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An Evaluation for a PV-RO system compared to MSF System in the Area of North East of Libya – Derna Case Study

A. H.Gadir[1] and H. Safwat[2]

[1]Abdalla H. Wanis Gadir, Postgraduate Researcher, Faculty of Engineering, British University in Egypt, Cairo
[2]Hesham M. Safwat, PhD, Lecturer Mechanical Engineering Department, Faculty of Engineering, British University in Egypt, Cairo
A.h.w.gadir@gmail.com, Hesham.safwat@bue.edu.eg

Abstract: Libya is characterized by its water scarcity as there is no river; rain water or ground water which is considered the basic source for potable water. The increase in population imposes urgent need for desalination water plants, especially for far zones from the Great man made river project (GMMR).The selected zones include cities that are partially supplied through the (GMMR) and other that are not supplied by the GMMR such as Derna city; thus the study is applied on the selected cities. This thesis aims to compare between thermal Multi-stage flash (MSF) plants and Reverse Osmosis (RO) plants partially supplied by photovoltaic solar energy. The study compare the cost of cubic meter of desalinated water for both MSF desalination plants and RO desalination plants partially supplied by PV system. The cost of RO plant is estimated with and without adding Energy Recovery Device (ERD). The study included forecasting of population in the studied zones and water demand for the year 2030 in order to make the appropriate design that cope with the future needs in this city. The study concluded that RO desalination plant partially supplied by PV system with ERD has lower cost than both MSF desalination plant and RO desalination plant partially supplied by PV system.
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Key words: MSF plants, RO Plants, PV System, ERD, desalination, GMMR.

1. Introduction

Water scarcity is very important issue in many semi-arid and arid countries, especially where the limited natural water resources are heavily exploited. The increase of water scarcity threatens economic development and sustainability of human livelihoods as well as environment especially in developing countries. The challenges generated by water scarcity will become even greater in future because of growth in population, urbanization, climatic change and growing urban food demand which will contribute to increasing the gap between water supply and demand for water [1].It is expected that about 40% of the population around the world will live in countries facing water scarcity in next few decades [2]. Libya is one of those countries that suffer scarcity of water resources availability due to the majority parts of the country are either arid or semi-arid. The area of Libya is located among the driest areas in the earth, as the average rainfall per year ranging from ten millimeters to about 500 mm. Just 5% of the whole area of Libya exceeds 100 mm per year. Rates of evaporation are high due to high rise of temperatures The Evaporation rates range from 6,000 mm in the south to 1,700 mm in the north. The prevailed water conditions do not save sustainable alternative for developing surface water, thus creating huge pressures on ground water resources. The majority of the ground water resource is exploited in agriculture, which represents about 80 % of the total water consumption [3]. The water research indicates that Libya will face extreme deficit in water resources, among the highly populated cities because of the increase in the consumption of the drinkable water and in domestic purposes.

Due to the shortage of the feeding water and the renewable resources to the ground water reservoirs different techniques are considered Man-Made River Project to save all the water demands in Libya [4].

This paper aims to compare between thermal Multi-stage flash (MSF) plants and Reverse Osmosis (RO) plants partially supplied by photovoltaic solar energy. The study compared the cost of cubic meter of desalinated water for both MSF desalination plants and RO desalination plants partially supplied by photovoltaic (PV) system.

2. Literature review

Some studies in the nineties of the previous century had warned from the disadvantages of the Great Man-made River Project because it is an unconventional method to secure Libya’s present and future water supplies.

The project has shown the technical feasibility of a large scale water transfer using an extensive pipeline system, built under extreme conditions. The studies [5] showed that, given the current state of the conveyance system, expansion of the GMRP is more cost effective compared to desalination when meeting the desired future water supplies in Libya. Without an existing large scale conveyance system, water supply and demand might more appropriately be matched by options, other than large scale water transfer systems; where these options are either supply-oriented, e.g. desalination and pollution control, or demand-oriented, e.g. pricing and water conservation. This is in addition to the current security problems that are facing the Libyan society due to the spread of armed militias that control some parts of the pipeline of the GMPR Fig. (1).Another problem that faces the current desalination plant is that it works on using fossil fuel; and because of the previously mentioned reasons, direction towards the desalination using renewable energy is an alternative solution.

