82221	9470
1	15	50	35	0.0	9.E+06	18414	0	114	0.1	108757	17329	82221	9207
1	16	50	34	0.0	9.E+06	17888	0	114	0.1	109649	18485	82221	8944
1	17	50	33	0.0	9.E+06	17362	0	114	0.1	110542	19640	82221	8681
1	18	50	32	0.0	1.E+07	16836	0	114	0.1	111434	20795	82221	8418
1	19	50	31	0.0	1.E+07	16310	0	113	0.1	112326	21951	82221	8155
1	20	50	30	0.0	1.E+07	15784	0	113	0.1	113218	23106	82221	7892

Fraction % of RES	Pv size	Wind size	Waste size	LLP %	NPC$	CO2 kg/year	DG kg/year	Num. of Battery	CO2%	total Supplied from RE	Supplied PV kg/year	Supplied Wind kg/year	Supplied Waste kg/year
0.1	7	1	2	0.0	1.E+06	179683	103	0	1.0	10258	8087	1644	526
0.1	6	2	2	0.0	1.E+06	179433	103	0	1.0	10747	6932	3289	526
0.1	5	3	2	0.0	1.E+06	178982	103	0	1.0	11236	5776	4933	526
0.1	4	4	2	0.0	1.E+06	178665	103	0	1.0	11725	4621	6578	526
0.1	3	5	2	0.0	1.E+06	178280	103	0	1.0	12214	3466	8222	526
0.1	2	6	2	0.0	1.E+06	177962	103	0	1.0	12703	2311	9866	526
0.1	1	7	2	0.0	1.E+06	177644	103	0	1.0	13192	1155	11511	526
0.1	0	8	2	0.0	1.E+06	177259	103	0	0.9	13681	0	13155	526
0.1	7	0	3	0.0	1.E+06	181089	103	0	1.0	8876	8087	0	789
0.1	6	1	3	0.0	1.E+06	180773	103	0	1.0	9365	6932	1644	789
0.2	2	1	17	0.0	5.E+05	185284	92	0	1.0	8427	2311	1644	4472
0.2	2	2	16	0.0	6.E+05	184123	92	0	1.0	9808	2311	3289	4209
0.2	2	3	15	0.0	8.E+05	185771	103	0	1.0	11190	2311	4933	3946
0.2	2	4	14	0.0	9.E+05	184431	103	0	1.0	12571	2311	6578	3683
0.2	2	5	13	0.0	1.E+06	183091	103	0	1.0	13952	2311	8222	3420
0.2	2	6	12	0.0	8.E+05	182843	92	0	1.0	15334	2311	9866	3157
0.2	2	7	11	0.0	1.E+06	177596	92	0	1.0	16715	2311	11511	2894
0.2	2	8	10	0.0	1.E+06	176312	92	0	0.9	18097	2311	13155	2631
0.2	2	9	9	0.0	2.E+06	174969	92	0	0.9	19478	2311	14800	2368
0.2	2	10	8	0.0	2.E+06	27639	92	0	0.1	20859	2311	16444	2104
0.3	2	1	27	0.1	5.E+05	181394	80	0	1.0	11058	2311	1644	7103
0.3	2	2	26	0.1	6.E+05	180014	80	0	1.0	12439	2311	3289	6840
0.3	2	3	25	0.1	8.E+05	178842	80	0	1.0	13820	2311	4933	6576
0.3	2	4	24	0.0	9.E+05	177720	80	0	1.0	15202	2311	6578	6313
0.3	2	5	23	0.0	1.E+06	176648	80	0	0.9	16583	2311	8222	6050
0.3	2	6	22	0.0	1.E+06	175366	80	0	0.9	17964	2311	9866	5787
0.3	2	7	21	0.0	1.E+06	174135	80	0	0.9	19346	2311	11511	5524
0.3	2	8	20	0.0	1.E+06	173008	80	0	0.9	20727	2311	13155	5261

0.3	2	9	19	0.0	2.E+06	171671	80	0	0.9	22108	2311	14800	4998
0.3	2	10	18	0.0	2.E+06	124892	80	0	0.7	23490	2311	16444	4735
0.4	4	1	35	0.1	8.E+05	171374	69	0	0.9	15473	4621	1644	9207
0.4	4	2	34	0.1	1.E+06	170335	69	0	0.9	16854	4621	3289	8944
0.4	4	3	33	0.1	1.E+06	169160	69	0	0.9	18235	4621	4933	8681
0.4	4	4	32	0.1	1.E+06	168252	69	0	0.9	19617	4621	6578	8418
0.4	4	5	31	0.1	1.E+06	167027	69	0	0.9	20998	4621	8222	8155
0.4	4	6	30	0.1	1.E+06	165756	69	0	0.9	22379	4621	9866	7892
0.4	4	7	29	0.1	2.E+06	164439	69	0	0.9	23761	4621	11511	7629
0.4	4	8	28	0.1	2.E+06	163347	69	0	0.9	25142	4621	13155	7366
0.4	4	9	27	0.1	2.E+06	162073	69	0	0.9	26524	4621	14800	7103
0.4	4	10	26	0.1	2.E+06	160975	69	0	0.9	27905	4621	16444	6840
0.5	7	1	42	0.2	1.E+06	158601	57	0	0.8	20780	8087	1644	11048
0.5	7	2	41	0.2	1.E+06	157509	57	0	0.8	22161	8087	3289	10785
0.5	7	3	40	0.1	2.E+06	156414	57	0	0.8	23543	8087	4933	10522
0.5	7	4	39	0.1	2.E+06	155168	57	0	0.8	24924	8087	6578	10259
0.5	7	5	38	0.1	2.E+06	154107	57	0	0.8	26305	8087	8222	9996
0.5	7	6	37	0.1	2.E+06	153043	57	0	0.8	27687	8087	9866	9733
0.5	7	7	36	0.1	2.E+06	151937	57	0	0.8	29068	8087	11511	9470
0.5	7	8	35	0.1	2.E+06	150716	57	0	0.8	30449	8087	13155	9207
0.5	7	9	34	0.1	2.E+06	149605	57	0	0.8	31831	8087	14800	8944
0.5	7	10	33	0.1	2.E+06	148017	57	1	0.8	33212	8087	16444	8681
0.6	9	1	50	0.2	2.E+06	140802	46	0	0.8	25195	10398	1644	13153
0.6	8	2	50	0.2	2.E+06	140058	46	0	0.7	25684	9242	3289	13153
0.6	7	3	50	0.2	2.E+06	139370	46	0	0.7	26173	8087	4933	13153
0.6	7	4	49	0.2	2.E+06	138382	46	0	0.7	27555	8087	6578	12890
0.6	7	5	48	0.2	2.E+06	137301	46	0	0.7	28936	8087	8222	12627
0.6	7	6	47	0.2	2.E+06	136306	46	0	0.7	30317	8087	9866	12364
0.6	7	7	46	0.2	2.E+06	135278	46	0	0.7	31699	8087	11511	12101

