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Assessment of Reverse Osmosis Process for Brackish Water Desalination in the Jordan Valley

MSc. Thesis By

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Dedication

To the spirit of our prophet Mohammed

Blessings and Peace be upon him

To my son, friend and soulmate (Osama)

To my mother& father

To my brother (Omar), and sister (Balqees)

To my brother's family (Mhammad , Israa ,& their little angle (Mustafa))

To my husband (Mohammad)

To all of them,

I dedicate this work

Thank you all

For being a great source of support, inspiration and encouragement

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الاقرار

انا الموقع أدناه مقدم الرسالة التي تحمل عنوان :

Assessment of Reverse Osmosis Process for Brackish Water Desalination in the Jordan Valley

أقر بأن ما اشتملت عليه هذه الرسالة انما هي نتاج جهدي الخاص، باستثناء ما تمت الاشارة اليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أي درجة علمية أو بحث علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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Date: **التاريخ: 12 / 2017/9**

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List of Abbreviations:

ARIJ	Applied Research Institute -Jerusalem
BW	Brackish Water
BWRO	Brackish Water Reverse Osmosis
BWRO-PV	Brackish Water Reverse Osmosis powered by PV cells
CO_2	Carbon Dioxide
CO	Carbon Monoxide
Cl	Chlorine
COE	Cost of Energy ($/kWh)
DG	Diesel Generator
$/yr	Dollar per year
ED	Electro Dialysis
ERC	Energy Research Centre
GES	General Environment Services
GIS	Geographical Information System
GHG	Green House Gasses
GW	Ground Water
HF	Hollow Fiber
HFF	Hollow Fine Fiber
HOMER	Hybrid Optimization of Multiple Energy Resources
ICA	Incremental Cost Analysis
IR	Interest rate %
IDA	International Desalination Association
IEC	Israeli Electrical Corporation
JDECO	Jerusalem District Electricity Co
Kg/yr	Kilogram per year
kVA	kilo Volt Amber
kWh	kilo Watt hour
l/c/d	liter per capita per day
LF	Load Following
MVC	Mechanical Vapor Compression
MEDRC	Middle East Desalination Research Centre
MENA	Middle East North Africa
MED	Multi Effect Distillation
MSF	Multi Stage Flash
MED	Multi Effect Flash

MCM/yr	Million Cubic Meter per year
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory
Na	(form latin Natrium) Sodium
NPC	Net Present Cost
NO_X	Nitrogen Oxides
NEDCO	Northern Electric Distribution Company
OSW	Office of Saline Water
O&M	Operating and Maintenance
PCBS	Palestinian Central Bureau of Statistics
PNA	Palestinian National Authority
PWA	Palestinian Water Authority
ppm	part per million
PV	Photovoltaic
pH	potential of Hydrogen
REs	Renewable Energies
RO	Reverse Osmosis
SW	Sea Water
SE	Solar Energy
SO_2	Sulfur Dioxide
TVC	Thermal Vapor Compression
TDS	Total Dissolved Salts in ppm
TNPC	Total Net Present Cost
UAE	United Arab Emirates
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
US$	United States Dollar
USA	United States of America
VC	Vapor Compression
W_P	Watt Photovoltaic

Assessment of Reverse Osmosis Process for Brackish Water Desalination in the Jordan Valley

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Abstract

This thesis investigates the assessment of three suggested energy systems that power an existing desalination unit, which are: Photovoltaic (PV) system, Diesel Generator (DG) system, and hybrid powered system. All systems use Reverse Osmosis (RO) technology to desalinate Brackish Water (BWRO) in Az Zubaidat desalination unit located in the Jordan Valley in the West Bank.

A general framework was followed; a cost analysis procedure was conducted which analyzed the economic viability of the systems using Hybrid Optimization of Multiple Energy Resources (HOMER Pro) a software program developed by the U.S National Renewable Energy Laboratory.

Three different scenarios were analyzed economically and environmentally using HOMER Pro ,the third scenario was to operate the system for twice the time as it is using hybrid system consist of Photovoltaic/Battery/diesel generator (PV/Battery/DG) with different sensitivity variables which gave an optimal configuration with the least

COE of $0.424/kWh when the fuel price is minimum(1.3$/L) and the solar scaled average is maximum(8.91kWh/m^2/day) , for both 6 and zero Interest Rate(IR) ,the best configuration compromises of 10 kW diesel generator, a 27.2 kW of PV modules and 24 batteries of 1.75 kWh capacities, and the system has 70% renewable energy fraction with a 68% GHG reduction.

We recommend that policy makers should take into consideration ccombining both renewable and conventional energies with desalination units; in addition, designing such units should be an integrated process between both engineers and economists.

Chapter One

Introduction

Chapter One

Introduction

1.1General background

The global fresh water sources are being insufficient and having a shortage problem; (mainly because of climate change, droughts, and contamination in water resources), at the same time global demand for fresh water is vastly growing due to population growth and urbanization, expansion in both industrial and tourism sector. That among other reasons caused the need for new applications and technologies for extracting fresh water from both surface and ground water (Lazad, 2007).

Water desalination may be the solution to the shortage and scarcity problems (Karagiannis & Soldatos, 2008), conventional desalination which uses fuels or fossil fuels as its energy supply (Miller, et al., 2015) can't be implemented in arid, semi-arid and remote areas as stand-alone system because no or very few electrical power grid connections are available, and if existed, they are very expensive (Mathioulakis, et al., 2007).

The best solution for these regions is desalination using Renewable Energies (REs) desalination systems (which are available in nature, environmental friendly, unexhausted such as: solar, wind, geothermal and biomass energy, the most globally used types of energy are wind and solar (Mathioulakis, et al., 2007).

Brackish water (BW) is defined as the water which have Total Dissolved Solid (TDS) of an average about (1500 –15,000 ppm), and constitutes a quarter of the global water Brackish water primary is a result of contact between freshwater sources and seawater intrusion (Fritzmann, et al., 2007).

Desalination of brackish water using REs may partly addresses the majority problems of conventional desalination that in particular sustainability problem and adverse environmental impact problem. It is expected that in the coming years the cost and economic efficiency of desalination of saline water will both be reasonable knowing that the price of fuel is significantly increasing (Buonomenna & Bae, 2015).

The combination of REs and desalination systems can be categorized into two main processes: Thermal processes such as Multi Effect Distillation (MED), Vapor Compression (VC), and electromechanical processes such as: Reverse Osmosis (RO) and Electro Dialysis(ED) (Charcosset, 2009; Gude, 2015).

The main predominant and reliable electromechanical process is RO which is defined as a non-phase change operation where a semi-permeable membrane (allowing water to pass through but not the salts to pass through the membrane (Buonomenna & Bae, 2015).The main disadvantage of running RO system using fuel is the high price of the end product which may be overcome by combining it with the appropriate type of REs (Garg & Joshi, 2014).

Palestine has a similar situation like the rest of the world regarding water sources shortage, water shortage is aggravated to the increase in both population and consumption of water (Abu Zahra, 2001).

Cost analysis of brackish water reverse osmosis powered by photovoltaic cells (BWRO) desalination plant has become a very important concern worldwide especially in Middle East and North Asia (MENA) region (Banat & Jwaied, 2008). This study is considered to be one of the first studies regarding conducting a cost and sensitivity analysis; in addition to optimization of hybrid renewable energy BWRO system in Palestine.

Cost studies have done a remarkable work in investigation and optimization of hybrid renewable energy for BWRO desalination systems. This study aims to analyze the feasibility of both BWRO stand-alone system powered by PV cells and hybrid RE unit located in Az Zubeidat village, by first assessing the water resources with the corresponding demand, then assessing the renewable energy sources available in order to decide optimal renewable energy sources suitable for desalination using RO technique, finally developing a reliable cost analysis approach for desalination system.

1.2. Research objectives:

The main objectives of this research are:

1) Assess the BWRO desalination unit powered by different types of energy located in the Jordan Valley (Az Zubeidat village).
2) Assess the optimal type of RE that is available in Palestine.
3) Optimize the BWRO hybrid powered system (for the least COE) located in the Jordan Valley.

1.3. Research problem:

Desalination using conventional energy is an energy intensive process, which has many problems including: the bad impact on the environment, and the difficulty of implementing it in remote areas; at the same time using REs in desalination which are environmental friendly may face both fluctuation of energy supply, resulting in intermittent delivery of power and causing problems if supply continuity is required.

1.4. Research questions

1) What is the optimal scenario of an energy system powering a BWRO desalination plant located in the Jordan Valley?

2) How do both IR and diesel price affect the COE required for hybrid powered BW desalination system?

3) Is a BWRO desalination unit cost effective if it is powered by hybrid energy system?

1.5. Motivations:

The following are the main motivations resulted in caring out this thesis:

1) Water supply in Palestine is suffering from stress water shortage.
2) West bank main recourses of water are mainly Ground Water (GW) from mountain aquifer, 80% of it is derived by Israel, and so we need a new source of fresh water in the area.
3) According to PWA data bank, TDS in west bank's wells are increasing especially in the Jordan Valley area. Moreover; 10-15

MCM /yr were BW. This means that desalination of brackish water will be needed in the near future in order to get fresh water.

1.6 Study area:

1.6.1 Location and population

The Jordan Valley is part of the Jordan Rift, which is a long depression of the earth's crust that extends from Turkey in the north to the Red Sea in the south, passing through Syria, Lebanon, Jordan and Palestine. The Jordan Valley is located in the eastern part of the West Bank; it is bounded by the Jordan River, which forms the eastern border of Palestine with Jordan, in the east (Da'as and Walraevens, 2013).

The Jordan Valley area covers about 1,611,723 dunams, constituting 28.8 percent of the total area of the West Bank (Yael, 2011). According PCBS, 64,451 Palestinians lived in the Jordan Valley in 2009, which represents 2.6 percent of the Palestinian population of the West Bank (PCBS, 2010).

1.6.2 Case study (Az Zubeidat BWRO desalination unit)

The Following table summarizes background data for the case study:

Table1.1: background Data (ARIJ (Applied Research Institute - Jerusalem), 2016)

latitude	35° 31.8' L
Longitude	32°10.3' N
Location	about 35.4 km north of Jericho City
Elevation(in meter)	275 below sea level
Area of the village(Dunom)	4123(3944 agricultural area)
Water wells	3 brackish wells
Total population	1569 (PCSB, 2015)
Educational Facilities	2 school buildings
Medical Facilities	5
Annual average solar radiation	5.37 kWh/m^2
Main Occupation	Agriculture

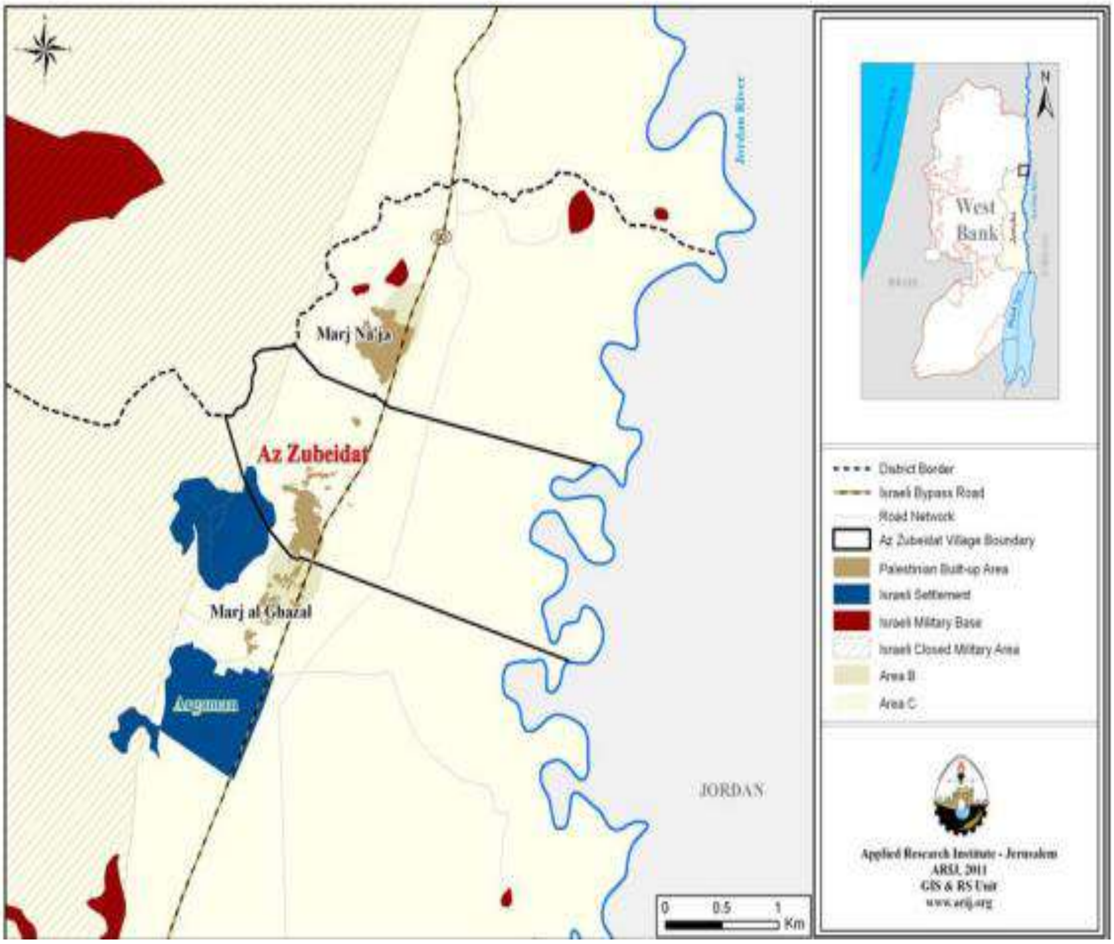

Figure1. 1: Map of Al -Zubeidat (Location &Border).