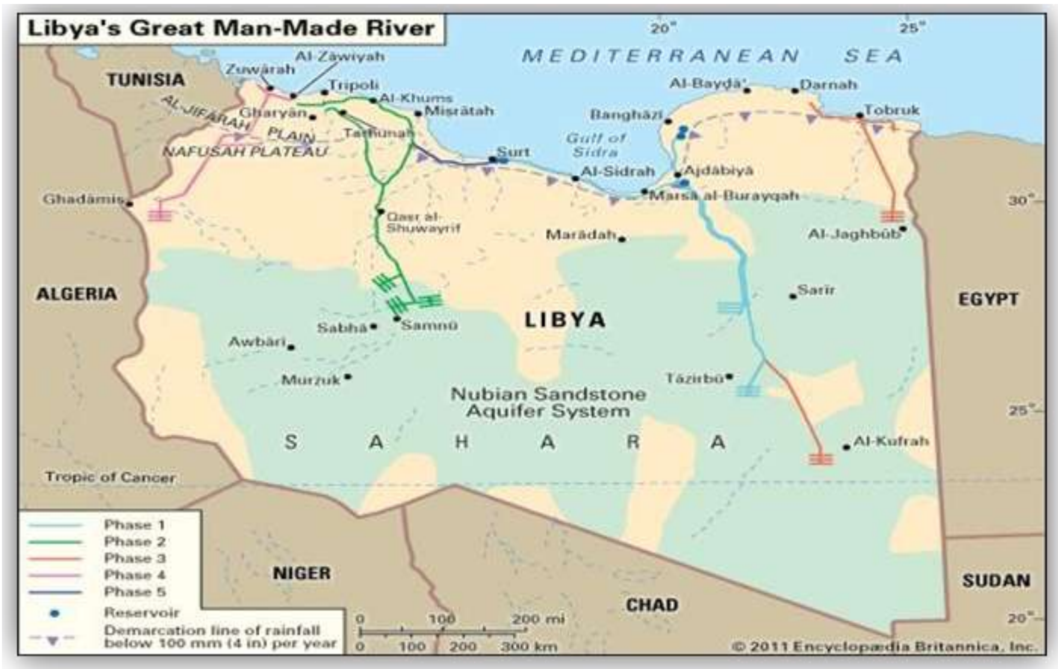


Figure (1) Great Man-Made River (GMMR)
,https://www.britannica.com/topic/Great-Man-Made-River, 20. May 2017

Figure (2) Libya map indicating layout of Derna.

3. Methodology

The methodology is based on estimation of the future population and future demand of potable water in the city of Derna, in Libya. Excel program has been utilized for making extrapolation of the curves in order to predict population on 2030. IMS Design program also has been utilized for designing a reverse osmosis plant. PV system also has been utilized for calculation of monthly meteorological values and solar paths at the different selected sites for desalination plants. The PVsyst program also used for designing the PV system, The steps of the technique used in this study is illustrated in the form of flow charts as shown in Fig (3) as it starts with data collection, then forecasting population, forecasting water demand, design of PV&RO system, thermal system then comparing between them and ended by discussion & recommendations.

Lab Fit version (4) program has been used for confirming the results obtained by Microsoft excel program version (2016) related to the population forecasting, and load demand forecasting.

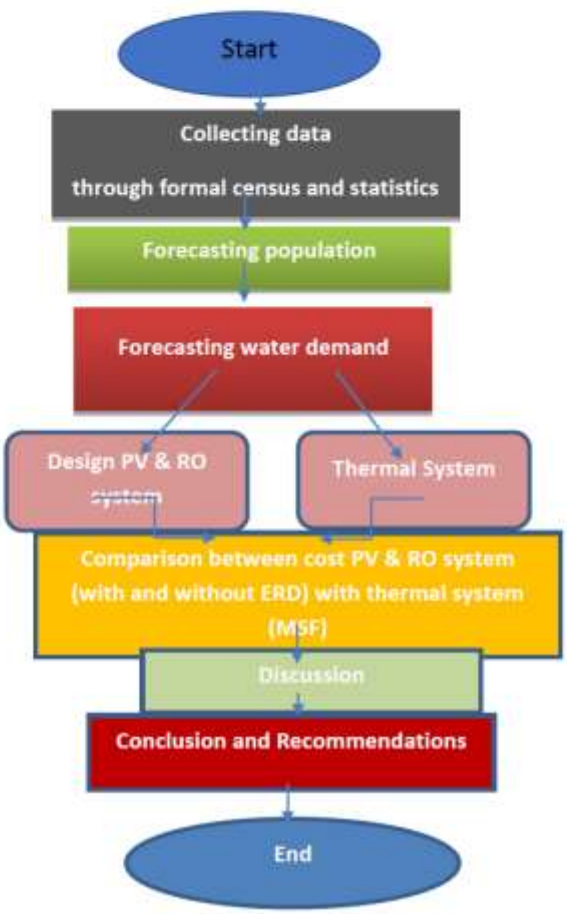


Figure (3) flow chart indicating the steps of the study [7].

4. Results and Discussion

Forecasting models & design equations linear regression model had been used to estimate the population of Derna till 2030.