0.6	7	8	45	0.2	2.E+06	134307	46	0	0.7	33080	8087	13155	11838
0.6	7	9	44	0.2	2.E+06	133090	46	0	0.7	34461	8087	14800	11575
0.6	7	10	43	0.2	2.E+06	132109	46	1	0.7	35843	8087	16444	11312
0.7	29	1	40	0.3	5.E+06	112785	34	1	0.6	45670	33504	1644	10522
0.7	29	2	39	0.3	5.E+06	112501	34	1	0.6	47052	33504	3289	10259
0.7	29	3	38	0.2	5.E+06	106229	34	1	0.6	48433	33504	4933	9996
0.7	29	4	37	0.3	5.E+06	110738	34	1	0.6	49814	33504	6578	9733
0.7	29	5	36	0.0	5.E+06	27680	34	1	0.1	51196	33504	8222	9470
0.7	29	6	35	0.3	5.E+06	108474	34	1	0.6	52577	33504	9866	9207
0.7	29	7	34	0.0	6.E+06	26392	34	1	0.1	53958	33504	11511	8944
0.7	29	8	33	0.0	6.E+06	40969	34	1	0.2	55340	33504	13155	8681
0.7	29	9	32	0.2	6.E+06	106643	34	1	0.6	56721	33504	14800	8418
0.7	29	10	31	0.2	6.E+06	105599	34	2	0.6	58103	33504	16444	8155
0.8	40	1	39	0.4	7.E+06	72922	23	5	0.4	58116	46212	1644	10259
0.8	40	2	38	0.4	7.E+06	70325	23	5	0.4	59497	46212	3289	9996
0.8	40	3	37	0.0	7.E+06	37785	23	5	0.2	60878	46212	4933	9733
0.8	40	4	36	0.4	7.E+06	71686	23	6	0.4	62260	46212	6578	9470
0.8	40	5	35	0.4	7.E+06	71198	23	6	0.4	63641	46212	8222	9207
0.8	40	6	34	0.4	7.E+06	70422	23	6	0.4	65022	46212	9866	8944
0.8	40	7	33	0.4	7.E+06	69732	23	7	0.4	66404	46212	11511	8681
0.8	40	8	32	0.0	8.E+06	30103	23	7	0.2	67785	46212	13155	8418
0.8	40	9	31	0.4	8.E+06	68010	23	7	0.4	69166	46212	14800	8155
0.8	40	10	30	0.4	8.E+06	67146	23	8	0.4	70548	46212	16444	7892
0.9	40	1	49	0.1	7.E+06	30893	11	5	0.2	60746	46212	1644	12890
0.9	40	2	48	0.1	7.E+06	30428	11	6	0.2	62127	46212	3289	12627
0.9	40	3	47	0.5	7.E+06	31720	11	6	0.2	63509	46212	4933	12364
0.9	40	4	46	0.5	7.E+06	31602	11	6	0.2	64890	46212	6578	12101
0.9	40	5	45	0.5	7.E+06	31343	11	6	0.2	66272	46212	8222	11838
0.9	40	6	44	0.5	7.E+06	31014	11	7	0.2	67653	46212	9866	11575

0.9	40	7	43	0.5	7.E+06	30673	11	7	0.2	69034	46212	11511	11312
0.9	40	8	42	0.5	8.E+06	30358	11	7	0.2	70416	46212	13155	11048
0.9	40	9	41	0.5	8.E+06	30006	11	8	0.2	71797	46212	14800	10785
0.9	40	10	40	0.5	8.E+06	29729	11	9	0.2	73178	46212	16444	10522
1	50	1	49	0.5	8.E+06	25780	0	16	0.1	72299	57765	1644	12890
1	50	2	48	0.5	8.E+06	25254	0	17	0.1	73680	57765	3289	12627
1	50	3	47	0.1	8.E+06	24728	0	17	0.1	75062	57765	4933	12364
1	50	4	46	0.1	9.E+06	24201	0	17	0.1	76443	57765	6578	12101
1	50	5	45	0.1	9.E+06	23675	0	18	0.1	77824	57765	8222	11838
1	50	6	44	0.5	9.E+06	23149	0	18	0.1	79206	57765	9866	11575
1	50	7	43	0.1	9.E+06	22623	0	19	0.1	80587	57765	11511	11312
1	50	8	42	0.1	9.E+06	22097	0	19	0.1	81969	57765	13155	11048
1	50	9	41	0.5	9.E+06	21571	0	19	0.1	83350	57765	14800	10785
1	50	10	40	0.5	9.E+06	21045	0	20	0.1	84731	57765	16444	10522