Az Zubeidat desalination unit description:

Az Zubeidat desalination unit was constructed in Az Zubeidat village; the RO unit was implemented by both Al-Najah National University and the local contractor (General Environment Services - GES) with the Palestinian Water Authority (PWA) as supervisor and Middle East Desalination Research Center MEDRC as a donor (An Najah National University, 2012; Bsharat, 2014).

The desalination unit was established with solar system as the power source so it can serve the residents of Az Zubeidat village with about 10 m^3/day, the village's wells has brackish water which can't be used as drinking water; However the water was pumped from one well to a tank built specifically with capacity of 200 cubic meter to store the feed water of the unit (Yousef, 2013; Bsharat, 2014).

Reverse osmosis unit is a two-stage process; the first stage contains two membranes and the rest for the second stage, the unit contains three vessels connected in series (each vessel consists of two RO membranes in series), this means that there are six RO membranes in unit, spiral wound FILMTEC LE-4040 was selected and used as membrane type (An Najah National University, 2012 ; Yousef, 2013).

2. Methodology

In order to achieve the objectives of the proposed study a general framework will be followed:

1) **Data Collection**:

Data will be obtained from:

1) Geographical Information System (GIS) database will be required to analyze temporal and spatial data; database will include the available REs potential (mainly solar) for the selected study area, in addition to the brackish water quality in West Bank data(Cl, Na,… etc),in order to get a suitable brackish water location map.
2) Water supply and demand data.
3) Finally, data from Az Zubeidat desalination unit (the case study) will be collected, analyzed and compared to the analyzed results.

2) Economic Analysis:

In this research, the BWRO system was analyzed economically using HOMER Pro® which is a microgrid software developed by the U.S National Renewable Energy Laboratory(NREL).

HOMER nests three powerful tools (simulation, optimization, and sensitivity analysis) in one software product, so that engineering and economics work side by side.

HOMER Pro is considered the global standard for optimizing microgrids design in all sectors; it navigates the complexities of building cost effective and reliable microgrids that combines both conventional and renewable resources.

The software is a decision support tool which makes simulation of an existing energy system powering desalination unit easy; In addition, deciding the optimal configuration of the power system.

HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations as there is large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult.

The best possible or optimal system configuration is the one that satisfies the user-specified constrains at the lowest Total Net Present Cost (TNPC) (HOMER, 2016).

1.6.3 Water recourses in Palestine

1) Groundwater: as Figure 1.2 shows, three groundwater basins (Western, Eastern and Northeastern) represent the groundwater aquifer system in the West Bank. Part of Costal Aquifer exists in Gaza Strip. GW represents 95% of Palestinian water supply.
2) Surface Water : (Jordan River , flood Wadis & Dead Sea)

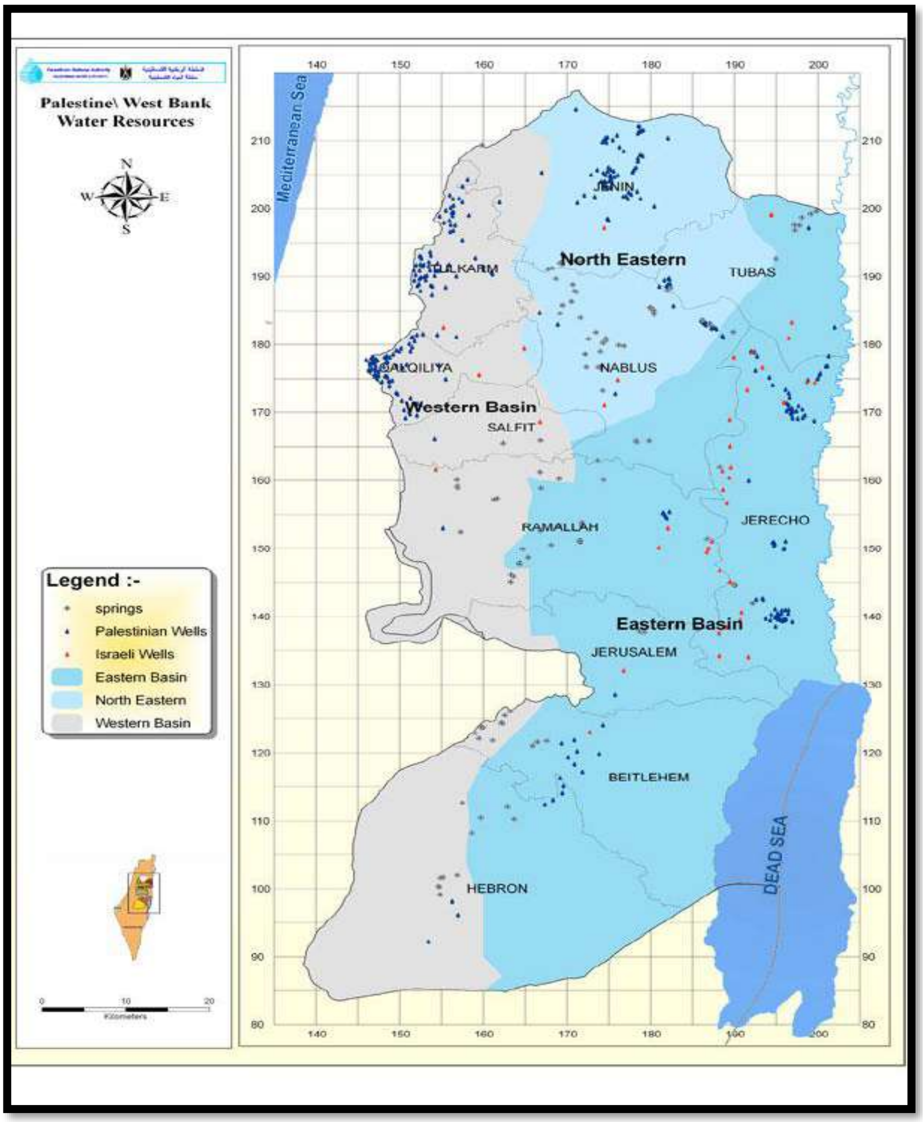

Figure 1. 2: Water Resources in west bank (basins, wells, and springs)1

Available water:

According to Palestinian Central Bureau of Statistics (PCBS), the annual available water quantity in Palestine for year 2015 was 365.3 MCM (PCSB, 2015).

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[1] http://www.pwa.ps/ar_page.aspx?id=FMzzH4a1344826989aFMzzH4

1.6.4 Energy sources in Palestine (electricity, potential REs, & diesel).

Energy situation:

Fossil fuels and REs represent the vast majority of energy sources available in Palestine (see Figure 1.3). Fossil fuels include diesel, liquefied petroleum gas, and gasoline which are mainly used for transportation, heating, and generating electricity (diesel generators). They represent about 78 % of the primary energy source (43087Tera joules).In addition; REs in Palestine represents 22% of the primary energy source (11,8071Tera joules) can be in the form solar energy (which represent 46% of total REs supply in Palestine, basically used for heating, in household solar water heaters), and biomass energy (which represent 54% of the total RE supply in Palestine divided into wood and olive cake which are used in heating (PCSB, 2015).

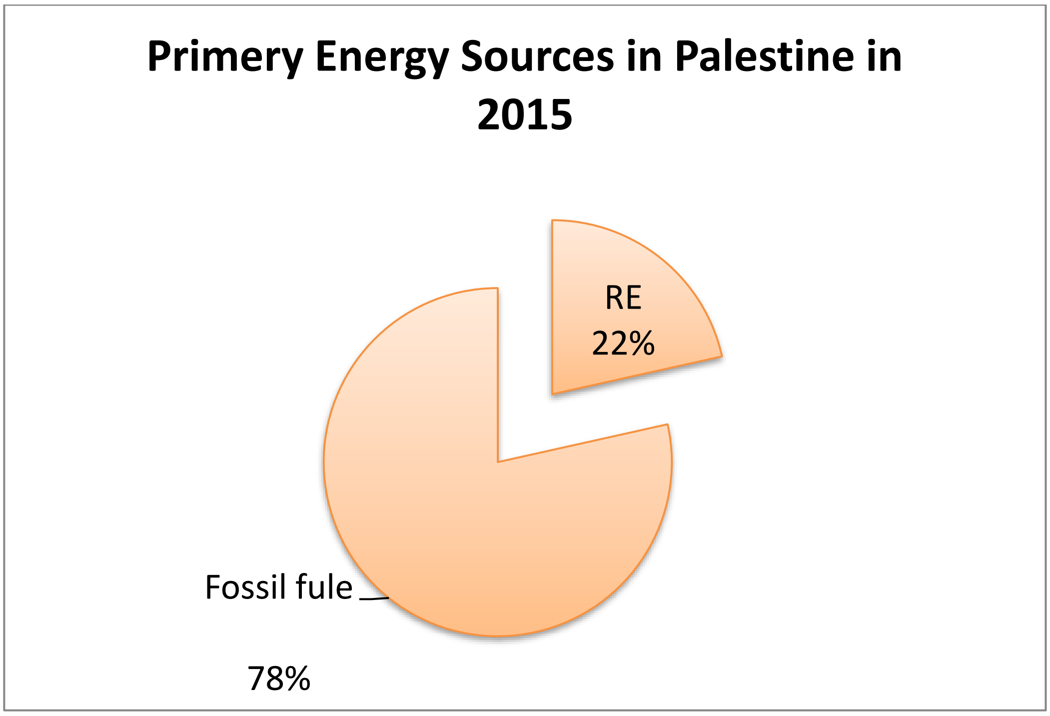

Figure 2. 3: Primary energy sources in Palestine (adapted from (PCSB, 2015)).

Regarding energy supply, WB depends entirely on Israel; the whole quantity of fossil fuels is purchased from Israel (PCSB, 2015).If one took a look to the Palestinian energy system he will fine that there are two main problems, the dependence on the Israeli side power generation and pricing as well as planning is considered the most complicated one, the second problem is Palestinian energy suppliers (mainly electricity) have large debt to the Israeli Electrical Corporation (IEC), these financial problems largely because of two main factors: erroneous billing and theft of electricity.

Although a field of natural gas was discovered in Gaza Strip in 2000 which was known as Gaza Marine field, it is not operating at full load due to infrastructural and technical issues (Boersma & Sachs, 2015).

4.3.2: Electricity sector:

Separated electrical grids (which are considered the distribution networks) are the fundamental method of connecting municipalities in Palestine; Palestinian electricity companies get a voltage of 22 or 33 kV overhead lines from Israel Corporation Company ICE, then it is distributed to the consumers. In addition, there are to more suppliers to the Palestinian electricity, the first one is in Jericho-West Bank from the Jordanian side, while the other one is in Rafah- Gaza Strip from the Egyptian side (Palestinian National Athourity [PNA], 2011).

Regarding electricity suppliers, in West Bank, there are four main companies providing electricity: Jerusalem District Electric Company (JDECO), and Southern Electricity Company (The Hebron Electric Power

Company (HEPCO)), Northern Electric Distribution Company (NEDCO) and Tubas District Electric Company (MNSSD, 2007).

