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Economic Evaluation of RO and MEH Desalination Units in Iranian South-Eastern Villages

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Abstract
The primary objective of desalination research is the development of a way to produce fresh water at lower cost. The present study investigated two freshwater production methods of Reverse Osmosis (RO) and Multi-Effect Humidification (MEH) (artificial distillation), and analyzed them from an economic standpoint, and subsequently pointed out the important and effective factors in decreasing saltwater desalination expenditure for each one of the mentioned units. Different aspects of these units were investigated as well. However, all the prices are assumed with the current condition and expenses in Sistan Baluchestan province, Iran. The results from economic analyses, obtained employing COMFAR III, showed that, in regions where locals have access to local grid, application of RO unit has no economic justification, while MEH units, powered by solar energy, are more economic in remote regions receiving adequate solar irradiation. However, the water produced by RO can be purchased at 0.02 $/lit, and by solar MEH unit (Respect to introduced characterization), at 0.032 $/lit. Although, the sensitive analysis of IRRs' variation in proportion to three factors namely sales income, fixed capital expenditure and operational expenditure were conducted.

Keywords: Economic Evaluation, Desalination, RO & MEH, COMFAR, Iran.

Introduction

Potable water has not always been easily available in numerous regions worldwide; and potable water shortage crisis is expected to rise in the years to come. Huge amount of ground water is available in many arid, semi-arid, and coastal areas across the globe with the salinity levels are usually more than 30.0 ppt which is inappropriate for human use (EPA, 2006; Mitsch and Gosselink, 1986). Water shortage, today, is considered as one of the problems threatening agriculture, industry, and even human lives in many countries. However, 'Desalination' is one of the solutions to the said problem, most applicable in certain countries close to the sea or those in where surface or groundwater is not available (Tan and Ng, 2010; Wijmans and Baker, 1995). Moreover, due to the environmental impacts desalination is much better than using dams which causes desalination get more popular (Al-Sahali and Ettouney, 2007).

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Reverse Osmosis (RO)

This certain desalination system employs membranes, as they play important roles in nature in separating salts. Salt rejection and water permeability rates are key functions in the type of membrane used. Membranes are assessed through TDS (Total Dissolved Solid) percentage, indicating total percentage of dissolved solid materials ranging from %98 to %99.5. Osmosis process is referred to the separation of dilute from concentrated solution. Water flow continues up to the point that the osmosis-induced pressure is identical to the pressure of concentrated solution.

Up to now, many articles are conducted to study RO. Some of them are discussed as follows. Hafez and El-Manharawy worked on the detailed cost analysis of grid connected small RO plants built at tourist resorts in Sinai and Hurgada on the Red Sea coasts in Egypt (Hafez and El-Manharawy, 2003). Moreover, Helal et al. studied on RO desalination unit powered by a photovoltaic array which showed an ideal solution to provide small communities isolated at remote areas with freshwater (Helal et al., 2008). Also, Manolakos et al. experimented on the low-temperature Organic Rankine Cycle (ORC) engine coupled with a Reverse Osmosis (RO) desalination unit.

RO is a pressure-based process in which freshwater is passed through the membrane, by the applied pressure, and salt is retained on the other side of the membrane. In brief, RO is a membrane-technology filtration method in which water from pressurized concentrated saline solution is separated from insoluble materials by passing through the membrane. No phase or heat alteration is required for this separation.

The required energy to pressurize the saltwater solution is provided through a high pressure pump. Pressure ranges between 5 – 80 bars, depending on the extent of water salinity. In addition, RO membranes have significant advantages such as highly selective separation properties, high recovery ratio, and better mechanical and chemical properties (Al-Sahali and Ettouney, 2007).

Reverse osmosis system is comprised of the following components:

- Water supply (well or sea water)
- Pre-treatment section, entailing separation of solid particles from water (filtration), as well as addition of chemical materials such as acids to prevent the development of micro-organisms, bearing extra importance since the membrane needs to stay disinfected.
- High-pressure pump, requiring an electrical energy of 3-12 kWh/m^3. This unit provides the required pressure for the circulation of water along the membrane while retaining the salt. The membrane needs to be able to endure the inflow water pressure. No membrane succeeds in total exclusion of salt, therefore, there are, always, low amounts of salt find their way through the membrane and into the purified water. Two types of commercial membranes are normally applied: spiral wound and hollow fiber.
- Storage system
- Control system
- Post-treatment section or, in other words, purification and transfer, comprising water preparation and distribution for use.
- Membrane disinfection unit

Artificial Distillation Multi Effect Humidification (MEH)

This process follows, artificially, natural water cycle, starting by water evaporation as a result of solar irradiation, which later on is condensed in a separate compartment, and consequently turned back into water.