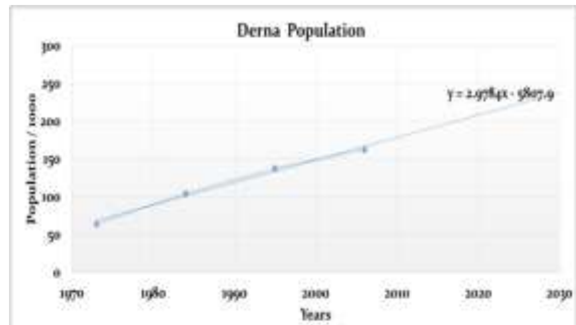


Figure (4) Forecasted Population in year 2030 for the city of Derna

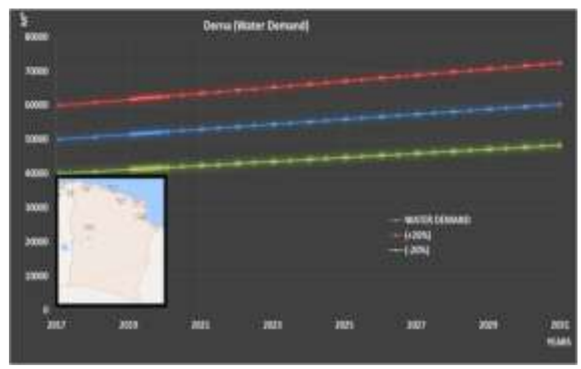


Figure (5) Forecasted Water demand in year 2030 for City of Derna

Cost of electric power generated from PV plant and Grid in Derna.

Availability and Redundancy of operating Ro system.

Availability: number of operation hours in a year after reducing the downtime.

Redundancy: spare production ability.

The plant yearly capacity = 65.000 m^3/day.

The plant yearly capacity=65.000×365=23.725.000 m^3/yr.

Number of hours in a year =365×24=8,760 hours.

Plant average flow =

The number of operation hours in a year are 8.0000 hours. Where 760 hours are for downtime due to maintenance etc.)

Plant flow with availability factor =

Plant flow with availability and redundancy factors of 10% = 2.966×1.1=3.263 m^3/hr.

Required power = 3.263×2.17=7.080.7 Kw

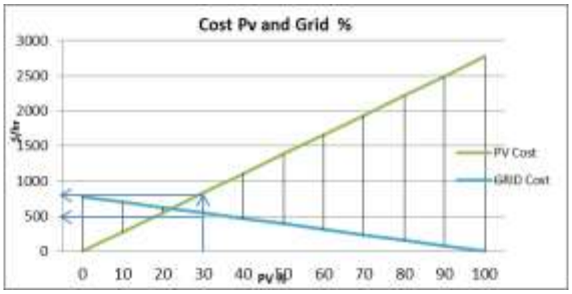


Figure (6) cost analysis for PV and Grid cost

According to the cost analysis indicating in Fig.6) 70% of electric power from the grid had been selected and 30% from PV plant

Grid power = $7{,}080.7 \times 0.7 = 4{,}956.5\ Kw$ (1)

PV power = $7{,}080.7 \times 0.3 = 2{,}124.2\ Kw$ (2)

For Minimum day light hours: 10:06 According to the Sun Graph for Derna City in Fig. (7)

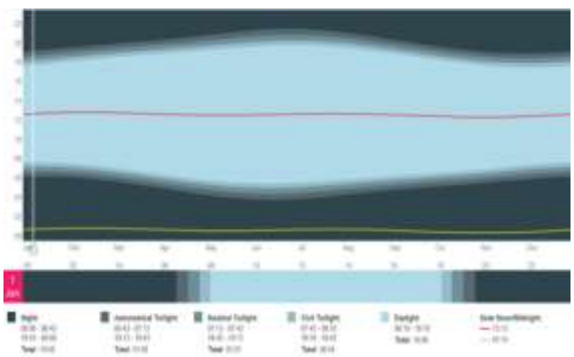


Figure (7): Sun Graph for Derna City

This means that during daylight, the consumption will be about 40% of the total required power, 30% from PV and 10% from the grid. The rest of the day will be covered by electricity grid.

$\text{Cost (PV)} = 2{,}124.2 \times 0.391 = \$830.56$ (3)

Where cost of Kwh of PV power is estimated to be $0.391.

$\text{Cost (Grid)} = 4{,}956.5 \times 0.11 = \$545.22$ (4)

Where cost of Kwh in the grid is $0.11 according to the price announced by Libyan ministry of electricity.

Total cost during the full day $= 830.56 + 545.22$ (5) $= \$1{,}357.78$

$\text{Cost per Kwh} = \frac{1{,}357.78}{7{,}080.7} = \$\ 0.194$ (6)

According to the assumed value of the PV% (assumed 30%), the required area is 11,778 m^2,and as there is no obstacles regarding the utilization of the area, it is possible to use more area for producing more PV is illustrated in Fig. (8).