Table 4.6 shows the details of monthly electricity purchased by electricity companies from both Jordan and Israel in 2015, In that year the total imported electricity to West Bank was about 4,281,615 MWh most of that (4,240,225MWh) is imported from the Israeli side and small quantity of 41,390 MWh from Jordanian network.

4.3.4: REs Sector:

The attention to the Renewable energies in Palestine can be attributed to many reasons; such as: the fast technological developments, betterment in levels of living, and growing population density (Abu-Madi & Abu Rayyan, 2013).In addition, climate change issues and fossil fuel depletion play a huge role in finding alternative (renewable) energy sources(Mezher, et al., 2012).

Solar energy in Palestine:

According to Energy Research Centre (ERC), there is a high solar energy potential in Palestine, where the daily average of solar radiation intensity on horizontal surface is 5.4 kW h/m^2, while the total annual sunshine hours amounts to about 3000 (Mahmoud & Ibrik, 2006).

Wind potential:

Generally, regarding Gaza Strip the wind speeds is not considerable at any level; the central parts of the West Bank have the highest recorded wind speeds (De Meij, et al., 2016).These location which are mainly mountains with elevation of about 1000 m above sea level, in Nablus, Ramallah and Hebron governorates have wind speed above 5 m/s and the potential of wind energy of about 600 kwh/m^2 (Juaidi , Montoya, Ibrik, & Manzano-Agugliaro, 2016).The Jordan Valley, represented in Jericho, is classified as a low wind speeds region which has annual average of about 2–3 m/s (Basel & Yaseen, 2007). Recently; Energy Research Centre (ERC) at An Najah National University has been measuring both the speed and direction of wind using modern meteorological stations equipped with automatic data loggers (Kitaneha & Alsamamraa, 2012).

Chapter Two

Literature Review

Chapter Two

Literature Review

2.1 Water desalination definition.

There is no unique definition for desalination, it might be defined as any treatment process that separate salts from water (Buros, 2002). In another definition; it is an energy consuming process that basically a separation technique producing freshwater from salt water (either sea or brackish water) using membranes or thermal processes, the salts are concentrated in the brine stream (EL-Dessouky&Ettouny,2002). In another words desalination is defined as decreasing the concentration of dissolved solids using a separating process (Watson, et al., 2003). Moreover; Desalination had been defined as process which eliminates salts among other dissolved minerals mainly from brackish water, seawater or treated wastewater (Cooley, et al., 2006). In a similar definition; Charcosset (2009) defined desalination as a process for producing potable water from saline water via a technique such as thermal or membrane.

2.2. Historical background of water desalination using REs.

It is very hard to determine the precise time that mankind recognized and used the renewable energies either as subversive or useful forces (Belessiotis & Delyannis, 2000). At the beginning human dependence was on sun or Solar Energy (SE) (as known nowadays) in addition to wood products which correspond to biomass energy nowadays. Concerning wind energy use was limited mainly for sailing ships as kinetic energy. At that time today's conventional energy sources, such as fossil fuels and gas, were totally unknown (Belessiotis& Delyannis, 2000; Delyannis, 2003).

2.2.1. SE in water desalination.

Solar radiation "sun" is the oldest form of energy that humanity used, furthermore, the most important one (Belessiotis & Delyannis, 2000). Up to 1800 fishermen practiced desalination by separating salt from seawater which produce potable water using evaporation, although they did not know the exact technique they were using (Belessiotis & Delyannis,2000; El-Dessouky&Ettouney,2002).There were no remarkable thoughts or applications of desalination using solar energy until medieval period.

In the late eighteenth century, the first large scale distillation solar plant was designed and built (Delyannis, 2003). At the beginning of the nineteenth century industry of desalination began mainly because the oil industry was begun (El-Dessouky & Ettouney, 2002).

The rapid increase in population and the tremendous industrial development after World War II (1939-1945) led to global water shortage refocused on fresh water sources problem (Buros, 2000; Delyannis, 2003).

In the mid-nineteenth century, the Office of Saline Water (OSW) was founded with a specific mission to finance research on desalination (Delyannis, 2003). During the sixties new and large Multi Stage Flash (MSF) plants were constructed in Shuwaikh, Kuwait and Guernsey (El-Dessouky &Ettouney, 2002).

In the beginning of the seventies, membrane units entered the world of desalination (Buros, 2000). Commercial grade RO membranes were developed, the permeator used for both brackish and sea water desalination was invented using Hollow Fine Fibers (HFF), in 1975 Dow Chemical Company had presented cellulose triacetate hollow fiber permeator, few years later a standard Multi Stage Flash Unit was constructed, during that period the Japanese manufacturing companies were leading in the MSF unit construction (El-Dessouky &Ettouney, 2002).

Desalination technology became a commercial business by 1980’s, firstly a low temperature multiple effect evaporation units were designed and operated. In the mid-eighties an antiscalent polymer was introduced, during that period membranes were remarkably developed in order to increase salt rejection when used in BW or SW desalination (El-Dessouky& Ettouney, 2002).

Since 1990’s desalination technologies (thermal or membrane) had been used for municipal water supply(Buros,2000),during that period many large Multi Stage Flash plants were constructed especially in the Arabian Gulf particularly in United Arab Emirates UAE, in 1999 large scale desalination plant using RO technologies was constructed in United States of America USA (El-Dessouky &Ettouney,2002).

At the beginning of the 21th century, many high performance MSF desalination plants were constructed, (El-Dessouky & Ettouney, 2002).

2.3 Desalination technologies.

2.3.1 Desalination technologies.

Desalination processes can be categorized into two main families, membrane processes or thermal processes as table 2.1 shows (Hamed, 2005; Mezher, et al., 2011).

Table 2.1: Major desalination processes.

Thermal Processes	Membrane Processes
Multiple-Stage Flash distillation (MSF)	Reverse Osmosis (RO)
Multiple Effect Distillation (MED)	Electrodialysis (ED)
Vapor Compression (VC): 1) Mechanical Vapor Compression (MVC) 2) Thermal Vapor Compression (TVC)	

2.3.2 RO in water desalination:

Both (Fritzmann, et al.,2007; Mezher, et al.,2011) have defined RO as a pressure-driven process that separates two solutions with different concentrations across a semi-permeable membrane .Amongst the various desalination technologies: thermal, electromechanical or hybrid processes, reverse osmosis (RO) is one of the most efficient requiring less electric energy than others ,with a high product recovery and quality, intensified process, which can be scaled up in no time (Villafafila & Mujtaba,2003). Meanwhile, RO has the highest capacity of the global desalination with 53 percent as shown in Figure 2.1.That proves that RO may be the most convenient technology used in water desalination (Mezher, et al., 2011).

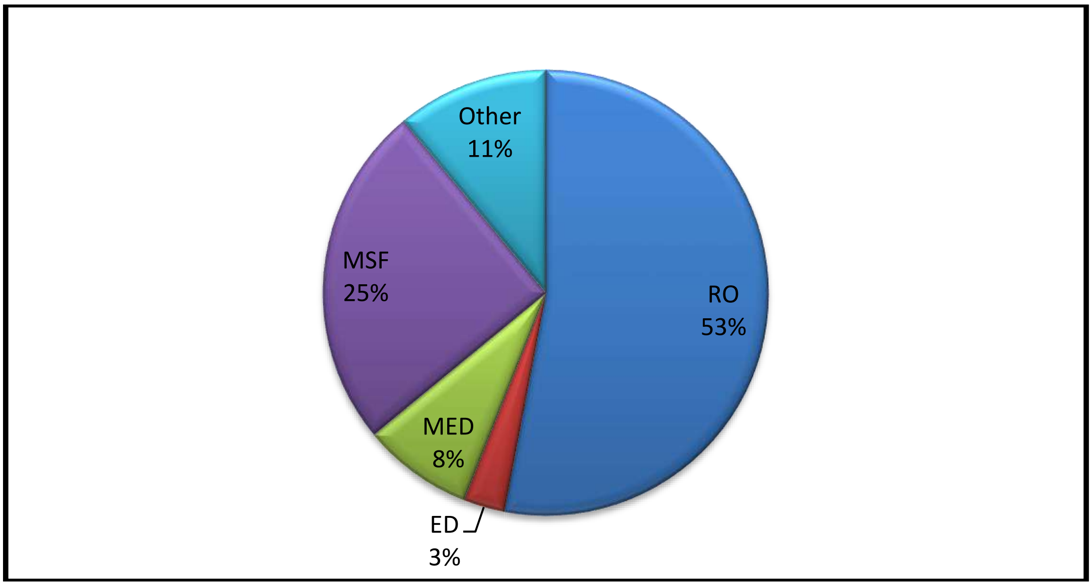

Figure 2.1: Global desalination capacity by process (ESCWA, 2009).

In RO process the desalted water passes through the membrane and is called permeate, and the remaining water is discharged and called brine, permeate or concentrate (Mezher, et al., 2011; Crittenden, et al., 2012).

The permeate stream exits at nearly atmospheric pressure, while the concentrate stream stays the same (the feed pressure). Pretreatment and post treatment of feed stream and product stream are an essential steps for RO process, in order to prevent scaling, fouling ,and degradation and increase membrane life pretreatment is applied ,filtration which removes colloidal matters and disinfection which removes bio maters are the dominant processes that are used to pretreat the feed water. Screening is the very first step which physically eliminates suspended solids. Post-treatment is the process in which the dissolved gases such as Carbon Dioxide (CO_2) are removed and pH is adjusted as shown in Figure 2.2 (Crittenden, et al., 2012).

Membrane element can be described as the tiniest unit in any RO plant. If one want to describe an RO unit it is a number of element that are gathered in pressure vessels installed above skids with all the necessary piping system (feed stream, permeate stream and brine)(Crittenden, et al., 2012).

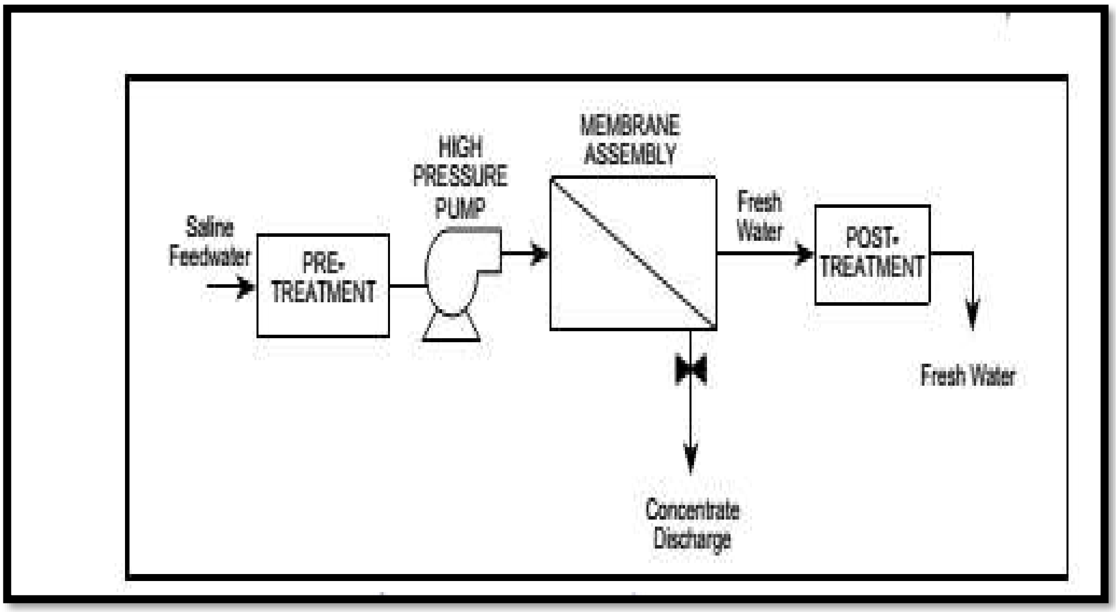

Figure 2.2: Basic Configuration of RO process.

Membranes are categorized into two main groups according to material used in production: cellulosic which use cellulose acetate which uses different forms off the polymer to form both layers. And non- cellulosic called composite membrane which uses different polymers (Watson, et al., 2003). Semi permeable material is the key material for an ideal RO membrane (Crittenden, et al., 2012).

RO membrane modules and module configurations:

There are four main (commercially available) types of modules used in RO processes:

1) Spiral wound,
2) Hollow fine fiber (HF),
3) Plate-and-frame,
4) Tubular, (Williams, 2003).