On the occasion of application of the foregone process in a desalination unit, the consumed energy in water evaporation section can be recycled in the condenser section through certain measures. On the other hand, maximum required temperature for this process is 80 $^{\circ}$C; hence, the system does not need electricity for operation. The required thermal energy for solar desalination units is provided by solar irradiation, which is transferred to water via thermal solar collectors as a result of which, water evaporates. Increased temperature causes the water to move, which is afterwards condensed to liquid at the MEH desalination unit. Unheated inlet water is utilized in order to reduce temperature in this unit. As a result, besides an increase in the inlet water temperature in this stage, the outlet steam temperature from collectors falls simultaneously. Consequently, freshwater is produced in the outlet of MEH desalination unit. The unevaporated additional water returns to the original water storage.

In 2002, Farid et al. conducted a mathematical modeling and simulation study of solar MEH units based on humidification-dehumidification that focused on assessing the effects and performance of various components participated in the process of desalination (Farid et al., 2002).

The manufacturing expenditure of the discussed system can be lowered through mass production as well as modular production. Several methods are employed by TiNOX to reach this goal including:

- Application of CSC tanks as containers
- Application of components with longer life spans
- Equipped with modular components, these units are applicable in 1000, 5000, and 10000 lit capacities
- Application of special aluminum profiles designed for easy and quick installation;
- Application of high tech welding accessories for innovation in manufacturing plastic condensers

Alternative heating systems for providing the required heat include: application of the additional heat from gas or diesel engines, gas or diesel burners, and solar thermal collectors. The main customers of MEH units are remote hotel facilities, ecotourism, villas, military stations, small communities and small farms.

The prospect of application of the mentioned systems is very promising. Manufacturers, thus, are considering future objectives of reduced production expenditure, simultaneous production of electricity and water (CPW), market development, as well as industrial mass production.

The complexity of economic evaluation and comparison of different methods of fresh water production

Supply of water through desalination is already recognized as a stable source for production of potable water in countries with limited sources of freshwater; however, the extent of application of these technologies is dependent upon the results of pertinent economic evaluations and determination of their important economical parameters including:

1. Local availability of each certain method
    - The amount of initial investment in each certain method
    - Maintenance and repair expenditure for each method
    - Operation expenditure (including energy consumption, man power, etc.)
2. Location
    - Manner of supply of water in the location
    - Real estate price
    - Accessibility to national power grid
    - Energy price
    - Skilled man power
3. Probable applications
    - Drinking
    - Tourism
    - Industry
    - Animal husbandry
    - Horticulture
    - Agriculture

The main question regarding the equipments of desalination units is that whether they are effective in terms of investment. Considering high expenditure of salt and brackish water desalination, expenditure of fossil fuels, environmental concerns, population increase, as well as government policies regarding liberalization of prices for energy carriers and its influence on energy expenditure, there is the question of whether these methods of water production are economically justifiable.

The present study aims at answering the question of justification of desalination units subsequent to investigation and assessment of pertinent contributing factors.

Material & Methods

All the data are gathered by site visiting, searching related databases and governmental and private organizations such as Iranian ministry of power. In addition, amortization is obtained through multiplying direct and indirect capital expenditure by installments coefficient, expressed by the following equation:

$$a = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (1)$$

in which 'i' is annual interest rate, and 'n' represents installations life (Brent, 2006; OECD, 2008).

Moreover, COMFAR 3 is used in this study which is computer software that permits the user to simulate the short and long term financial and economic situation of investment projects (Benjamin, 2006).

Results and Discussion

Components of Economic Calculations

Calculation of unit production expenditure is dependent upon processing capacity, installation location profile, as well as design features. System capacity will determine the dimensions of different equipments such as pumping units and membrane area. Production expenditure is divided into direct, indirect, and current annual expenditure, which will be elaborated separately in the following sections.