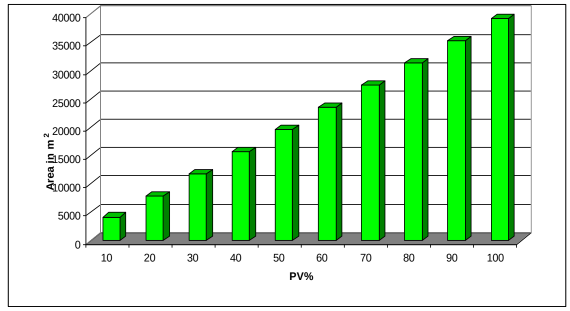


Figure (8) Area in square meter required for PV%

PV system design:

PVsyst program have been utilized for the design of the PV system for the electric power plant required for desalination plants in the study area.

The following procedures had been applied through the Pvsyst program. Locations of the PV plants had been determined by GPS system for Derna.

The design concept is based on designing units for PV as shown in Fig. (9)

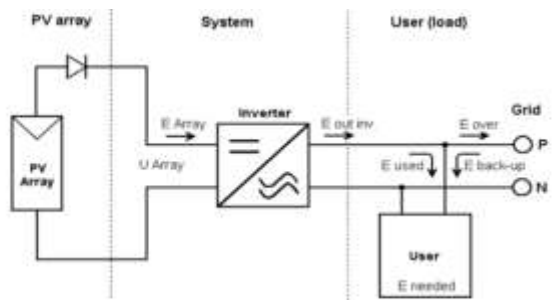


Figure (9) The used PV system

Derna plant:

Situation:

Latitude: 32.2° N Longitude: 20.1° E , Altitude: 6m,Albedo: 0.2.

The input data included the geographical sites, monthly Meteorology values (through Meteonorm7.1station),

Determination of number of modules

Number of modules 5.904modules, In series: 18 modules (Sunmodule XL SW 360 mono).

In Parallel: 328stringModules area:11.778 m^2

Inverters design

Model: RPS ND 0500, Manufacturer: BonfigiolioVictron.

Unit nominal power = 500, No. of inverters: 4, Total power: 2,000 KW (AC).

For the case of 30% PV, it is found that number of modules are 5,904 modules.

Where 18 modules in series and 328 strings in parallel as shown in Fig (10).

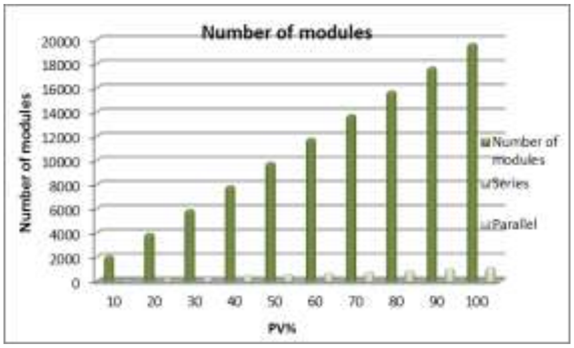


Figure (10) number of modules, series and strings against PV%.

Saved Carbon Dioxide (CO_2) Emission for Derna:

For calculating the quantity of saved CO_2 Emission for 15 years in Derna desalination plant due to the usage of PV plant for feeding part of its electric consumption, PVsyst program have been employed for this calculation. The saving in CO_2 is illustrated in Fig. (11). The quantity of Saved CO_2 Emission (15 years) = 149,036.509 ton.

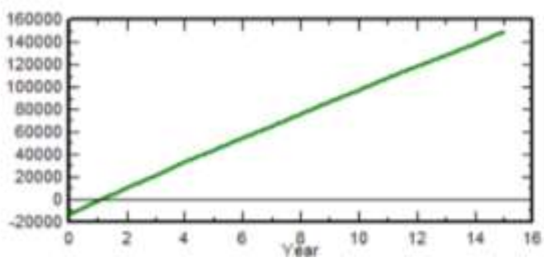


Figure (11) The quantity of Saved CO2 Emission (15 years)

Design of RO membrane:

IMS Design program has been utilized for designing the membrane for RO system. Sample of waters from Benghazi, had been analyzed in Libyan laboratory (Benghazi University laboratory) for obtaining the percentages of Total dissolved solids (TDS), potassium (K), Sodium (Na), Magnesium (Mg), Calcium (Ca), strontium (Sr), Barium (Ba), Carbonates (CO_3), Bicarbonate (HCO_3),Nitrate (NO_3), Chloride (Cl), Fluorid (F), Sulfate (SO_3), Silica (Si) and Boron (B). This is addition to measurement of the pH values. Temperature (T^oC) of sample water was measured at the collection time by a thermometer. The data of the analyzed sample used as input data for the Rosa Program. The IMS Design outputs are represented in the characteristics of the used membrane, its type and cost.