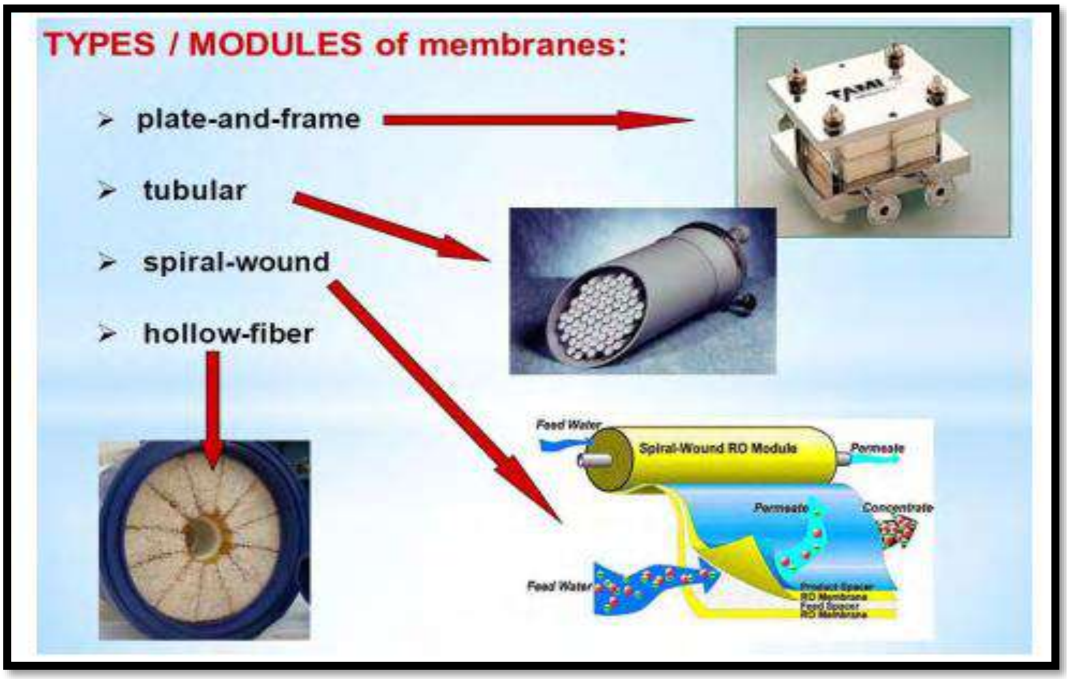

Figure 2.3: Types/Modules of RO membrane.

RO membrane modules arrangement configurations:

There are several arrangement configurations of RO modules that could be used in the process; single-pass configuration and a double-pass configuration. When a single pass configuration is used; rejection of the membrane is high, efficient enough to eliminate salt from feed water. In a double-pass configuration, the out coming feed which is salt free goes to the next set of membranes as feed flow which enhances the overall removal of the salt (Williams, 2003).

RO membrane materials:

The main factors affecting any RO membrane life are: membrane materials and the application (Greenlee, et al., 2009).the most important RO membrane materials are:

1) Cellulosic polymers (cellulose acetate, cellulose triacetate, etc.),

2) Linear and cross-linked aromatic polyamide,

3) Aryl-alkyl polyetherurea (Williams, 2003).

2.3.3 Combining REs with RO in water desalination:

REs have a promising future in water desalination. There are several ways to combine REs (solar, wind, geothermal and biomass) with desalination plant, energy generated by renewable could be in three forms electricity, thermal, or shaft, renewable energy usually a stand-alone system especially for arid and semi-arid areas, which means that it combines two different energies and mostly have storage devices (Mathioulakis, et al., 2007)

Recently, combing solar energy in RO desalination unit has been studied. Figure 2.4 shows the best ways of coupling REs with desalination technologies. When energy produces electricity, it is usually used to operate membrane desalination (RO, ED) or thermal desalination technology (MVC), coupling PV with RO is the predominant combination (Charcosset, 2009).

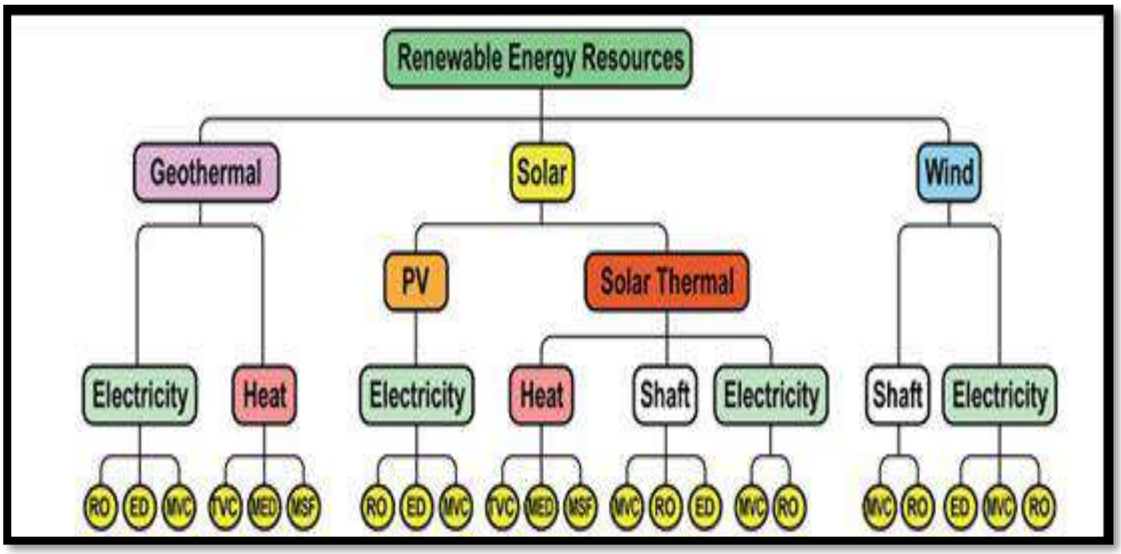

Figure 2.4: Possible combinations of REs with desalination plants.

2.4 Desalination economics.

In order to decide if a submitted project is beneficial or not, an economic analysis is usually conducted. Unbiased and fair comparisons between different scenarios or alternatives can be attained by using economic analysis (De Souza, et al., 2011).

Many researches and studies have been conducted to address the possibility of using renewable energy (especially solar photovoltaic PV in remote areas with abundant of brackish water and sunshine hours) to power water desalination units (García-Rodríguez, 2007; Charcosset, 2009).

The following table (Table 2.2) shows a summary of these studies:

Table 2.2: Summary of studies on water desalination cost.

No	Country	System description	Cost study method and price of desalted m^3 of water	Reference
1	Gran Canaria Island	RO-PV ($3m^3/d$)	Economic analysis (16 $/$m^3$)	Herold, et al., 1998
2	Riyadh –KSA	RO-PV ($4.8m^3/d$)	Economic analysis (0.5 $/$m^3$)	Hasnain & Alajlan,1998
3	Chbeika - Tan Tan city- Morocco	RO-PV ($3m^3/d$)	Feasibility study for integration of REs for electricity production	Tzen, et al., 1998
4	Qatar –Wadi Araba -Jordan	RO-PV ($45m^3/d$)	Technical feasibility study for pilot plant	Gocht, et al., 1998
5	Heelat ar Rakah camp - Sultanate of Oman	RO-PV ($5m^3/d$)	Experimental study on the combination and use of BWRO- PV desalination system (6.5 $/$m^3$)	Suleimani & Nair, 2000
6	Cyprus Island	Hyprid RO desalination system (DG/PV)	1) Estimated the effect of fuel cost on the desalinated water cost, 2) Investigated coupling PV system with desalination and estimated its cost	Kalogirou , 2001
7	Portugal	RO-PV ($0.1\text{-}0.5m^3/d$)	Experimental pilot plant - cost estimation	Joyce, et al., 2001
8	Egypt	RO-PV ($1m^3/d$)	Feasibility study of water desalination unit (3.73 $/$m^3$)	Ahmad & Schmid , 2002
9	Australia	RO-PV ($0.4\text{-}1m^3/d$)	Design of combined PV-RO-UF desalination unit	Richards & Schäfer , 2002
10	Ginostra - Sicily	Hyprid RO desalination system (DG/PV)	Energy management and a digital surface model (DSM) techniques on SW desalination unit	Scrvani , 2005
11	Worldwide	**All desalination systems**	Cost literature: review and assessment	Karagiannis & Soldatos , 2006
12	Adelaide - South Australia	Multiple plants	Cost Data Methodology	Wittholz et al., 2008
13	Babylon - Iraq	RO-PV ($5\ m^3/d$)	Optimization and economic analysis of desalination plant	Al-Karaghouli &Kazmerski , 2010
14	Naples - Italy	novel solar tri-generation system producing	Investigation of the integration of REs and water systems using dynamic simulation and economic analysis.	Calise, et al., 2014

2.5 An overview of Global Water Situation.

2.5.1: Global Water Resources.

Water is vital element in human life, existence of life and civilization is dependent mainly on the existence of water, although about three quarters of earth's surface is water, it is not available completely for human utilization (World Water Council, 2000).

About 97% of this water is non-drinkable (seawater), as Figure 2.5 shows about 2.5 % is fresh water but frozen, only 0.5 % is freshwater available in many forms (aquifers, rainfall, lakes, reservoirs and rivers) (WBCSD, 2009)

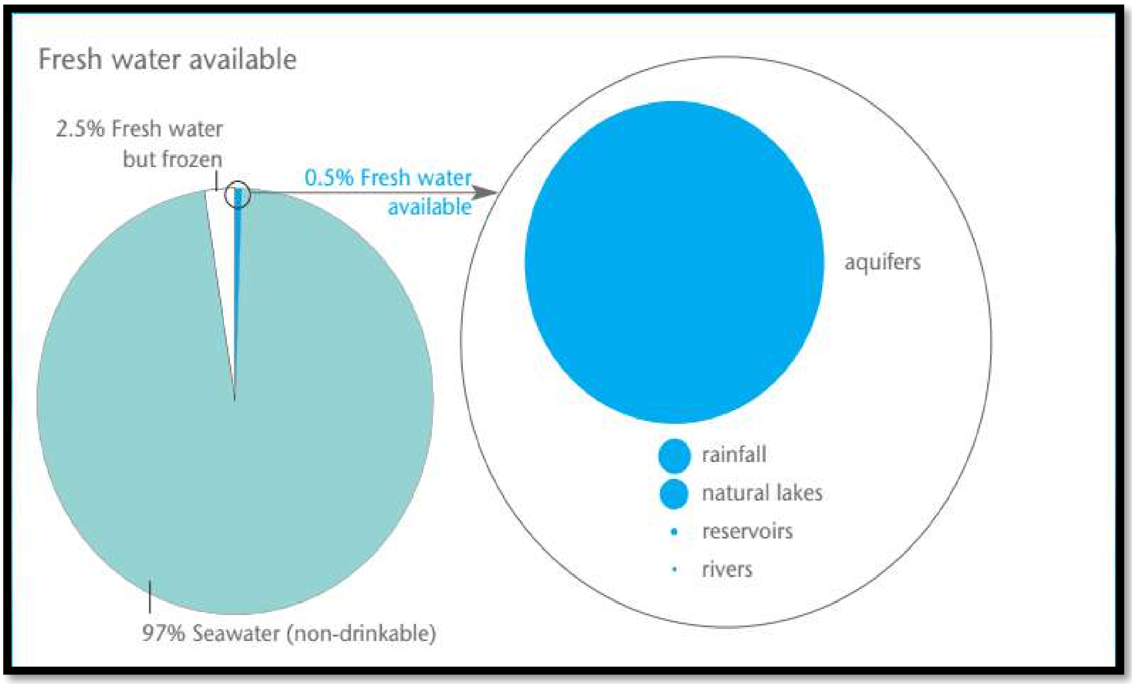

Figure 2. 5: Available fresh water (WBCSD, 2009).

It's very difficult to assess global water resource, due to the continuous movement of water and frequent transformation of water state, natural water resources do not mean they are available for humans; those are stored on Earth also known as “water storage”; meanwhile available water resources should be at quantity and quality which is sufficient for specific demand and use (WBCSD, 2009).

Generally, many water interested organizations have defined water scarcity, such as: UN-water which defined it as :” the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully”, scarcity is related with water shortage, and is influenced significantly by droughts, large climate variability, rapid population growth and economic development in the arid and semi-arid regions (UN- Water, 2007).