Direct Capital Expenditure

Preliminary direct expenditure includes purchase costs of different types of equipment, auxiliary equipment, property prices, and construction expenditure, explained as follows.

a. Property Prices

The price of property ranges significantly from zero to an amount proportionate to the certain properties of the installation location. Public properties are usually zero-priced. The expenditure pertaining to installations contracted with municipalities or state organizations, also, can be zero or very low. Price of land is considered zero in rural regions.

b. Water supply from wells

Due to the local data gathering and field visiting, it was indicated that well drilling expenditure reaches up to $ 650 per meter. Average water well capacity is estimated at 500 m^3/d. Drilling cost of a water well at a depth of about 30 meters in Sistan Baluchestan province, Iran, is approximately $20,000 manually, and $30,000 mechanically.

c. Process equipments

The required equipments comprise the most costly division of direct capital expenditure and depend on the type of process and production capacity. The pertinent equipment expenses are listed as follows:

- Process equipments
- Measurement and control instruments
- Pipelines and valves
- Electrical wiring
- Pumps
- Pre-treatment and ultra-filtration equipments
- Seawater suction and discharge lines
- Chlorination facilities

d. Auxiliary equipments

- Transfer pipes
- Storage tanks

e. Construction price

Construction price widely ranges from $100 to $1000 per square meter. In Sistan Baluchestan province, Iran, an approximate cost of $15,000 is foreseen for all the above. Well drilling, fencing, and construction expenditure are given in Table 1.

Table 1. Well drilling, fencing, and construction expenditure in Iran

Well drilling and pertinent Construction	Expenditure ($)
Well Drilling	20,000
Fencing & Building Construction	15,000
Equipments pertinent to the well & buildings	10,000
Total Preliminary Construction Expenditure	45,000

Indirect Capital Expenditure

Every single propounded instance in this section is expressed by a percentage of direct capital expenditure. Indirect capital expenditure includes:

a. Transportation and insurance expenditure
   Equal to 5% of the total capital expenditure
b. Construction overhead expenditure
   Equal to 15% of direct constructional materials and labor expenditure, adjusted in accordance with unit dimensions (total capital expenditure). Construction overhead expenditure includes:
   - Non-cash benefits
   - Handling labor
   - Field monitoring
   - Temporary facilities
   - Construction equipments
   - Small tools
   - Miscellaneous
   - Contractors' Fees
c. Personal Expenditure

Personal expenditure includes legal and engineering remunerations which comprise equal to 10% of material and labor expenditure and are adjusted for unit measurement.

d. Discretionary expenditure

The discretionary expenditure of the projects is estimated at 10% of total capital expenditure.

Current Expenditure

Current expenditure covers the entire incurred expenditure subsequent to construction termination and during the actual operation. The above-said entails expenditure of: labor, energy, chemicals, spare parts, and miscellaneous affairs. A brief account of every instance of current expenditure estimation follows:

a) Electricity

Electricity expenditure ranges from 0.04 to 0.09 $/kWh which represents expenses in European countries versus Middle East and the United States respectively.

b) Labor

This type of expenditure, depending on the state or private nature of the constructed unit, is determined by properties of the installation location. Recent tendency in repair and operation tasks concerning the operation of desalination units are invested with contractors. As a result, the number of full-time labor such as unit manager, engineering team, and experienced technicians is reduced.

c) Membrane Replacement

Annual membrane replacement rate may be anywhere between 5 to 20%. The lower rate representing low salinity well waters accompanied by adequate function and pre-treatment of the system, whereas, the higher rate represents high salinity waters in regions such as Persian Gulf, where the function and pre-treatment of the system is not desirable.

d) Maintenance & Spare Parts

The annual maintenance and spare parts expenditure comprise less than 2% of total capital expenditure annually.

e) Insurance

Insurance rate is 0.5% of total capital expenditure.

f) Amortization

Pertinent to annual payments, amortization covers the entire direct as well as indirect capital expenditure. Experience suggests that the life of 30-year installments is appropriate. The average amount for annual interest is 5%; however, economic analyses consider the range of 3 to 8%. Moreover, Price of chemicals used in RO desalination unit are given in Table 2.

Table 2. Price of chemicals used in RO desalination unit

Chemical	Unit Cost ($/kg of Chemical)	Dosing Rate (kg Chemical/kg water)	Specific Cost
Sulfuric acid	0.504	2.42×10^{-5}	0.122
Caustic soda	0.702	1.4×10^{-5}	0.0098
Antiscalent	1.9	4.99×10^{-6}	0.0095
Chlorine	0.482	4.00×10^{-6}	0.00193

Capital & Installation Expenditure

Table 3 shows purchase expenses of modules and their supporting bases, as well as battery and inverter prices. Cabling and installation expenditure is considered 300 $/kW in network-independent systems.