Membrane type:

The membrane type has been selected to fulfil the requirements of the design, the following are the characteristics of the selected membrane: Membrane model: SWC5 1640 Dimensions of the designed membrane: Membrane area:1670ft^2(155m^2).

Figure (12) membrane design.
(source: output of IMS Design software)

Table (1) dimension of the designed RO membrane.

A inch(mm)	B inch(mm)	C inch(mm)	Weight Ibs (Kg)
40 (1016)	15.75 (400.05)	3(76.2)	139 (63)

Max applied pressure:6.9 MPa, pH range:2-11 Maximum operating temperature: 45^{o}C

Design of RO desalination plant:

The next step after the design of RO membrane is to find a method for saving energy in order to have efficient design, the method represented here in energy recovery device. Energy Recovery Devices (ERDs) are at the core of saving energy in the operation of any seawater reverse osmosis.

(SWRO) desalination facility. Isobaric or "positive displacement" These devices are the most efficient solution available today and can reduce the energy consumption of seawater reverse osmosis (SWRO) systems by up to 60 percent.

This motivated the researcher to compare between the cost of the designed RO plant with and with ERDs as follows:

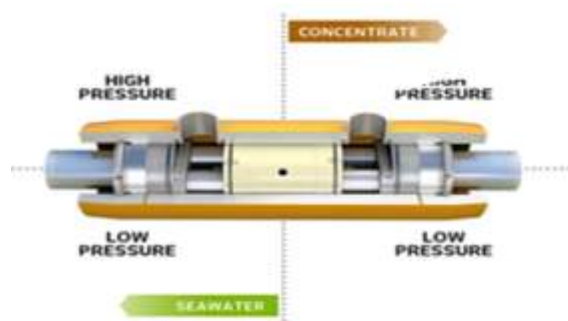


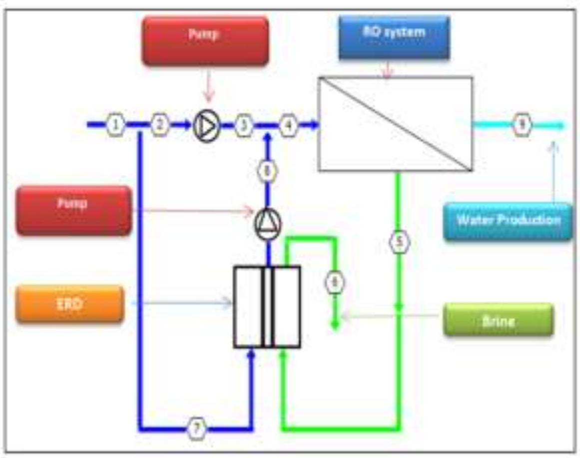
Figure (13) Energy Recovery Device.
(source: Energy Recovery Inc, 2011). [8]

Table (2) Design of RO desalination Derna plant (without ERD)

Array	Vessels	Feed(bar)	Conc(bar)	Feed(m³/h)	Conc(m³/h)	Flux (lmh)	Highest flux (lmh)	Highest beta
1-1	207	59.2	57.8	31.53	15.78	17	36	1.07

Table (3) Design of RO desalination Derna plant (with ERD)

Array	Vessels	Feed(bar)	Conc(bar)	Feed(m³/h)	Conc(m³/h)	Flux (lmh)	Highest flux (lmh)	Highest beta
1-1	207	61	59.6	31.53	15.78	17	36.3	1.07



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	pH	Econd (µs/cm)
1	6526	0	34484	7.60	54753
2	3293	0	34484	7.60	54753
3	3293	61.0	34484	7.60	54753
4	6526	61.0	35565	7.60	56370
5	3266	59.6	70837	7.82	108197
6	3266	0	68656	7.82	105034
7	3233	0	34484	7.60	54753
8	3233	61.0	36665	7.60	58015
9	3263	0	225	6.13	490

Figure (14) Design of RO desalination Derna plant.

Design of Thermal MSF desalination plant:

The city of Derna has been selected for the case study of thermal energy fed MSF system due to the reality that this city is the sole city that is fed