Water stress happens when the water demand transcends available water through a certain period. It makes freshwater resources to deteriorate in terms of quantity and quality (Jie, et al., 2011). Below 1,700 m^3/capita annually the country is experiencing regular water stress; below 1,000 m^3/capita annually the country is facing water scarcity which will impact development, health and well-being (WBCSD, 2009). Today, around 700 million people in 43 countries suffer from water scarcity. By 2025, about 1.8 billion people live in regions suffering from water scarcity, and two-thirds of the world's population could be living areas suffering from water stress. By 2030, almost half the world's population will be living in areas of high water stress; Sub-Saharan Africa is categorized as the region with the highest number of countries suffering from water stress, majority of the Near East and North Africa countries are suffering from acute water scarcity, in addition to Mexico, Pakistan, South Africa, and large parts of China and India (United Nations, 2016).

Figure 2-6 shows the available water globally over 75 years, North Africa region suffered from water scarcity in 1950 and 1995 and also predicted to suffer in 2025, Middle East especially The Arabian Gulf and west Asia suffered from water scarcity in 1995 and predicted to suffer in 2025.

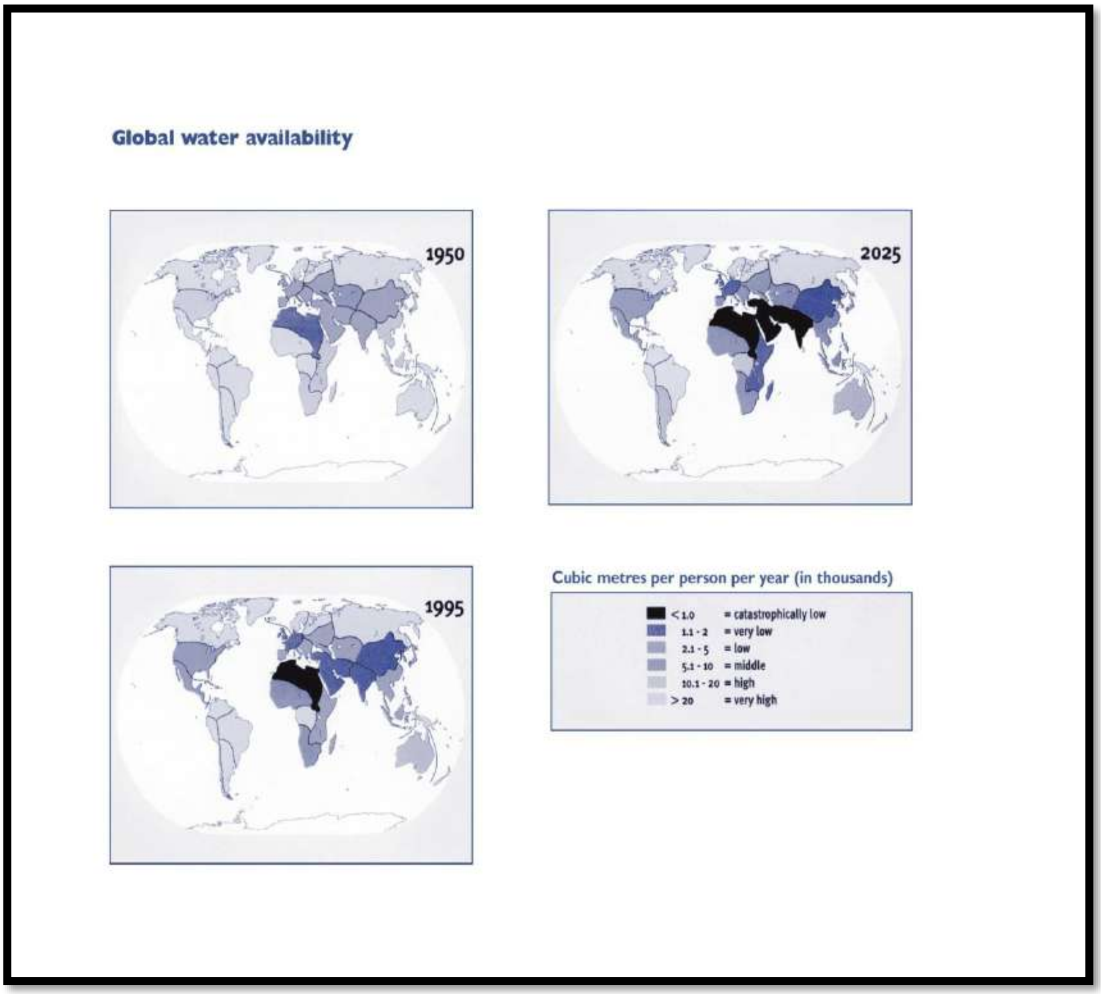

Figure 2. 6: A history of global water scarcity in1950, 1995 and a projection to 2025[1].

[1] http://www.un.org/events/water/images/WaterYearGraph.jpg

Worldwide, irrigation, urban ,industry are the most consuming sectors; agriculture sector is considered as the biggest consumer of water resources, especially in Middle East and North African (MENA) countries (Clayton, 2015). Agriculture takes the lion's share of available water which makes it a very important cause of scarcity, because producing crops requires nearly seventy times more water than that required for drinking and domestic purposes (Lazad, 2007; Clayton, 2015).

Generally, developing new sources for water supply can be achieved using one or both of the following methods:

1. The traditional approach.

   Mainly building dams, reservoirs, canals and pumps, digging wells in order to collect water flows.

2. Un-conventional and exotic methods.

   Because of the restricted available water and the modern perspective of public about reducing both the cost of water and the bad impact on the environmental, suppliers have recently considered new and novel alternatives for developing new sources of water such as: waste water treatment, desalination, cloud seeding, fog collection and towing icebergs (Lazad, 2007).

2.5.2 Global installed desalination capacity:

According to International Desalination Association (IDA), global installed desalination capacity has been growing very quickly (Lattemann, et al., 2010).Annual desalination capacity is growing quickly especially in regions where water availability is considered low (Zotalis, et al., 2014).The biggest desalination plants using thermal technologies around the world are located in Saudi Arabia and, United Arabic Emirates, which are Ras Al-Khair(2 plants), Shuaiba, Al Jubail, Jebel Ali desalination plant[1].

Table 2. 3: Major (RO) desalination plants in the world[2].

Plant Name/Location	Capacity (m^3/d)
Tampa Bay Desalination Plant, USA	94635
Point Lisas, Trinidad	109019
Almeria, Spain	49967
Las Palmas – Telde	34825
Larnaca, Cyprus	53752
Muricia, Spain Design-Bid-Build	65108
The Bay of Palma/Palma de Mallorca	62837
Dhekelia, Cyprus	40125
Marbella – Malaga, Spain	54888

2.5.3 Desalination by the Numbers:

1) According to IDA, globally around three hundred million people depend on desalinated water ether totally or partially.
2) In 2015, about 19000 desalination plants worldwide are operating.
3) In 2015, globally the capacity of installed desalination plants was more than eighty six million cubic meters daily.
4) More than 150 countries are practicing desalination worldwide.[3]

2.5.4 Global Desalination Market:

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[1]http://www.constructionweekonline.com/article-22824-largest-desalination-plant-in-world-75-complete/#.UgjrLtJM_7E (accessed on 14 July 2015)
[2]http://hbfreshwater.com/desalination-101/desalinationworldwide(accesed on 12 October 2015)
[3] http://idadesal.org/desalination-101/desalination-by-the-numbers/(accessed on 26 November 2016)

Global markets of brackish desalination are basically in central Asia, Australia and the continental United States, which is attributed to the propagation of saline aquifers (UNESCO, 2008). Worldwide The major number of desalination plants are located mainly in the Gulf Region (Middle East), followed by the Mediterranean, the Americas, and finally Asia (Clayton, 2015). Forty-eight percent of the global desalination production is in the Middle East, mainly in the Gulf country states, nineteen percent of the global desalination capacity is obtained from brackish water sources eighty percent of them use RO as treatment technology (Lattemann, et al., 2010).

China which is home to nearly twenty percent of the world’s population is suffering from water shortage; many attempts have been conducted to control and reduce the gap between fresh water supply and demand including using both distillation and RO technologies in water desalination through the past decades (UNESCO, 2008; Clemente, 2013).

2.6 Cost Benefit Analysis (CBA) and Cost Effectiveness Analysis (CEA).

CBA is considered inappropriate for the evaluation of investments that generate social or environmental externalities. The main difficulties and objections lie in the assignment of monetary values to benefits, a procedure which is usually biased and time-consuming, and the fact that the method reduces the multiplicity of criteria and objectives underlying decision making to a single monetary criterion, namely the net present value of the investment.

On the other hand, CEA which is an alternative to CBA is a method that can provide value added information to aid decision-makers (WATECO Group, 2002). The outcome is a set of solutions achieving the stated objectives at the minimum cost through a relatively easy standard procedure, which determines whether the additional cost for a more effective solution corresponds to the gain in effectiveness. The output of alternative solutions is usually a single, quantified physical measure. Outputs can also be environmental or social indicators; the term “output” does not indicate “impact”, but the desired and intended effects of solutions.

CEA usually compares a series of mutually exclusive alternative projects. Costs are monetized. Project costs are typically measured as actual expenditures rather than as opportunity costs (Steiguer, n.d.).

It should be noted that CEA and Incremental Cost Analysis (ICA) do not identify a unique or “optimal” solution, but can lead to better-informed choices among alternative solutions, providing a basis for comparison of the relevant changes in costs and outputs on which such decisions should be made. In such analysis, costs are typically calculated as the direct financial or economic costs of implementing a proposed measure, with effectiveness being defined in terms of some physical measure of environmental outcome. Thus, the two methods provide results that can easily be interpreted and evaluated by policy makers. Furthermore, and with regard to the specific goals of energy planning, the selection of CEA over traditional cost-benefit analysis allows addressing the different benefits of RE integration swiftly and objectively. Through the choice of appropriate indicators, local benefits associated with improved environmental quality, economic growth, job creation, increased control of energy production and energy supply security can easily be taken into account, while at the same time avoiding the time-consuming and often biased procedure of assigning monetary values to benefits (Angelis-Dimakis et al.,2008).

Chapter Three

Research Methodology

Chapter Three

Research Methodology

3.1. Research Methodology:

1) Data collection was performed regarding RO-PV system used in brackish water desalination system, average solar radiation, and average wind speed data were obtained from:

- The available REs potential (mainly solar) for the selected study area, in addition to the brackish water quality in the study area (Cl, pH,NO_3, TDS,… etc concentrations),in order to get a suitable brackish water location map.
- Water supply and demand data.
- Grid and diesel prices…etc.

3) A cost analysis procedure was used in this study using HOMER Pro software,

Three different scenarios were economically analyzed, the first one is a (BWRO) unit powered by PV cells, the second was system completely depending on DG, and the third was hybrid system uses both SE and DG, all systems were simulated and the optimum system is the one which has the least-cost of energy and to compare and differentiate between the proposed and existing systems.

1) Software Description: In this research, simulation, optimization, and cost analysis of BWPV-RO system was done using HOMER Pro® software program developed by the U.S National Renewable Energy

Laboratory (HOMER, 2016). HOMER (Hybrid Optimization of Multiple Electric Renewables),the micropower simplifies optimization model, the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications (HOMER,2016)

2) Simulation using HOMER Pro:

- Simulation of different BWRO-PV system configurations (using the entered data to the model such as: components costs, resource availability, technology options) was done using the model.

Simulation using HOMER Pro by conducting energy balance calculations for the entire system for the year. For each time step in the year, the software compares the overall demand (both the electric and thermal demand) in that time step with the energy that the system can supply in that time step; in addition, for each component in the system the software calculates the flows of energy to and from. Moreover, if there is storage components (eg: batteries) or fuel-powered generators (eg: Diesel), it makes the decision when to operate the generators and whether batteries should be charged or discharged.

3) Concerning the feasibility of the system, the software determines whether the proposed configuration is feasible. Cost calculations over the lifetime of the project include capital, replacement, and operation and maintenance O&M costs.

4) Sensitivity analysis was carried out using the model: in order to explore the effect of changing a specific factor such as: resource availability (e.g.: average solar radiation), economic conditions (e.g. Interest Rate

(IR)) on the cost effectiveness of the different system configurations. First, the sensitivity values were provided to the model, and then HOMER simulates each system configuration over the range of these values.

- Optimization of the suggested BWPV-RO, HOMER Pro model uses a proprietary derivative free algorithm in order to find system with the least cost. Then it displays a list of configurations sorted by net present cost NPC (lifecycle cost), the first raw includes optimum system (Lilienthal, 2005).