% fraction of RES	Pv size	Wind size	Waste size	LLP%	NCP$	CO2 kg/year	DG kg /year	Num. of Battery	CO2%	total Supplied from RE kg/year
0.1	0	7	100	0.0	9.E+05	73549	103	1	0.4	37817
0.1	10	0	100	0.0	2.E+06	215289	103	0	1.2	37859
0.1	7	0	115	0.0	1.E+06	222874	103	0	1.2	38339
0.1	0	5	115	0.0	7.E+05	81967	103	1	0.4	38474
0.1	4	0	129	0.0	7.E+05	229966	103	0	1.2	38556
0.1	0	3	129	0.0	4.E+05	229496	103	1	1.2	38868
0.1	4	5	100	0.0	1.E+06	214262	103	0	1.1	39149
0.1	7	3	100	0.0	2.E+06	214283	103	0	1.1	39326
0.1	4	3	115	0.0	1.E+06	221800	103	0	1.2	39806
0.1	7	7	115	0.0	2.E+06	80623	103	1	0.4	49850
0.2	10	16	143	0.0	4.E+06	191122	92	21	1.0	75481
0.2	13	14	143	0.0	4.E+06	183114	92	16	1.0	75658
0.2	23	7	143	0.0	5.E+06	89808	92	3	0.5	75700
0.2	33	0	143	0.0	5.E+06	213160	92	6	1.1	75742
0.2	26	5	143	0.0	5.E+06	213165	92	3	1.1	75877
0.2	4	21	143	0.0	3.E+06	139076	92	35	0.7	76771
0.2	7	19	143	0.0	4.E+06	201150	92	29	1.1	76948
0.2	17	12	143	0.0	4.E+06	211511	92	11	1.1	76990
0.2	20	10	143	0.0	5.E+06	209531	92	7	1.1	77167
0.2	30	3	143	0.0	5.E+06	89836	92	4	0.5	77210
0.3	13	0	371	0.0	9.E+06	165341	80	46	0.9	112541
0.3	0	5	399	0.0	6.E+05	212190	80	33	1.1	112541
0.3	6	0	399	0.0	1.E+06	210227	80	24	1.1	112541
0.3	3	2	399	0.0	9.E+05	210463	80	29	1.1	112541
0.3	0	0	428	0.0	4.E+04	225235	80	28	1.2	112541

0.3	3	5	385	0.0	1.E+06	203571	80	31	1.1	112541
0.3	0	2	414	0.0	3.E+05	217971	80	30	1.2	112541
0.3	3	0	414	0.0	6.E+05	217731	80	26	1.2	112541
0.3	6	2	385	0.0	1.E+06	202985	80	27	1.1	112541
0.3	10	0	385	0.0	2.E+06	202723	80	23	1.1	112541
0.4	71	0	257	0.0	1.E+07	135380	69	60	0.7	150054
0.4	68	2	257	0.0	1.E+07	135351	69	57	0.7	150054
0.4	75	0	242	0.0	1.E+07	127880	69	64	0.7	150054
0.4	65	0	285	0.0	1.E+07	150292	69	53	0.8	150054
0.4	62	2	285	0.0	1.E+07	150349	69	52	0.8	150054
0.4	65	2	271	0.0	1.E+07	142850	69	54	0.8	150054
0.4	68	0	271	0.0	1.E+07	142881	69	56	0.8	150054
0.4	58	2	299	0.0	1.E+07	157841	69	49	0.8	150054
0.4	62	0	299	0.0	1.E+07	157793	69	49	0.8	150054
0.4	55	2	314	0.0	9.E+06	165341	69	46	0.9	150054
0.5	6	107	14	0.0	2.E+07	7540	57	309	0.0	187568
0.5	16	100	14	0.0	2.E+07	23251	57	286	0.1	187568
0.5	26	94	14	0.0	2.E+07	21427	57	262	0.1	187568
0.5	0	112	14	0.0	1.E+07	7541	57	325	0.0	187568
0.5	23	96	14	0.0	2.E+07	16864	57	270	0.1	187568
0.5	29	91	14	0.0	2.E+07	21734	57	255	0.1	187568
0.5	10	105	14	0.0	2.E+07	16024	57	302	0.1	187568
0.5	19	98	14	0.0	2.E+07	7539	57	278	0.0	187568
0.5	3	110	14	0.0	2.E+07	7540	57	317	0.0	187568
0.5	13	103	14	0.0	2.E+07	22864	57	294	0.1	187568
0.6	81	2	485	0.0	1.E+07	255280	46	103	1.4	225081
0.6	84	2	471	0.0	1.E+07	247776	46	105	1.3	225081
0.6	101	0	414	0.0	2.E+07	217651	46	122	1.2	225081
0.6	97	0	428	0.0	2.E+07	225155	46	118	1.2	225081
0.6	94	2	428	0.0	2.E+07	225282	46	115	1.2	225081

0.6	94	0	442	0.0	2.E+07	232658	46	114	1.2	225081
0.6	88	2	456	0.0	1.E+07	240285	46	108	1.3	225081
0.6	91	0	456	0.0	1.E+07	240161	46	110	1.3	225081
0.6	91	2	442	0.0	2.E+07	232780	46	111	1.2	225081
0.6	88	0	471	0.0	1.E+07	247664	46	107	1.3	225081
0.7	81	2	627	0.0	1.E+07	330321	34	128	1.8	262595
0.7	68	5	670	0.0	1.E+07	352945	34	125	1.9	262595
0.7	71	5	656	0.0	1.E+07	345334	34	126	1.8	262595
0.7	84	2	613	0.0	1.E+07	322816	34	129	1.7	262595
0.7	97	2	556	0.0	2.E+07	292797	34	134	1.6	262595
0.7	91	2	585	0.0	2.E+07	307807	34	132	1.6	262595
0.7	94	2	570	0.0	2.E+07	300302	34	133	1.6	262595
0.7	88	2	599	0.0	1.E+07	315312	34	130	1.7	262595
0.7	65	5	685	0.0	1.E+07	361009	34	124	1.9	262595
0.7	78	2	642	0.0	1.E+07	337819	34	127	1.8	262595
0.8	94	2	713	0.0	2.E+07	375349	23	161	2.0	300108
0.8	97	0	713	0.0	2.E+07	375209	23	159	2.0	300108
0.8	91	5	713	0.0	2.E+07	375296	23	162	2.0	300108
0.8	88	7	713	0.0	2.E+07	375452	23	163	2.0	300108
0.8	101	0	699	0.0	2.E+07	367705	23	161	2.0	300108
0.8	94	5	699	0.0	2.E+07	367804	23	163	2.0	300108
0.8	97	2	699	0.0	2.E+07	367844	23	162	2.0	300108
0.8	91	7	699	0.0	2.E+07	367905	23	164	2.0	300108
0.8	97	5	685	0.0	2.E+07	360357	23	164	1.9	300108
0.8	101	2	685	0.0	2.E+07	360340	23	163	1.9	300108
0.9	120	7	713	0.0	2.E+07	375294	11	203	2.0	337622
0.9	117	9	713	0.0	2.E+07	375190	11	204	2.0	337622
0.9	114	11	713	0.0	2.E+07	375187	11	205	2.0	337622
0.9	130	0	713	0.0	2.E+07	375172	11	204	2.0	337622
0.9	123	5	713	0.0	2.E+07	375175	11	202	2.0	337622