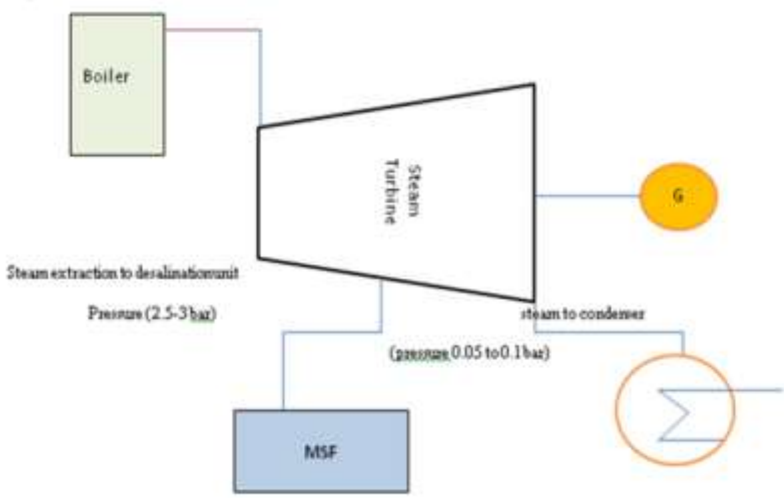


Figure (15) Steam turbine supplying (source: by the researcher)

$$W_{eq} = m_s * (H_{su} - H_{sc}) * E_{st} \quad (7)$$

$$GOR = m_d / m_s \quad (8)$$

$$W_{eq} = \frac{1000kg\ Waterproduct\ ((H_{su} - H_{sc}) * E_{st}}{GOR} = \ * 0.000277\ Kwh/Kj \quad (9)$$

$$E_{Total} = \frac{W_{eq}(t) + (Elec_{one\ hour} * Hours_t)}{P_t} \quad (10)$$

$$E_{Total} = \frac{W_{eq}(t) + (Elec_{one\ hour} * Hours_t)}{P_t} \quad (11)$$

W_{eq}: The energy conversion from thermal to mechanical.
md: weight of distilled water
ms: weight of steam
GOR: gained output ratio
H_{su}: is the enthalpy of inlet steam
H_{st}: is the enthalpy of the steam extracted
E_{st}: the power losses at the desalination
E_{Total}: is energy consumption in kWh/ m^3 at time period t
ELec (1hour): is the total electric power consumption
$Hours_t$: represents the total operating hours of the MSF
Pt: is the total water production in m^3

Table (4) Thermal specifications of the MSF desalination units.

Plant	No. of units	Unit installed capacity m^3/Day	Steam to brine heater and before			Steam to ejectors			
			Temperature °C	Pressure bar	Enthalpy (Hsu)Kj/kg*	Temperature °C	Pressure bar	Enthalpy Kj/Kg* HSC	Ton/Operation Hour
Derna	10	65000	112	1.2	2698.1	210	18	2335.5	2.7

Table (5) The hourly electric power requirement for one unit operation at the MSF desalination plants (KW).

Plant	Sea water pumps	Brine recycle pumps	Blow-down pumps	Distillate pumps	Condensate pumps	Ball Cleaning pump	Auxiliary, ejector condenser pumps	Sea water intake electrical equipment	Total
Derna	3490	8790	243.1	772	228	5.8	0.0	294.2	13823

$$W_{eq} = \frac{1000((2698.1 - 2335.5) * 0.9}{7} * 0.000277 = 12.91\ Kwh/Kj$$

Average electric power consumption = (13823 /65000) = 0.212 *Kwh/m^3*

$$E_{Total} = E_{Total} = \frac{12.91 + (0.212 * 24)}{1} = 12.9 + 5.1 = 18 Kwh/m^3$$

$$Cost\ of\ Energy\ for\ Producing\ 1\ m^3 = 18 \times 0.11\$ = 1.98\ \$/m^3$$

Table (6) comparison between Ro and MSF desalination systems in Derna city.

Techniques	Electric energy equivalent to thermal (Kwh/m³)	Electric energy consumed in equipment (Kwh/m³)	Total (Kwh/m³)
MSF system	12.9	5.1	18
Ro system	0	4.06	4.06
RO system with ERD	0	2.17	2.17

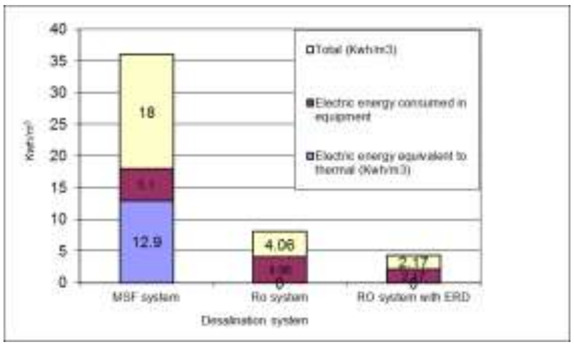


Figure (16) Energy consumption for MSF, RO and RO with ERD system

For estimating the payback period for the suggested capital cost system, it is clear from Fig (17) that the pay pack period will be in the fourth year as indicated.