Homer Pro Input Data:

a. The monthly average solar radiation (kWh/m^2) for the study area.

b. The daily average load of the unit in kWh/day.

c. The proposed PV system used to power the RO units.

d. The prices for the PV system and components such as batteries and converters

e. The diesel fuel price $/l.

f. The assumed interest rate (IR).

Three system configurations were investigated (concerning energy used):

(1) BWRO unit powered by PV system only with batteries.

(2) BWRO unit powered by DG only.

(3) BWRO unit powered by diesel generator plus PV-system (Hybrid system).

Homer Output Data:

1) RO unit daily load and peak wattage.

2) Total system\ net present value NPC.

3) The cost of electricity produced COE.

4) Environmental Benefits represented the annual reduction of greenhouse gases (GHG) using the proposed small system (including: CO_2, CO, Hydrocarbon, Particulate Matter, SO_2, and NO_X.

5) The model calculated the cost of electricity (COE) needed to operate the system), benefits were calculated from the annual reduction of greenhouse gases (GHG).

Chapter Four

Results and Discussion

Chapter Four

Results and Discussion

4.1 Inputs of the Model:

The inputs include the following: Resources, Loads, Components, Optimization, and Constrains.

4.2.1 Resources

1) Solar Radiation:

Solar resources used for Az Zubidat village are shown in Figure 4.1 and 4.3 were obtained from both Energy Research Center –Nablus (ERC) (Energy Research Center ERC-Nablus, 2016) and NASA surface Metrology and Solar Energy Website (NASA Surface Metrology and Solar Energy, 2005) respectively.

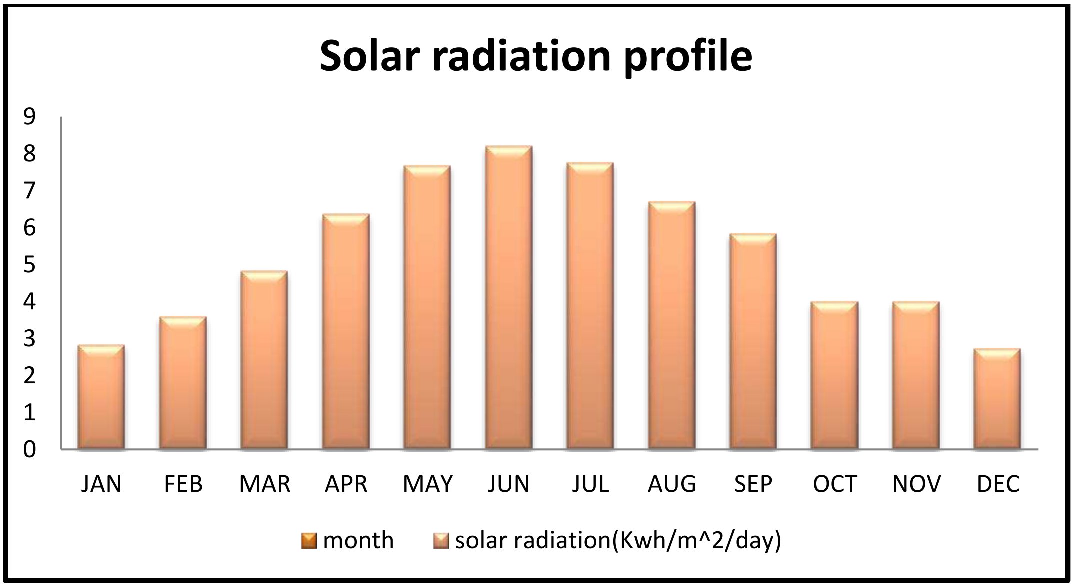

Figure 4.2: Solar Radiation Profile for 1-year period- 2012 (Az Zubeidat village-Jordan Valley (ERC, 2016).

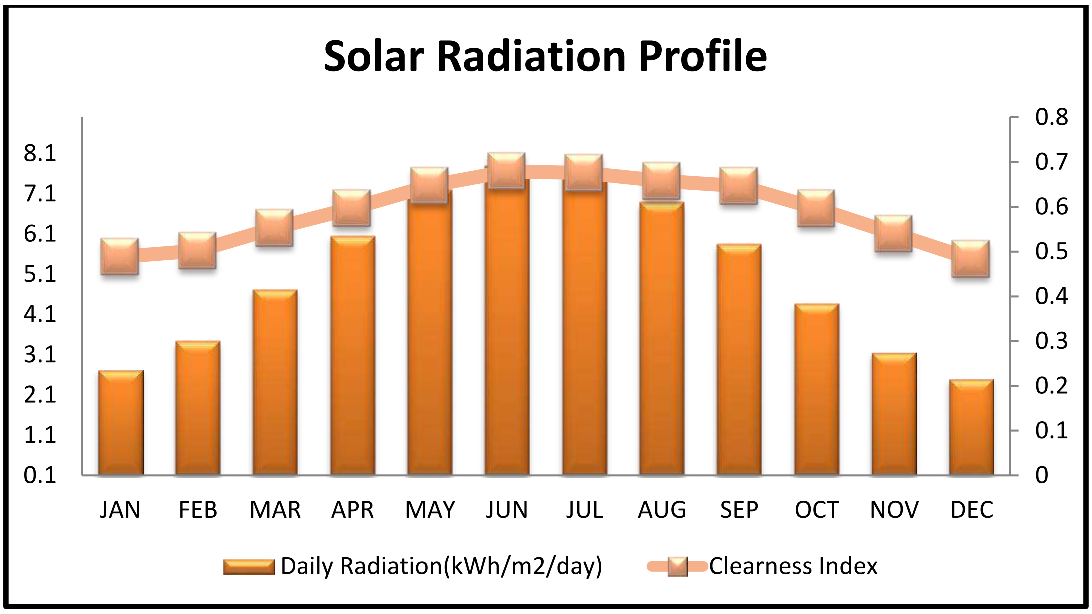

Figure 4.2: Solar Radiation Profile based on 22year period (July1983-June2005).

As both figures show, throughout the year the quantity of solar radiation in village is sufficient (annual average solar radiation) which indicates that the use of the PV cells (wither hybrid or on grid system) is appropriate.

2) Wind Resources:

According to several Palestinian researcher's wind energy potentials in Jericho is not suitable for running turbines for electricity generation (Shabbaneh, 1997 ; Kitaneh , etal., 2012; Ismail , etal., 2013). Meanwhile; wind speed data at the NASA's surface meteorology and solar energy site is an average over an entire area which cannot be reliable (NASA Surface Metrology and Solar Energy, 2005).

4.2.2: Unit Loads:

The design of the BWRO desalination unit was done by Engineer Yousef, the unit was designed in 2103, and the total daily load energy was calculated depending on the pumps input power which is equal to **25.4**

kWh/m² considering a daily operation of 6.5 hours, with a **5274.5 Wp** necessary peak power of PV generators (Yousef, 2013).

When designing RO desalination system, energy is the most important element. Energy use of the system depends significantly on system's capacity, which usually is in the range of 2-10 kWh/m ^{3} of the produced water (Hafez & El-Manharawy , 2002). In the original design the energy use was calculated equals 2.3 kWh/m^3 of the produced water.

According to the model the main load occurs at 8 am to 1pm at winter (Jan, Feb, Mar, Sep, Oct, Nov, and Dec) which means that the unit operate 6 hours in winter seasons, and 9 hours in summer from 8am -4pm (May, Jun, Jul, Aug).

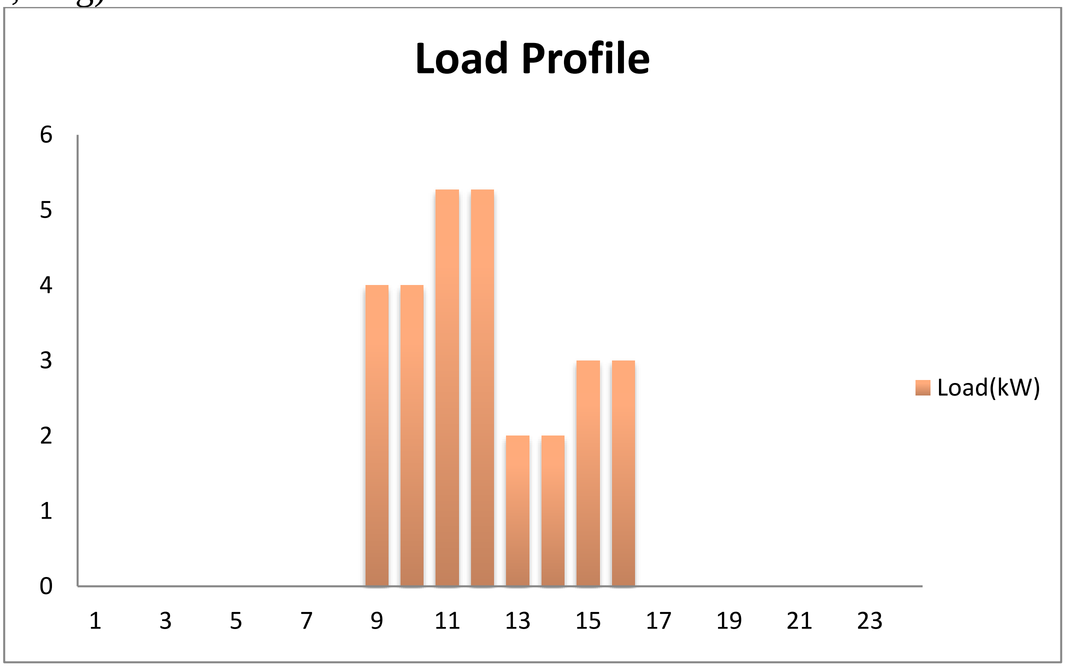

Figure 4.3: Daily load profile of the existing BWRO desalination unit.

4.3 System Components:

The existing system includes PV modules, batteries, charge controller, inverters, and the supplementary parts (modules structure, wiring, fuses, and safety devices. The prices and components specifications for the PV system devices were taken from the full design done by Engineer Yousef and the quality analysis technical report published by An Najah National University (An Najah National University, 2012). Meanwhile; the proposed system has more components.

This research aims mainly in determining the optimal energy choices, which are feasible, cost-effective, and capable of producing the demanded quantity of water using the brackish water reverse osmosis existing design. HOMER, software developed by the National Renewable Energy Laboratory (NREL) was used to define energy choice with the least cost.

First the current design was simulated separately using HOMER software; the system operates at 100 percent renewable energy using PV cells, secondly the PV system is replaced entirely by a diesel generator, then the system was integrated using both energy options.

4.3.1: PV Arrays:

The existing PV panels which I used in the simulation of the desalination unit are SCHOTT 185-Gernany rated at 185 Wp at standard conditions (1000 W/m^2 and 25̊ C), with open circuit voltage of 45 **V**, voltage at the maximum power point 36.3**V**, short circuit current 5.4**A**, current at the maximum power point 5.1**A**, peak efficiency of 14.1, and nominal operating cell temperature of 46˚ C. Yousef (2013) has estimated the capital cost of the PV modules of 5180 $(US$ 1/Wp).Life time is considered 20 years and derating factor of 80% ,PV arrays were installed at height of 8m above earth ,facing south with a tilt angle of 45 ° on the horizon. Zero, 1, 2, 3, 4, 5, 6, 8, 9, and 10 kW capacities were considered in the analysis.

4.3.2: PV-Batteries

In Yousef's design the system was operated using batteries in order to store the required quantity of electricity as DC form, they can be charged and discharged continuously with no fair of ruining them along their lifetime (assumed 10 years). The original design contains 24 battery cells (VARTA PZS875 each battery cell is rated at 2V/875 Ah) with a total energy capacity of 42kWh, each one has a capital cost (price) of US$ 437.5 (Yousef, 2013).

The software simulates the battery, assuming that its properties will stay steady along its proposed, that means no outside factor such as temperature or humidity may affect its performance. In this research several numbers of batteries were analyzed (0, 24).

The current scenario is using PV cells with batteries as the only power source, and when simulating this system in the software it appears that it a stability problem because it has high renewable penetration if it is used with no storage which makes the system unfeasible.

4.3.3 Inverters (DC/AC):

The original design contains 3 inverters with a rated power capacity of 3.6 kW, and unit price for each (0.59US$/W), life time is assumed to be 20 years, their maximum efficiency could reach to 96%, STUDER module XTM 2600-48/ Switzerland type was used, and its lifetime is 20 years.