0.9	127	2	713	0.0	2.E+07	375209	11	201	2.0	337622
0.9	117	11.0	7.E+02	0	20508069	367684	11.4	206	2	337622
0.9	120	9.0	7.E+02	0	20732419	367682.2	11.4	205	2	337622
0.9	123	7.0	7.E+02	0	20956793	367783	11.4	204	2	337622
0.9	120	11.0	7.E+02	0	21031856	360181.1	11.4	208	2	337622
1	133	21.0	7.E+02	0	24350213	375135	0.0	249	2	375135
1	140	16.0	7.E+02	0	24798914	375135	0.0	247	2	375135
1	143	14.0	7.E+02	0	25023265	375135	0.0	246	2	375135
1	127	25.0	7.E+02	0	23901511	375135	0.0	251	2	375135
1	130	23.0	7.E+02	0	24125862	375135	0.0	250	2	375135
1	136	18.0	7.E+02	0	24574563	375135	0.0	248	2	375135
1	130	25.0	7.E+02	0	24425298	367632.3	0.0	253	2	375135
1	136	21.0	7.E+02	0	24874000	367632.3	0.0	251	2	375135
1	140	18.0	7.E+02	0	25098350	367632.3	0.0	250	2	375135
1	133	23.0	7.E+02	0	24649649	367632.3	0.0	252	2	375135

pv	wind	Sce pv	Sce wind	sum	pv size	wind size	LLP%	NPC$	CO2 kg/year	DG kg/ year	NUM.BATT ERY	CO2%	Total Supplied from RES kg/year
18757	18757	0.05	0.05	0.10	16	11	0.0	4.E+06	162753	103	2	0.87	37513.5
11254	26259	0.03	0.07	0.10	10	16	0.0	4.E+06	162061	103	11	0.87	37513.5
3751	33762	0.01	0.09	0.10	3	21	0.0	3.E+06	152820	103	24	0.82	37513.5
30011	7503	0.08	0.02	0.10	26	5	0.0	5.E+06	162899	103	0	0.87	37513.5
22508	15005	0.06	0.04	0.10	19	9	0.0	4.E+06	162899	103	0	0.87	37513.5
37514	0	0.10	0.00	0.10	32	0	0.0	5.E+06	162882	103	1	0.87	37513.5
26259	11254	0.07	0.03	0.10	23	7	0.0	5.E+06	162899	103	0	0.87	37513.5
33762	3751	0.09	0.01	0.10	29	2	0.0	5.E+06	162897	103	0	0.87	37513.5
15005	22508	0.04	0.06	0.10	13	14	0.0	4.E+06	162598	103	6	0.87	37513.5
7503	30011	0.02	0.08	0.10	6	18	0.0	3.E+06	127419	103	16	0.68	37513.5
0	37514	0.00	0.10	0.10	0	23	0.0	3.E+06	125899	103	29	0.67	37513.5
56270	18757	0.15	0.05	0.20	49	11	0.0	9.E+06	8566	92	16	0.05	75027
48768	26259	0.13	0.07	0.20	42	16	0.0	9.E+06	136715	92	18	0.73	75027
52519	22508	0.14	0.06	0.20	45	14	0.0	9.E+06	136456	92	17	0.73	75027
7503	67524	0.02	0.18	0.20	6	41	0.0	7.E+06	106787	92	79	0.57	75027
41265	33762	0.11	0.09	0.20	36	21	0.0	8.E+06	115511	92	23	0.62	75027
0	75027	0.00	0.20	0.20	0	46	0.0	6.E+06	112383	92	94	0.6	75027
33762	41265	0.09	0.11	0.20	29	25	0.0	8.E+06	134024	92	35	0.72	75027
45016	30011	0.12	0.08	0.20	39	18	0.0	9.E+06	136752	92	18	0.73	75027
18757	56270	0.05	0.15	0.20	16	34	0.0	7.E+06	90258	92	60	0.48	75027
26259	48768	0.07	0.13	0.20	23	30	0.0	8.E+06	131986	92	47	0.71	75027
11254	63773	0.03	0.17	0.20	10	39	0.0	7.E+06	5620	92	73	0.03	75027

3751	71276	0.01	0.19	0.20	3	43	0.0	6.E+06	90373	92	87	0.48	75027
75027	0	0.20	0.00	0.20	65	0	0.0	1.E+07	5404	92	31	0.03	75027
37514	37514	0.10	0.10	0.20	32	23	0.0	8.E+06	134428	92	29	0.72	75027
30011	45016	0.08	0.12	0.20	26	27	0.0	8.E+06	129692	92	41	0.69	75027
22508	52519	0.06	0.14	0.20	19	32	0.0	7.E+06	6691	92	54	0.04	75027
71276	3751	0.19	0.01	0.20	62	2	0.0	1.E+07	5322	92	28	0.03	75027
15005	60022	0.04	0.16	0.20	13	37	0.0	7.E+06	129363	92	66	0.69	75027
67524	7503	0.18	0.02	0.20	58	5	0.0	1.E+07	80160	92	25	0.43	75027
63773	11254	0.17	0.03	0.20	55	7	0.0	1.E+07	71063	92	22	0.38	75027
60022	15005	0.16	0.04	0.20	52	9	0.0	1.E+07	5042	92	19	0.03	75027
93784	18757	0.25	0.05	0.30	81	11	0.0	1.E+07	3014	103	61	0.02	112540.5
52519	60022	0.14	0.16	0.30	45	37	0.0	1.E+07	92344	103	74	0.49	112540.5
56270	56270	0.15	0.15	0.30	49	34	0.0	1.E+07	83593	103	70	0.45	112540.5
97535	15005	0.26	0.04	0.30	84	9	0.0	1.E+07	3438	103	64	0.02	112540.5
45016	67524	0.12	0.18	0.30	39	41	0.0	1.E+07	93319	103	84	0.5	112540.5
86281	26259	0.23	0.07	0.30	75	16	0.0	1.E+07	81848	103	59	0.44	112540.5
90032	22508	0.24	0.06	0.30	78	14	0.0	1.E+07	21148	103	59	0.11	112540.5
48768	63773	0.13	0.17	0.30	42	39	0.0	1.E+07	96795	103	79	0.52	112540.5
30011	82530	0.08	0.22	0.30	26	50	0.0	1.E+07	1443	103	111	0.01	112540.5
37514	75027	0.10	0.20	0.30	32	46	0.0	1.E+07	96604	103	96	0.52	112540.5
78778	33762	0.21	0.09	0.30	68	21	0.0	1.E+07	76301	103	61	0.41	112540.5
22508	90032	0.06	0.24	0.30	19	55	0.0	1.E+07	87275	80	127	0.47	112540.5
7503	105038	0.02	0.28	0.30	6	64	0.0	1.E+07	1459	80	158	0.01	112540.5
15005	97535	0.04	0.26	0.30	13	59	0.0	1.E+07	96739	80	142	0.52	112540.5
0	112541	0.00	0.30	0.30	0	68	0.0	9.E+06	77348	80	174	0.41	112540.5
41265	71276	0.11	0.19	0.30	36	43	0.0	1.E+07	4187	103	90	0.02	112540.5
82530	30011	0.22	0.08	0.30	71	18	0.0	1.E+07	4953	103	60	0.03	112540.5
33762	78778	0.09	0.21	0.30	29	48	0.0	1.E+07	5883	103	103	0.03	112540.5
112541	0	0.30	0.00	0.30	97	0	0.0	2.E+07	595	103	78	0	112540.5