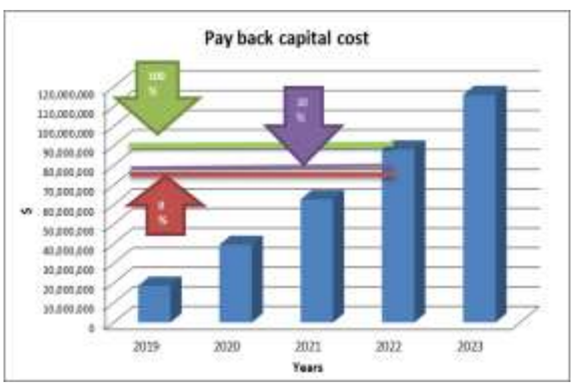


Figure (17) Pay back period of the designed capital cost system

For selling price ($1), it is clear that pay back period will be 5 years when using RO (grid) without ERD and will be 4 years when using RO (pv30%+ grid) with ERD as show in Fig. (18).

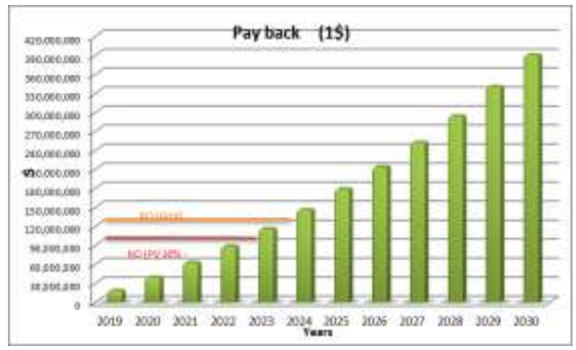


Figure (18)pay back period according to selling prices of ($1)

For selling price ($0.9), it is clear that pay back period will be 5 years when using RO (grid) without ERD and will be 4 years when using RO (pv30%+ grid) with ERD as shown in Fig. (19).

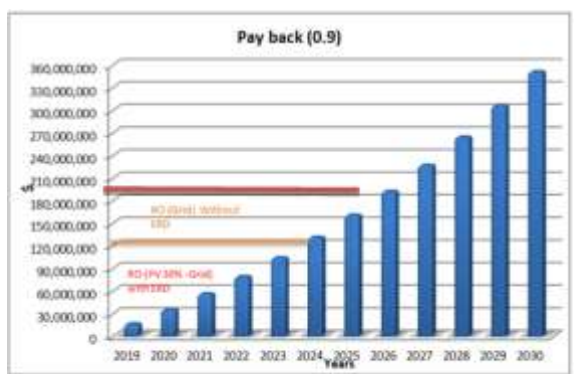


Figure (19) pay back period according to selling prices of (0.9$)

For selling price ($0.8), it is clear that pay back period will be 6 years when using RO (grid) without ERD and will be 5 years when using RO (pv30%+ grid) with ERD as shown in Fig. (20).

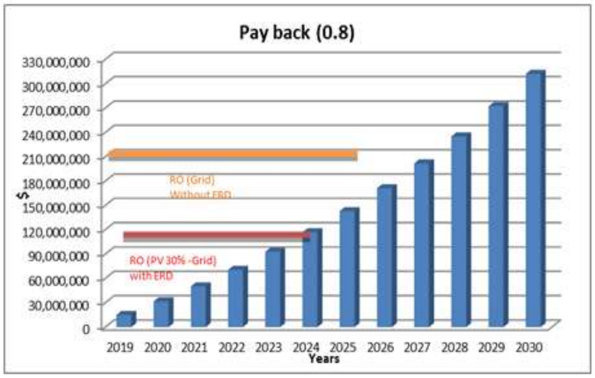


Figure (20) pay back period according to selling prices of (0.8$)

5. Conclusion

The different costs of the different combinations of RO PV and RO grid systems with and without ERD in addition to MSF are illustrated in the following figure.

- According to the presented case of Derna, the calculated cost of producing water for RO with PV (without ERD) is 1.06 $/m^3$.
- According to the presented case of Derna, the calculated cost of producing water for RO with PV (with ERD) is 0.7 $/m^3$.
- Also the calculated cost of producing one cubic meter of desalinated water, using RO with (with ERD) in case of using the electric power produced by the electricity utility (Grid) in Libya, is about 0.52 $/m^3$.
- Also the calculated cost of producing one cubic meter of desalinated water, using RO (without ERD) in case of using the electric power produced by the electricity utility (Grid) in Libya, is about 0.72 $/m^3$.
- Also the calculated cost of producing one cubic meter of desalinated water, using MSF (Grid) is about 1.98 $/m^3$.

The calculations obtained in this study are consistent with the literature review.

The lowest cost obtained with using combination of Grid electric power in addition to ERD for RO system, this refers to the savings resulted from ERD device and low cost of grid electric power.

MSF is higher cost due to non-existence of electric power plant in the neighborhood of MSF plant as MSF plant depend on exhausts of the electric power plant.