In this simulation three 3.6 kW inverters were used and analyzed to find the optimum configuration. As table 4.4 shows the maximum solar scaled average (8.2 kWh/m^2/day) has the least COE (0.02 \$/kWh) of all three solar radiation values which make sense, but the system should include the batteries to overcome the stability problems, and the minimum solar scaled average (2.3 kWh/m^2/day) has the highest COE (0.06 \$/kWh) of all three solar radiation values. Meanwhile; all of them do not work properly without batteries. All systems have approximately 6% of unmet load and capacity shortage of about 10% with 100% renewable energy fraction and of course zero kg/hr greenhouse gasses emissions.

Table 4. 2: Comparison between the different scales solar averages with the PV/Battery system.

Solar Scaled Average (kWh/m^2/day)	PV (kW)	BATTERY#	Converter (kW)	COE (\$)	NPC (\$)	Operating cost (\$)	PV Production(kWh)
8.2	11.20	0	5.7	0.02	2650	32	23
5.4	18.00	0	5.7	0.03	3927	40	31
2.8	28.20	24	5.84	0.06	7013	109	23

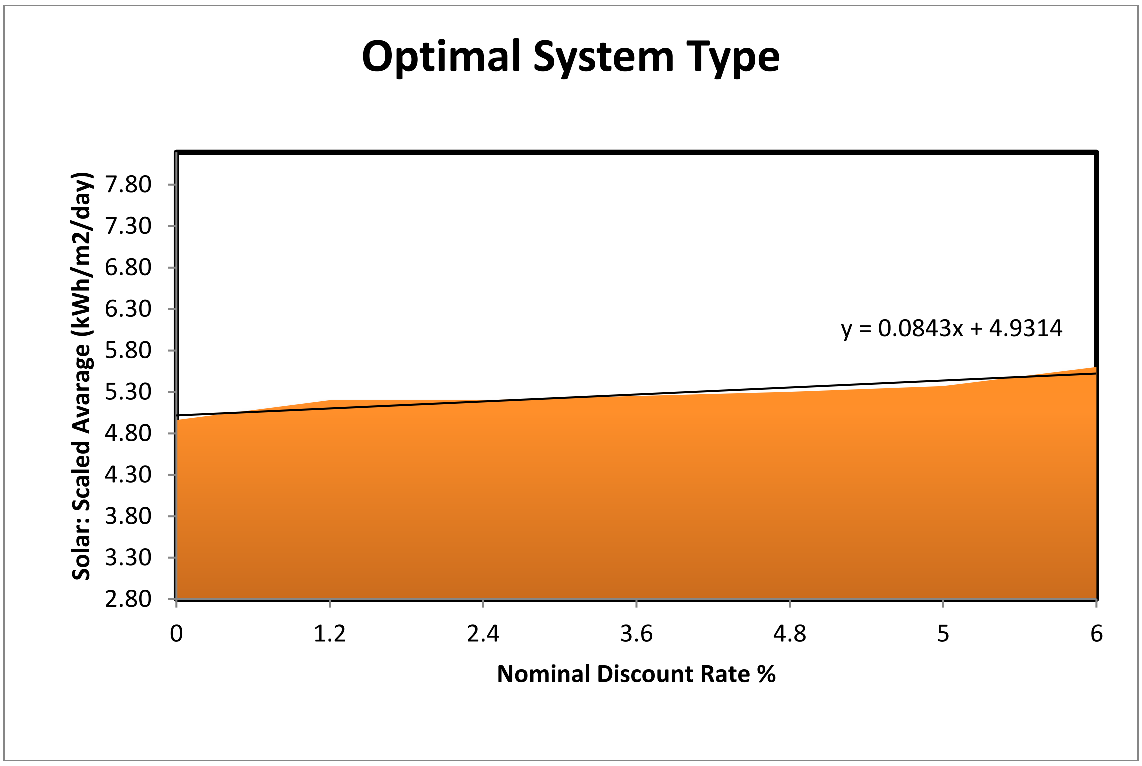

Figure 4.4: Graphical results of the sensitivity analysis of the PV system with and without batteries.

As the previous figure shows whenever the scaled average is in the white area (above the dividing line (approximately 5 kWh/m^2/day)), it is more economic to use the PV system alone and the PV/battery system is used otherwise.

4.3.4: Diesel Generator:

The existing system has one power supply source which is solar-PV, actually when homer simulated the system; it appears that the system may be unreliable, so an auxiliary generator is added to the system configuration to find the optimum power system, in this case only the system will depend totally on generator in this case so we could obtain a more reliable system. Interest rate of both 0% and 6% were studied and both the highest and the lowest diesel prices occurred in 2016 were analyzed also.

Generator Cost Estimation:

The proposed generator uses diesel fuel to produce electricity, the total load usually determines the generator's output ratings, the unit's total load is 26.5 kW ,so a 10KW (13.5kVa) is selected (using HOMER), the generator type is (caterpillar) with 3 phase output voltage (400/230 V), 50 Hz with a power factor of 0.80, the capital cost (price) of the generator is US$ 1/W, concerning maintenance per year depend on the duty of generator if it works as stand by or prime: in this system it is assumed to be prime, and it has a life time of 30000 hours.

For (10kW = 13.5 kva) generator: the maintenance costs are

1) Standby: 100$/year (oils & filters)

2) Prime: 1000$/year (based on 8 hours daily duty and 6 days per week)

= 0.0114 $/h

Operation costs: the sum of fuel consumption and labor cost per year.

1) Fuel consumption@75% load: see appendix A

-For standby operation: (l/h)*200hours /year, for prime operation: (l/h)*2500 hrs/year

-Labor: 600$/year for each generator set.

Operation costs $=\frac{2500}{8760} \times 3.7\ \frac{L}{yr} \times 1.50\frac{\$}{L} + \frac{600}{8760}\frac{\$}{yr}$ (for Diesel price see appendix B)

= 0.068 +1.583

=1.65 $/h.

O&M ($/h) = 0.012+1.65

= 1.67 (Shtewi, 2017).

The results show that the cost of electricity COE is relatively high (1.2 $/kWh), and whatever the fuel price or interest rate are the COE is high, with a zero renewable energy fraction obviously and an 11018 kg CO_2 yearly production and no unmet loads.

As Table 4.5 shows that the generator operates 8 hours /day and the optimal system has a COE of 1.2 $/kWh when the price of fuel is the lowest (1.3 $/L which is the lowest price happened in 2016).

Table 4.3: Homer sensitivity analysis and optimization results for generator option.

Sensitivity/Diesel Fuel Price ($/L)	Sensitivity/Solar Scaled Average (kWh/m²/day)	Architecture/Gen10 (kW)	COE ($)	NPC ($)	Operating cost ($)	Gen10/Hours	Gen10/O&M Cost ($)	Gen10/Fuel Cost ($)
1.3	2.82	10	1.22	283311	10932	2920	4876	5483
1.3	5.37	10	1.22	283311	10932	2920	4876	5483
1.3	8.19	10	1.22	283311	10932	2920	4876	5483
1.5	2.82	10	1.31	304398	11776	2920	4876	6326
1.5	5.37	10	1.31	304398	11776	2920	4876	6326
1.5	8.19	10	1.31	304398	11776	2920	4876	6326

Although diesel generators are a reliable solution which provides the continuity of the electrical current especially in Palestine required to operate the BWRO system; it is not environmental friendly solution, as it produces large quantities of emissions as table 4.6 shows.

Table 4. 4: Yearly emissions produced by a 10kW Diesel generator in Kg.

Quantity	Value	Units
Carbon Dioxide	11018	kg/yr
Carbone Monoxide	83	kg/yr
Unburned Hydrocarbons	3	kg/yr
Particulate Matter	5	kg/yr
Sulfur Dioxide	27	kg/yr
Nitrogen Oxides	94	kg/yr

4.3.5: Electric Grid:

The distance between the BWRO desalination unit and the nearest tower is about 1 km. The total daily electrical load is mainly from pumps (the three pumps already designed) which equals 3.5 kW (22.9 kwh/day assuming operating hours 6.5/day).With a grid power price of 0.14$/kWh, and grid sellback price of 0.07$/kWh, a monthly net metering pilling scheme is used which authorize the plant to sell electricity back to the grid if it generates more than the needed load monthly, grid is not included in the results because the village from awhile was connected to JDECO (Jerusalem District Electricity Co) and then the company separated its service because citizens refrain from paying(mainly due to the cut price that they have from the Israel Electric Corporation IEC).Regardless the current situation, grid choice can offer a very feasible solution because the unit has small load.

4.4: System integration (Renewable energy plus diesel generator):

Simulating the hybrid system was done using (as shown in figure 4.9) the combination of the current system (PV plus batteries) and the previous

Diesel generator in order to overcome the shortage in energy in general and especially at nights, and winters, so the system is operating for 16 hours instead of 8 hours as when system includes one source of energy.

The load following (LF) energy dispatch strategy was used on which whenever the diesel generator starts it produce only enough power to cover the load and lower priority loads such as charging battery bank left to renewable power source.

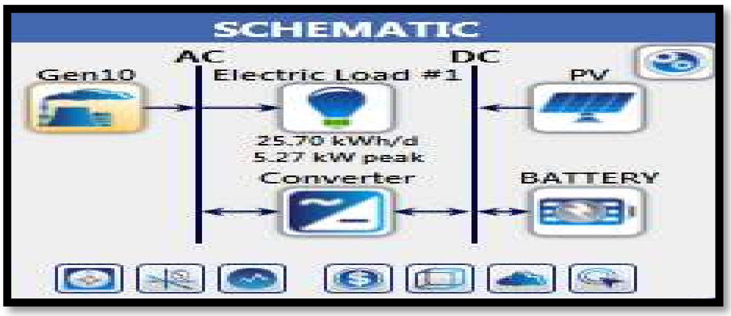

Figure 4.5: PV/Battery /DG hyprid system schematic diagram.

Sensitivity Analysis:

For this research several sensitivity variables were considered:

1) Interest Rate: 0 and 6 %.
2) Diesel price: the lowest and the highest recorded prices in 2016 (1.3 $/l and 1.5$/l respectively).
3) The solar scaled average radiation: the minimum2.8, average 5.37and highest 8.19 in kWh/m^2/day.

As both table 4.7 and figure 4.6 shows, for all systems' configurations the optimal design is hybrid system PV/DG/Battery, the first shaded raw for example; is an optimum system with the least electricity production cost is $0.424/kWh when the fuel price is minimum(1.3$/l) and the solar scaled average is maximum(8.9kWh/m^2/day) , for both 6 and zero IR percent ,the best configuration compromises of 10 kW diesel generator, a 27.2 kW PV modules and 24 batteries of 1.75 kWh capacities, and the system has 70% renewable energy fraction, the system Net Present Cost equals $ 99455 with yearly carbon dioxide production of 3501 Kg/yr.

Meanwhile the second shaded raw is the optimal system with the least electricity production cost is US$0.452/kWh when the fuel price is at the maximum value(1.5$/l) and the solar scaled average is maximum , for both 6 and zero IR percent ,the best configuration compromises of 10 Kw diesel generator, a 27.22 Kw of PV modules and 24 batteries of 1.75 Kwh capacities, and the system has 70% renewable energy fraction, the system Net Present Cost equals US$ 106121 with yearly carbon dioxide production of 3501Kg/yr.