18757	93784	0.05	0.25	0.30	16	57	0.0	1.E+07	8538	80	135	0.05	112540.5
71276	41265	0.19	0.11	0.30	62	25	0.0	1.E+07	94165	103	63	0.5	112540.5
26259	86281	0.07	0.23	0.30	23	52	0.0	1.E+07	88613	80	119	0.47	112540.5
3751	108789	0.01	0.29	0.30	3	66	0.0	9.E+06	91106	80	166	0.49	112540.5
108789	3751	0.29	0.01	0.30	94	2	0.0	2.E+07	564	103	74	0	112540.5
11254	101287	0.03	0.27	0.30	10	62	0.0	1.E+07	94908	80	150	0.51	112540.5
75027	37514	0.20	0.10	0.30	65	23	0.0	1.E+07	94667	103	62	0.51	112540.5
105038	7503	0.28	0.02	0.30	91	5	0.0	2.E+07	2600	103	71	0.01	112540.5
63773	48768	0.17	0.13	0.30	55	30	0.0	1.E+07	99328	103	66	0.53	112540.5
67524	45016	0.18	0.12	0.30	58	27	0.0	1.E+07	97881	103	65	0.52	112540.5
101287	11254	0.27	0.03	0.30	88	7	0.0	2.E+07	30192	103	67	0.16	112540.5
60022	52519	0.16	0.14	0.30	52	32	0.0	1.E+07	4050	103	68	0.02	112540.5
131297	18757	0.35	0.05	0.40	114	11	0.0	2.E+07	1312	69	113	0.01	150054
138800	11254	0.37	0.03	0.40	120	7	0.0	2.E+07	3980	69	120	0.02	150054
90032	60022	0.24	0.16	0.40	78	37	0.0	2.E+07	57539	69	114	0.31	150054
135049	15005	0.36	0.04	0.40	117	9	0.0	2.E+07	260	69	116	0	150054
93784	56270	0.25	0.15	0.40	81	34	0.0	2.E+07	7735	69	112	0.04	150054
52519	97535	0.14	0.26	0.40	45	59	0.0	2.E+07	73393	69	143	0.39	150054
56270	93784	0.15	0.25	0.40	49	57	0.0	2.E+07	5705	69	137	0.03	150054
82530	67524	0.22	0.18	0.40	71	41	0.0	2.E+07	59003	69	118	0.32	150054
97535	52519	0.26	0.14	0.40	84	32	0.0	2.E+07	899	69	110	0	150054
123795	26259	0.33	0.07	0.40	107	16	0.0	2.E+07	20445	69	106	0.11	150054
45016	105038	0.12	0.28	0.40	39	64	0.0	1.E+07	337	69	159	0	150054
18757	131297	0.05	0.35	0.40	16	80	0.0	1.E+07	60121	69	214	0.32	150054
11254	138800	0.03	0.37	0.40	10	84	0.0	1.E+07	218	69	230	0	150054
127546	22508	0.34	0.06	0.40	110	14	0.0	2.E+07	1524	69	109	0.01	150054
86281	63773	0.23	0.17	0.40	75	39	0.0	2.E+07	1908	69	116	0.01	150054
75027	75027	0.20	0.20	0.40	65	46	0.0	2.E+07	61965	69	123	0.33	150054
3751	146303	0.01	0.39	0.40	3	89	0.1	1.E+07	71804	69	245	0.38	150054

116292	33762	0.31	0.09	0.40	101	21	0.0	2.E+07	50184	69	106	0.27	150054
30011	120043	0.08	0.32	0.40	26	73	0.0	1.E+07	558	69	190	0	150054
48768	101287	0.13	0.27	0.40	42	62	0.0	1.E+07	56387	69	151	0.3	150054
37514	112541	0.10	0.30	0.40	32	68	0.0	1.E+07	59199	69	175	0.32	150054
67524	82530	0.18	0.22	0.40	58	50	0.0	2.E+07	622	69	127	0	150054
120043	30011	0.32	0.08	0.40	104	18	0.0	2.E+07	1003	69	105	0.01	150054
78778	71276	0.21	0.19	0.40	68	43	0.0	2.E+07	1552	69	120	0.01	150054
108789	41265	0.29	0.11	0.40	94	25	0.0	2.E+07	53638	69	106	0.29	150054
41265	108789	0.11	0.29	0.40	36	66	0.0	1.E+07	66013	69	167	0.35	150054
15005	135049	0.04	0.36	0.40	13	82	0.0	1.E+07	36412	69	222	0.19	150054
22508	127546	0.06	0.34	0.40	19	78	0.0	1.E+07	63670	69	206	0.34	150054
0	150054	0.00	0.40	0.40	0	91	0.0	1.E+07	57546	69	253	0.31	150054
7503	142551	0.02	0.38	0.40	6	87	0.0	1.E+07	70452	69	237	0.38	150054
150054	0	0.40	0.00	0.40	130	0	0.0	2.E+07	390	69	133	0	150054
71276	78778	0.19	0.21	0.40	62	48	0.0	2.E+07	38451	69	125	0.21	150054
33762	116292	0.09	0.31	0.40	29	71	0.0	1.E+07	47697	69	182	0.26	150054
112541	37514	0.30	0.10	0.40	97	23	0.0	2.E+07	52278	69	106	0.28	150054
26259	123795	0.07	0.33	0.40	23	75	0.0	1.E+07	56304	69	198	0.3	150054
146303	3751	0.39	0.01	0.40	127	2	0.0	2.E+07	408	69	128	0	150054
60022	90032	0.16	0.24	0.40	52	55	0.0	2.E+07	8151	69	132	0.04	150054
142551	7503	0.38	0.02	0.40	123	5	0.0	2.E+07	12758	69	123	0.07	150054
101287	48768	0.27	0.13	0.40	88	30	0.0	2.E+07	101	69	108	0	150054
63773	86281	0.17	0.23	0.40	55	52	0.0	2.E+07	72222	69	129	0.39	150054
105038	45016	0.28	0.12	0.40	91	27	0.0	2.E+07	49078	69	107	0.26	150054
187568	0	0.50	0.00	0.50	162	0	0.0	3.E+07	200	57	189	0	187567.5
11254	176314	0.03	0.47	0.50	10	107	0.1	2.E+07	39913	57	309	0.21	187567.5
22508	165059	0.06	0.44	0.50	19	100	0.0	2.E+07	39513	57	285	0.21	187567.5
97535	90032	0.26	0.24	0.50	84	55	0.0	2.E+07	27985	57	173	0.15	187567.5
176314	11254	0.47	0.03	0.50	153	7	0.0	3.E+07	3073	57	173	0.02	187567.5