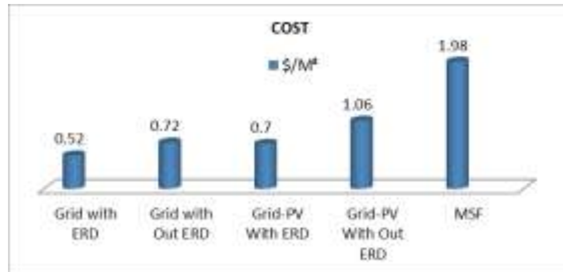


Figure (21) Different costs of the different combinations of RO PV and RO grid systems with and without ERD in addition to MSF.

Regarding the total cost of the different combination of energies, it is clear from Fig. (22) that the lowest cost comes from the Grid with energy recovery device; this refers to the governmental support of electricity, the matter that not reflect the actual cost of the energy, in addition to that reality that ERD had improved the energy consumption.

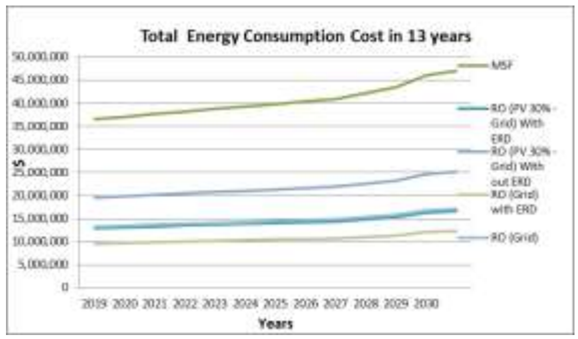


Figure (22) total cost for different energy combinations

Regarding the yearly total consumption (Kw) from 2019 to 2030, it is clear that MSF has the highest consumption, while RO with ERD has the lowest consumption (kW) as shown in Fig. (23).

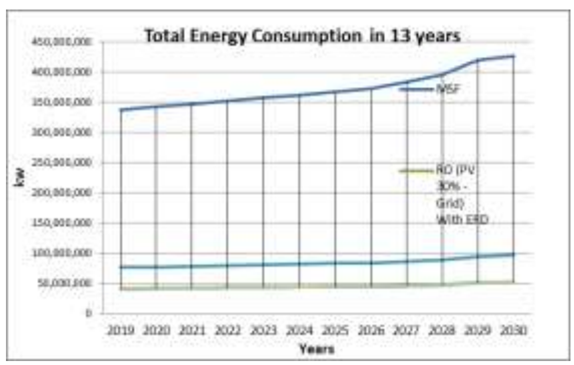


Figure (23) Different Total Energy Consumption in 13 years of the different combinations of PV and RO grid systems with and without ERD in addition to MSF.

Regarding the monthly total consumption (Kw) for the year 2019, it is clear that MSF has the highest consumption, while RO with ERD has the lowest consumption (kW) as shown in Fig. (24).

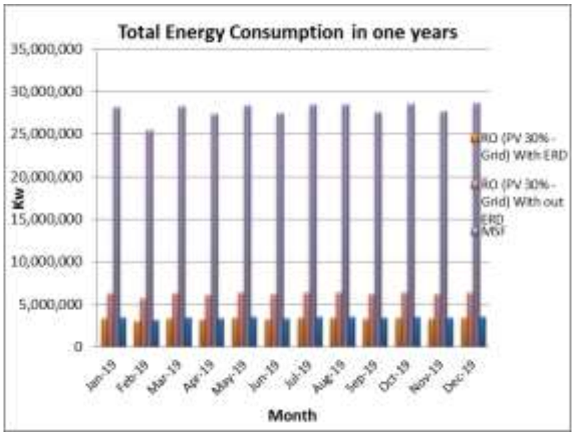


Figure (24) Different Total Energy Consumption in one years of the different combinations of RO PV and RO grid systems with and without ERD in addition to MSF.

6. Recommendation

- RO system with ERD is preferred as desalination system compared with the MSF thermal system; this is due to the low operation cost as its electric energy consumption is smaller than that consumed in MSF thermal system.
- Focusing on water desalination systems in Libya and trying to minimize use of the ground water as the ground water should be optimized for saving the rights of the coming generations.
- Studies should focus on the renewable energy systems for different purposes in Libya; in order to preserve oil and preserve sustainable development.
- Expanding the development of renewable energy systems in order to reduce pollution.
- Researches should focus on minimizing the cost of renewable energy in order to become competitive with the fossil energy (oil and gas).

Future Works

- The work developed during this thesis may be continued in different ways, as shown below:

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- Other studies should be conducted regarding the operation using wind energy with RO system.
- Other studies should be conducted regarding operation using hybrid systems energy with RO desalination system.
- Comparative studies should be conducted for investigating the optimal solution for energy alternatives with RO desalination system.
- Emissions should be studied in a comparative study between renewable and conventional energy.

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