Table 4. 5: Optimum systems of all configurations:

IR%	Fuel price$/l	Solar Scaled Average (kWh/m^2/day)	PV (kW)	COE ($)	Cost/NPC ($)	Cost/Operating cost ($)	System/RE Fraction (%)
0	1.3	2.8	59.53	0.475	111563	3982	68
0	1.3	5.37	41.6	0.439	102983	3762	70
0	1.3	8.19	27.2	0.424	99445	3720	70
6	1.3	2.8	44.9	0.522	62630	4157	67
6	1.3	5.37	33.6	0.471	56548	3834	69
6	1.3	8.19	21.9	0.449	53898	3783	70
0	1.5	2.8	72.3	0.505	118634	4178	69
0	1.5	5.37	41.9	0.467	109710	4029	70
0	1.5	8.19	27.2	0.452	106121	3987	70
6	1.5	2.8	49.9	0.553	66374	4382	67
6	1.5	5.37	33.6	0.500	60073	4110	69
6	1.5	8.19	23.5	0.478	57380	4034	70

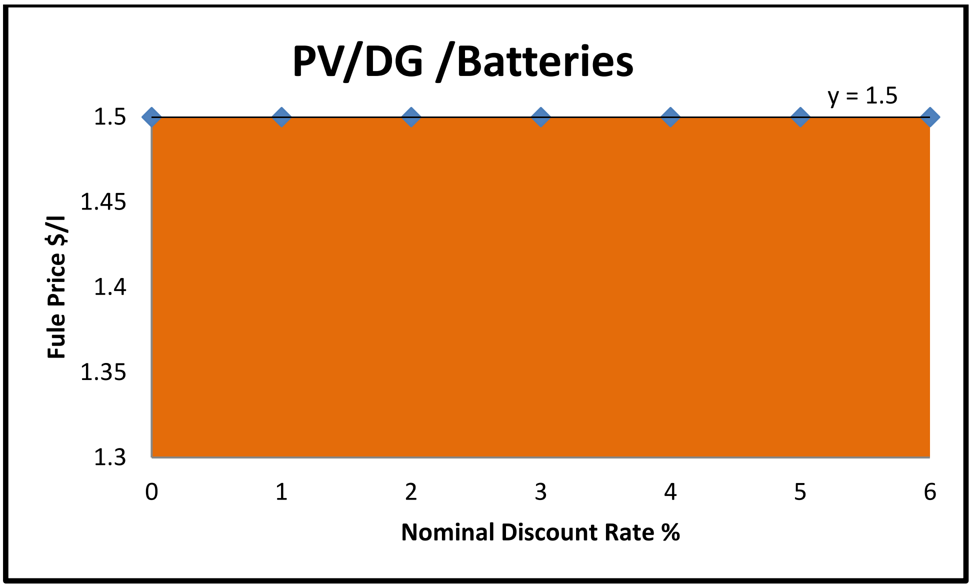

Figure 4.6: Graphical results of sensitivity analysis between Diesel fuel price and solar radiation value for optimal Hybrid system

The existence of the generator in such units increases the chance of GHG production; the following table (4.8) summarizes the produced emissions from the two optimal systems.

Table 4. 6: GHG produced from both optimal systems in Kg/yr.

Quantity	Value	Units
Carbon Dioxide	3501	kg/yr
Carbone Monoxide	26.5	kg/yr
Unburned Hydrocarbons	0.97	kg/yr
Particulate Matter	1.61	kg/yr
Sulfur Dioxide	8.59	kg/yr
Nitrogen Oxides	30.1	kg/yr

If one is going to compare all the three cases from environmental perspective the best system is PV only system, then PV/Battery, PV/Battery/DG, DG only system respectively based on the quantity of GHG produced, but both PV only system and PV/Battery could not provide neither stability of the current produced nor the continuity of the operation all daylong or in winter or cloudy days. So the competitors are the last two systems, when looking at both tables 4.6 and 4.8 it is clear that generator only solution is not environmentally friendly and PV/Battery/DG solution can decrease the GHG production as the next table shows.

Table 4. 7: Reduction percentage of the yearly GHG production when using PV/Battery/DG instead of using DG only.

Pollutant	**CO_2**	**CO**	**Hydrocarbon**	**Particulate Matter**	**SO_2**	**NO_X**
Percentage decrease %	68.3	68.2	68.3	67.1	67	68.2

Chapter Five

Conclusion and Recommendations

Chapter Five

Conclusion and Recommendations

5.1Conclusions:

1) We found that using the existing stand-alone PV-system with or without batteries (which is the current situation) could face both stability and continuity problems especially in the Jordan Valley.

2) Three separate scenarios were adapted, the first one is the current unit with PV/Battery system, as result showed whenever the solar scaled average is below approximately 5 kWh/m^2/day it is more economic to use the PV system alone and the PV/battery system is used otherwise. The maximum solar scaled average (8.19 kWh/m^2/day) has the least COE (0.0234 $/kWh) of all three solar radiation values, but the system should include the batteries to overcome the stability problems, and the minimum solar scaled average (2.28 kwh/m^2/day) has the highest COE (0.0618 $/kWh) of all three solar radiation values. Meanwhile; all of them do not work properly without batteries. All systems have approximately 6% of unmet load and capacity shortage of about 10% with 100% renewable energy fraction and zero kg/hr greenhouse gasses emissions.

3) The second scenario was powering the system with diesel generator alone. Analysis showed that a 10kW generator with 1$/W capital price, 0.7 replacement and1, 67 $/hr O&M, the optimal system when the interest rate was minimum 0%, the price of diesel was minimum 1.3$/l and COE of 1.25 US$/kWh which is relatively high with large GHG emissions.

4) The third scenario was to operate the system for twice the time as it is using hybrid system consist of PV/Battery/DG with different sensitivity variables which gave an optimal configuration with the least COE of US$0.424/kWh when the fuel price is minimum(1.3$/l) and the solar scaled average is maximum(8.91kWh/m^2/day) , for both 6 and zero IR percent ,the best configuration compromises of 10 Kw diesel generator, a 27.2 Kw of PV modules and 24 batteries of 1.75 Kwh capacities, and the system has 70% renewable energy fraction, the system Net Present Cost equals US$ 99455 with yearly carbon dioxide production of 3501 Kg/yr.

5) As the IR increases, the COE increases.

6) As Diesel price increases, the COE increases.

7) PV/Battery/DG solution gives an average of 68% GHG reduction.

5.2Recommendations:

Depending on the outputs of the research, the following can be recommended:

1. Palestinian Water Authority PWA and Water and Environment Institution should pay more attention to the existing pilot plant (the case study); redesigning it while taking into consideration the unique situation and climate of the Jordan Valley, especially when choosing and purchasing batteries as the existing batteries were not very useful and stopped working in short time after operating due to the high average high temperature in the area.

2. Jericho Municipality and Jerusalem District Electricity Company JDECO should coordinate between each other and to find new solutions regarding the useless existing grid connection ;(as it is a feasible solution but not friendly to environment, any way it may solve the water problem in the area.
3. Jericho Municipality, PWA and other authorities are recommended to have special awareness of the significance of hybrid powered desalination units in solving the problem of energy required, eventually to solve water crisis in Palestine.
4. Unit Designers and decision makers should put diesel generators within the basic alternatives of energy in operating such units, as the result showed they could be feasible solution due to many reasons including affordability and continuity of power at night and cloudy days.
5. Palestinian Water Authority PWA and Water and Environment Institution should collaborate to collect more accurate and related data on the existing desalination units in both West Bank and Gaza Strip, which should be easily accessed and obtained.
6. Awareness for both the public including farmers (particularly in Jericho) and the private sector of the role of using hybrid powered desalination unit should be increased.
7. Building culture for site specific designing involving government, private contractors, and concerned authorities especially when Jericho District is the case.

8. Further studies should be done regarding the use of brine which is the byproduct of any desalination system.
9. Designing such units should be an integrated process between both engineers and economists.
10. Palestinian Energy Authority PEA, PWA, and private sector should collaborate to investigate and apply if possible the solution of gathering power plant to generate energy required to operate desalination unit (large scale).
11. Regarding combining both renewable and conventional energies with desalination plants, more research should be done in order to reach general approach customized for Palestine.
12. Regarding the cost of desalination of brackish water, both researchers and concerned institutes should do more work to find the optimal approach which reduces cost.
13. More research should be done on scaling up the current desalination units, also on constructing new units in other candidate parts in West Bank.

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Appendices

Appendix A: Generator cost calculations

Appendix B: Diesel Prices in 2016 according to PALGAS

Appendix C: Percentage of reduction sample of calculations.

Appendix 1: Generator cost calculations

Generator cost caculations:

Convert kw to kva by dividing on P.F=0.8

kW	kVA	Cost of Generator
10	13.5	10,000 $
50	65	18,000$
100	110	23,000$
	150	30,000$

Maintenance Cost per Year depend on the duty of generator if it work as stand by or prime :

- 13.5 kva :standby :100$/year (oils & filters)

Prime :1000$/year (based on 8 hours daily duty and 6 days per week)

- 65 kva :standby 120$/year

Prime :1200$lyear

- 110 kva :standby :150$/year

1500$/year

-150 kva :standby   180$/year

1800$/year

Operation cost :

Fuel consumption :

The equation is for standby operation : (l/h)*200hours /year

For prime operation: (l/h)*2500 hrs/year

Please note that the fuel consumption for each generator set is as below table

KW	KVA	Fuel consumption @75% load standby	Fuel consumption @75% load prime
10	13.5	4	3.7
50	65	15	13.7
100	110 150	23.9 33.2	21.7 29.7

Life time: measured on working hours basis and it is approximately 30,000 hours.

Labor: 600$/year for each generator set.

Appendix 2: Diesel Prices in 2016 according to PALGAS

ALHUDA GROUP 2017/2016 مقارنة الأسعار سنة

2016

12/2016	11/2016	10/2016	09/2016	08/2016	07/2016	06/2016	05/2016	04/2016	03/2016	02/2016	01/2016	
5.34	5.42	5.22	5.28	5.05	5.26	5.28	5.02	4.94	4.76	4.69	4.80	سولار
5.86	5.92	5.78	5.85	5.58	5.85	5.90	5.73	5.72	5.42	5.61	5.66	بنزين 95
6.36	6.43	6.29	6.36	6.09	6.37	6.42	6.25	6.24	5.94	6.13	6.18	بنزين 98
5.34	5.42	5.22	5.28	5.05	5.26	5.28	5.02	4.94	4.76	4.69	4.80	غاز

2017

12/2017	11/2017	10/2017	09/2017	08/2017	07/2017	06/2017	05/2017	04/2017	03/2017	02/2017	01/2017	
							5.36	5.31	5.49	5.51	5.51	سولار
							5.94	5.88	6.02	6.07	6.07	بنزين 95
							6.47	6.41	6.55	6.57	6.61	بنزين 98
							5.36	5.31	5.49	5.51	5.51	غاز

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Appendix 3: Percentage of reduction sample of calculations.

% Decrease = Decrease ÷ Original Number * 100

CO_2 % decrease = 7517 ÷11018 *100

= 68.3

جامعة النجاح الوطنية
كلية الدراسات العليا

تقييم عملية تحلية المياه قليلة الملوحة باستخدام تقنية التناضح العكسي في منطقة غور الاردن

إعداد
بتول مصطفى يوسف عمارنه

إشراف
د . عبد الفتاح الملاح
د .رابح مرار

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية نابلس فلسطين.

2017

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الملخص

هذه الأطروحة تحقق في تقييم ثلاثة أنظمةمقترحة للطاقة التي تعمل عليها وحدة تحلية مياه قليلة الملوحة ،والتي هي: نظام الضوئية، مولد الديزل ، ونظام هجين بالطاقة. تستخدم جميع الانظمة تقنية التناضح العكسي لتحلية المياه المالحة في وحدة تحلية الزبيدات المتواجدة في وادي الاردن في الضفة الغربية.

وقد اتبع إطار عام للوصول للهدف الرئيسي من خلاله: حيث تم تحليل الجدوى الاقتصادية للنظم باستخدام برنامج (HOMER Pro) الذي تم تطويره بواسطة المختبر الوطني للطاقة المتجددة في الولايات المتحدة.

تم تحليل ثلاثة سيناريوهات مختلفة اقتصاديا وبيئيا باستخدام (HOMER Pro)وكان السيناريو الثالث هو تشغيل النظام لضعف الوقت الذي استخدم فيه النظامالسابقز وهذا النظام يتكون من خلايا شمسيه / بطاريات / مولد للكهرباء باستخدام السولار, مع اخذ متغيرات مختلفة لدراسه تغير النظام والتي أعطت تشكيلا للنظام مثاليا مع أقل تكلفة بحوالي 0.424 دولار / كيلوواط ساعة عندما يكون سعر الوقود على الأقل (1.3 دولار / لتر)، ومتوسط االاشعاع الشمسي هو الحد الأقصى (8.91 كيلو واط.ساعه /م2 / يوم)، لكلا نسب الفائدة صفر و 6 %، أفضل شكل لتشغيل النظام هواستخدام مولد كهرباء يعمل على السولار بقدرة 10 كيو واط وخلايا كهرضوئية بقدرة 27.2 كيلوواط من الوحدات الكهروضوئية و 24 بطارية (1.75 كيلوواط سعة)، وحصة الطاقة الشمسية للنظام هي 70٪ مع تخفيض في انتاج غازات الدفيئة بنسبة 68٪.

ونوصي بأن يأخذ صناع القرار والسياسات بعين الاعتبارمحاولة تصميم محطات تجمع ما بين الطاقات المتجددة والتقليدية مع وحدات تحلية المياه؛ بالإضافة إلى أن تصميم هذه الوحدات يجب أن يكون عملية متكاملة بين المهندسين والاقتصاديين.