138800	48768	0.37	0.13	0.50	120	30	0.0	2.E+07	27448	57	153	0.15	187567.5
168811	18757	0.45	0.05	0.50	146	11	0.0	3.E+07	194	57	165	0	187567.5
48768	138800	0.13	0.37	0.50	42	84	0.0	2.E+07	38	57	230	0	187567.5
131297	56270	0.35	0.15	0.50	114	34	0.0	2.E+07	2349	57	154	0.01	187567.5
90032	97535	0.24	0.26	0.50	78	59	0.0	2.E+07	43927	57	177	0.24	187567.5
135049	52519	0.36	0.14	0.50	117	32	0.0	2.E+07	83	57	154	0	187567.5
172562	15005	0.46	0.04	0.50	149	9	0.0	3.E+07	172	57	168	0	187567.5
93784	93784	0.25	0.25	0.50	81	57	0.0	2.E+07	266	57	175	0	187567.5
161308	26259	0.43	0.07	0.50	140	16	0.0	2.E+07	4583	57	158	0.02	187567.5
120043	67524	0.32	0.18	0.50	104	41	0.0	2.E+07	35367	57	160	0.19	187567.5
52519	135049	0.14	0.36	0.50	45	82	0.0	2.E+07	29969	57	223	0.16	187567.5
56270	131297	0.15	0.35	0.50	49	80	0.0	2.E+07	41422	57	215	0.22	187567.5
41265	146303	0.11	0.39	0.50	36	89	0.0	2.E+07	48727	57	246	0.26	187567.5
82530	105038	0.22	0.28	0.50	71	64	0.0	2.E+07	414	57	181	0	187567.5
165059	22508	0.44	0.06	0.50	143	14	0.0	2.E+07	1015	57	162	0.01	187567.5
123795	63773	0.33	0.17	0.50	107	39	0.0	2.E+07	1835	57	158	0.01	187567.5
33762	153805	0.09	0.41	0.50	29	94	0.0	2.E+07	49020	57	262	0.26	187567.5
3751	183816	0.01	0.49	0.50	3	112	0.0	2.E+07	6837	57	325	0.04	187567.5
45016	142551	0.12	0.38	0.50	39	87	0.0	2.E+07	45903	57	238	0.25	187567.5
187568	0	0.50	0.00	0.50	162	0	0.0	3.E+07	200	57	189	0	187567.5
153805	33762	0.41	0.09	0.50	133	21	0.0	2.E+07	15395	57	152	0.08	187567.5
127546	60022	0.34	0.16	0.50	110	37	0.0	2.E+07	26967	57	156	0.14	187567.5
112541	75027	0.30	0.20	0.50	97	46	0.0	2.E+07	29299	57	164	0.16	187567.5
86281	101287	0.23	0.27	0.50	75	62	0.0	2.E+07	38167	57	179	0.2	187567.5
75027	112541	0.20	0.30	0.50	65	68	0.0	2.E+07	36172	57	185	0.19	187567.5
116292	71276	0.31	0.19	0.50	101	43	0.0	2.E+07	581	57	162	0	187567.5
78778	108789	0.21	0.29	0.50	68	66	0.0	2.E+07	36567	57	183	0.2	187567.5
30011	157557	0.08	0.42	0.50	26	96	0.0	2.E+07	41239	57	270	0.22	187567.5
67524	120043	0.18	0.32	0.50	58	73	0.0	2.E+07	67	57	193	0	187567.5

157557	30011	0.42	0.08	0.50	136	18	0.0	2.E+07	129	57	155	0	187567.5
105038	82530	0.28	0.22	0.50	91	50	0.0	2.E+07	446	57	169	0	187567.5
108789	78778	0.29	0.21	0.50	94	48	0.0	2.E+07	9465	57	167	0.05	187567.5
146303	41265	0.39	0.11	0.50	127	25	0.0	2.E+07	32793	57	152	0.18	187567.5
37514	150054	0.10	0.40	0.50	32	91	0.0	2.E+07	46183	57	254	0.25	187567.5
15005	172562	0.04	0.46	0.50	13	105	0.1	2.E+07	47091	57	301	0.25	187567.5
150054	37514	0.40	0.10	0.50	130	23	0.0	2.E+07	20955	57	152	0.11	187567.5
26259	161308	0.07	0.43	0.50	23	98	0.0	2.E+07	37	57	278	0	187567.5
183816	3751	0.49	0.01	0.50	159	2	0.0	3.E+07	251	57	184	0	187567.5
180065	7503	0.48	0.02	0.50	156	5	0.0	3.E+07	735	57	178	0	187567.5
71276	116292	0.19	0.31	0.50	62	71	0.0	2.E+07	34637	57	188	0.19	187567.5
60022	127546	0.16	0.34	0.50	52	78	0.0	2.E+07	46670	57	207	0.25	187567.5
142551	45016	0.38	0.12	0.50	123	27	0.0	2.E+07	29775	57	153	0.16	187567.5
101287	86281	0.27	0.23	0.50	88	52	0.0	2.E+07	40133	57	171	0.21	187567.5
63773	123795	0.17	0.33	0.50	55	75	0.0	2.E+07	44367	57	200	0.24	187567.5
7503	180065	0.02	0.48	0.50	6	110	0.1	2.E+07	28783	57	317	0.15	187567.5
18757	168811	0.05	0.45	0.50	16	103	0.1	2.E+07	48255	57	293	0.26	187567.5
48768	176314	0.13	0.47	0.60	42	107	0.0	2.E+07	24805	46	310	0.13	225081
37514	187568	0.10	0.50	0.60	32	114	0.0	2.E+07	18	46	333	0	225081
60022	165059	0.16	0.44	0.60	52	100	0.0	2.E+07	32681	46	286	0.17	225081
135049	90032	0.36	0.24	0.60	117	55	0.0	3.E+07	7774	46	215	0.04	225081
93784	131297	0.25	0.35	0.60	81	80	0.0	2.E+07	26626	46	238	0.14	225081
176314	48768	0.47	0.13	0.60	153	30	0.0	3.E+07	10004	46	199	0.05	225081
165059	60022	0.44	0.16	0.60	143	37	0.0	3.E+07	12406	46	200	0.07	225081
138800	86281	0.37	0.23	0.60	120	52	0.0	3.E+07	13404	46	213	0.07	225081
97535	127546	0.26	0.34	0.60	84	78	0.0	2.E+07	32707	46	236	0.17	225081
86281	138800	0.23	0.37	0.60	75	84	0.0	2.E+07	25	46	242	0	225081
168811	56270	0.45	0.15	0.60	146	34	0.0	3.E+07	436	46	200	0	225081
127546	97535	0.34	0.26	0.60	110	59	0.0	3.E+07	25271	46	219	0.14	225081

90032	135049	0.24	0.36	0.60	78	82	0.0	2.E+07	26	46	240	0	225081
131297	93784	0.35	0.25	0.60	114	57	0.0	3.E+07	313	46	217	0	225081
157557	67524	0.42	0.18	0.60	136	41	0.0	3.E+07	9647	46	202	0.05	225081
52519	172562	0.14	0.46	0.60	45	105	0.0	2.E+07	23594	46	302	0.13	225081
41265	183816	0.11	0.49	0.60	36	112	0.0	2.E+07	18	46	326	0	225081
120043	105038	0.32	0.28	0.60	104	64	0.0	3.E+07	39	46	223	0	225081
172562	52519	0.46	0.14	0.60	149	32	0.0	3.E+07	75	46	199	0	225081
161308	63773	0.43	0.17	0.60	140	39	0.0	3.E+07	880	46	201	0	225081
78778	146303	0.21	0.39	0.60	68	89	0.0	2.E+07	32955	46	253	0.18	225081
153805	71276	0.41	0.19	0.60	133	43	0.0	3.E+07	327	46	204	0	225081
150054	75027	0.40	0.20	0.60	130	46	0.0	3.E+07	11550	46	206	0.06	225081
123795	101287	0.33	0.27	0.60	107	62	0.0	3.E+07	17639	46	221	0.09	225081
112541	112541	0.30	0.30	0.60	97	68	0.0	2.E+07	27319	46	227	0.15	225081
82530	142551	0.22	0.38	0.60	71	87	0.0	2.E+07	30686	46	247	0.16	225081
71276	153805	0.19	0.41	0.60	62	94	0.0	2.E+07	34949	46	266	0.19	225081
116292	108789	0.31	0.29	0.60	101	66	0.0	3.E+07	17457	46	225	0.09	225081
75027	150054	0.20	0.40	0.60	65	91	0.0	2.E+07	34561	46	260	0.18	225081
142551	82530	0.38	0.22	0.60	123	50	0.0	3.E+07	192	46	211	0	225081
183816	41265	0.49	0.11	0.60	159	25	0.0	3.E+07	1381	46	201	0.01	225081
67524	157557	0.18	0.42	0.60	58	96	0.0	2.E+07	25736	46	273	0.14	225081
105038	120043	0.28	0.32	0.60	91	73	0.0	2.E+07	31	46	232	0	225081
146303	78778	0.39	0.21	0.60	127	48	0.0	3.E+07	551	46	208	0	225081
108789	116292	0.29	0.31	0.60	94	71	0.0	2.E+07	1609	46	229	0.01	225081
187568	37514	0.50	0.10	0.60	162	23	0.0	3.E+07	5877	46	204	0.03	225081
180065	45016	0.48	0.12	0.60	156	27	0.0	3.E+07	10116	46	199	0.05	225081
63773	161308	0.17	0.43	0.60	55	98	0.0	2.E+07	20	46	279	0	225081
101287	123795	0.27	0.33	0.60	88	75	0.0	2.E+07	30617	46	234	0.16	225081
56270	168811	0.15	0.45	0.60	49	103	0.0	2.E+07	32921	46	294	0.18	225081
45016	180065	0.12	0.48	0.60	39	110	0.0	2.E+07	9697	46	318	0.05	225081

97535	165059	0.26	0.44	0.70	84	100	0.0	3.E+07	21426	34	300	0.11	262594.5
75027	187568	0.20	0.50	0.70	65	114	0.0	3.E+07	8	34	339	0	262594.5
86281	176314	0.23	0.47	0.70	75	107	0.0	3.E+07	13330	34	319	0.07	262594.5
131297	131297	0.35	0.35	0.70	114	80	0.0	3.E+07	9335	34	280	0.05	262594.5
172562	90032	0.46	0.24	0.70	149	55	0.0	3.E+07	406	34	257	0	262594.5
176314	86281	0.47	0.23	0.70	153	52	0.0	3.E+07	11614	34	255	0.06	262594.5
123795	138800	0.33	0.37	0.70	107	84	0.0	3.E+07	21	34	284	0	262594.5
138800	123795	0.37	0.33	0.70	120	75	0.0	3.E+07	7793	34	276	0.04	262594.5
165059	97535	0.44	0.26	0.70	143	59	0.0	3.E+07	9597	34	261	0.05	262594.5
135049	127546	0.36	0.34	0.70	117	78	0.0	3.E+07	13379	34	278	0.07	262594.5
168811	93784	0.45	0.25	0.70	146	57	0.0	3.E+07	53	34	259	0	262594.5
127546	135049	0.34	0.36	0.70	110	82	0.0	3.E+07	256	34	282	0	262594.5
116292	146303	0.31	0.39	0.70	101	89	0.0	3.E+07	17593	34	288	0.09	262594.5
90032	172562	0.24	0.46	0.70	78	105	0.0	3.E+07	17205	34	313	0.09	262594.5
78778	183816	0.21	0.49	0.70	68	112	0.0	3.E+07	8	34	332	0	262594.5
157557	105038	0.42	0.28	0.70	136	64	0.0	3.E+07	37	34	265	0	262594.5
108789	153805	0.29	0.41	0.70	94	94	0.0	3.E+07	16071	34	292	0.09	262594.5
187568	75027	0.50	0.20	0.70	162	46	0.0	3.E+07	3122	34	248	0.02	262594.5
161308	101287	0.43	0.27	0.70	140	62	0.0	3.E+07	6359	34	263	0.03	262594.5
153805	108789	0.41	0.29	0.70	133	66	0.0	3.E+07	6229	34	267	0.03	262594.5
150054	112541	0.40	0.30	0.70	130	68	0.0	3.E+07	8199	34	269	0.04	262594.5
120043	142551	0.32	0.38	0.70	104	87	0.0	3.E+07	14594	34	286	0.08	262594.5
112541	150054	0.30	0.40	0.70	97	91	0.0	3.E+07	19229	34	290	0.1	262594.5
142551	120043	0.38	0.32	0.70	123	73	0.0	3.E+07	28	34	273	0	262594.5
180065	82530	0.48	0.22	0.70	156	50	0.0	3.E+07	154	34	252	0	262594.5
183816	78778	0.49	0.21	0.70	159	48	0.0	3.E+07	880	34	250	0	262594.5
105038	157557	0.28	0.42	0.70	91	96	0.0	3.E+07	13330	34	295	0.07	262594.5
146303	116292	0.39	0.31	0.70	127	71	0.0	3.E+07	30	34	271	0	262594.5
101287	161308	0.27	0.43	0.70	88	98	0.0	3.E+07	5	34	297	0	262594.5

93784	168811	0.25	0.45	0.70	81	103	0.0	3.E+07	18036	34	306	0.1	262594.5
82530	180065	0.22	0.48	0.70	71	110	0.0	3.E+07	1531	34	326	0.01	262594.5
135049	165059	0.36	0.44	0.80	117	100	0.0	3.E+07	4881	23	354	0.03	300108
123795	176314	0.33	0.47	0.80	107	107	0.0	3.E+07	3953	23	360	0.02	300108
112541	187568	0.30	0.50	0.80	97	114	0.0	3.E+07	2	23	367	0	300108
168811	131297	0.45	0.35	0.80	146	80	0.0	3.E+07	3965	23	334	0.02	300108
161308	138800	0.43	0.37	0.80	140	84	0.0	3.E+07	3	23	338	0	300108
176314	123795	0.47	0.33	0.80	153	75	0.0	3.E+07	3300	23	329	0.02	300108
172562	127546	0.46	0.34	0.80	149	78	0.0	3.E+07	5217	23	332	0.03	300108
138800	161308	0.37	0.43	0.80	120	98	0.0	3.E+07	2	23	351	0	300108
165059	135049	0.44	0.36	0.80	143	82	0.0	3.E+07	3	23	336	0	300108
116292	183816	0.31	0.49	0.80	101	112	0.0	3.E+07	2	23	365	0	300108
153805	146303	0.41	0.39	0.80	133	89	0.0	3.E+07	7207	23	343	0.04	300108
127546	172562	0.34	0.46	0.80	110	105	0.0	3.E+07	5482	23	358	0.03	300108
187568	112541	0.50	0.30	0.80	162	68	0.0	4.E+07	1586	23	323	0.01	300108
146303	153805	0.39	0.41	0.80	127	94	0.0	3.E+07	3634	23	347	0.02	300108
157557	142551	0.42	0.38	0.80	136	87	0.0	3.E+07	3736	23	340	0.02	300108
150054	150054	0.40	0.40	0.80	130	91	0.0	3.E+07	6037	23	345	0.03	300108
142551	157557	0.38	0.42	0.80	123	96	0.0	3.E+07	3	23	349	0	300108
180065	120043	0.48	0.32	0.80	156	73	0.0	3.E+07	5	23	327	0	300108
183816	116292	0.49	0.31	0.80	159	71	0.0	4.E+07	5	23	325	0	300108
131297	168811	0.35	0.45	0.80	114	103	0.0	3.E+07	5689	23	356	0.03	300108
120043	180065	0.32	0.48	0.80	104	110	0.0	3.E+07	2	23	362	0	300108
161308	176314	0.43	0.47	0.90	140	107	0.0	4.E+07	85	11	417	0	337621.5
172562	165059	0.46	0.44	0.90	149	100	0.0	4.E+07	439	11	410	0	337621.5
150054	187568	0.40	0.50	0.90	130	114	0.0	4.E+07	2	11	423	0	337621.5
176314	161308	0.47	0.43	0.90	153	98	0.0	4.E+07	2	11	408	0	337621.5
165059	172562	0.44	0.46	0.90	143	105	0.0	4.E+07	184	11	415	0	337621.5
153805	183816	0.41	0.49	0.90	133	112	0.0	4.E+07	2	11	421	0	337621.5

183816	153805	0.49	0.41	0.90	159	94	0.0	4.E+07	33	11	404	0	337621.5
187568	150054	0.50	0.40	0.90	162	91	0.0	4.E+07	258	11	401	0	337621.5
180065	157557	0.48	0.42	0.90	156	96	0.0	4.E+07	3	11	406	0	337621.5
168811	168811	0.45	0.45	0.90	146	103	0.0	4.E+07	565	11	412	0	337621.5
157557	180065	0.42	0.48	0.90	136	110	0.0	4.E+07	2	11	419	0	337621.5
187568	187568	0.50	0.50	1.00	162	114	0.0	4145+I2:I 7442384	0	0	480	0	375135