Annual System Maintenance Expenditure

In order for a significant comparison to be rendered, the entire expenditures and revenues need to be equalized in terms of present value (PW). The annual system maintenance expenditure, therefore, considering the life span of 15 years, annual interest rate of 8%, and discount rate of 0.12, is 9137.7 $. With regard to the life of different components of a photovoltaic system, certain parts require replacement in a 15-year period. The lives of invertors and batteries in the present study are considered 10 and 5 years, respectively. In addition, part replacement expenditures are given in Table 4.

Table 3. Establishment expenditure for network-independent 25^{kw} photovoltaic plant equipped with battery array to provide the required annual power for RO unit of 32000^{kw}

Product	Number	Unit Price ($)	Total ($)
Sharp 185w NT-185U1 Module	136	925	125800
PSI PARS 6/48 Inverter	25	1500	37500
S6VGC SLD-G(12V-180AH) Battery	100	400	40,000
Handling Expenditure			6000
Cabling & Installation Expenditure			20,000
Manpower Expenditure for Design & Installation			5000
Overhead, Insurance, and Tax			70,290
Total Capital Expenditure			304,590

Table 4. Part replacement expenditure

Part Replacement	Cost ($)
Inverter Replacement (10 yrs)	37500
Battery Replacement (5 yrs)	40000
Battery Replacement (10 yrs)	40000
Battery Replacement (15 yrs)	40000

Price of an MEH Solar Desalination Unit and Unit Price of the Produced Water

The MEH hydration-dehydration unit manufactured by TiNOX-MAGE Company is considered the source of reference in the present study. The mentioned unit is designed in Munich and assembled and offered in Hamburg (Table 5).

Table 6 presents installation expenses of desalination unit facilities including man-hour as well as the required materials proposed by TiNOX-MAGE. Labor compensation per hour is considered at 10 € in the following calculations.

Annual maintenance expenditure of MEH units, including evaporators and general repairs, to be conducted in 6-month intervals, is presented in Table 7. Total annual expenditure based on a 15-year life span in provided as well.

Subsequent to the conducted evaluations, RO technology, among other membrane technologies, proved to maintain the lowest water production price. While, solar MEH technology, among many other, is an appropriate unit to utilize with flat solar collectors. Considering an interest of 10 -15% for the seller, the water produced by RO can be purchased at 0.02 $/lit, and the water produced by solar MEH unit (by the capacity of 5000 lit/day), at 0.032 $/lit (Table 8).

Table 5. Price of MEH Desalination Unit Manufactured by German Company of TiNOX-MAGE

Product	Price for 5000 lit/day Capacity
Desalination Module	20 kW Heat Exchanger, Seawater Circulator Pump, and Control Panel at: $91,308
Flat Solar Collectors	168 m2 Absorption Area, Piping, Pumps, and Controller Set at: $96,040
Multi-Storey Thermal Storage Tank for 24-hrs Operation	At 6*2000 liter capacity, made of Mild Steel, at 3 bar Pressure, Insulated at: $13,440
Photovoltaic power supply system for pumps and control panels	Four-cord terminal box, 40A cutout switch, charge controller, lead-acid batteries, independent inverter, AC/DC converter, 3 * 100 A NH switch a: $47,880
Healthy and Hygienic Potable Water System	Resalination and UV Disinfection units at: $ 3603.6
Monitoring Order and Installation by TiNOX (Optional)	An engineer, a technician, 14 working days, and travel expenses at: $ 44,940
Total	$ 297,211.6

Table 6. Installation Expenditure of MEH Desalination Unit

Equipment Installation Expenditure	5000 lit/day System	
	Man-Hour	Man-Hour
Preparation of Installation & Foundation Locations	25	50
Foundation Required Materials		2500
Piping of Solar System	20	600
Piping Required Materials		12000
Engineers’ Commission	15	1500
Saltwater Storage Tank		1200
Produced Water Storage Tank		1400
Total	60	19700

Table 7. Annual Maintenance Expenditure for MEH Unit

Annual Maintenance Expenditure	5000 lit/day System	
	Man-Hour	Price ($)
Evaporative Pads	60	840
Materials Employed in Evaporators		1050
General Repairs (every 6 months)	20	280
Materials Utilized in General Repairs		2100
Total Annual Expenditure		6650
Total Annual Maintenance Expenditure for 15 Years		56920.53

Table 8. Proposed Prices for Guaranteed Purchase of Potable Water

Desalination technology	Price of Water $/lit
RO	0.02
Solar MEH	0.032

Results of the Produced Reports by COMFAR 3 (RO)

Results from COMFAR software analysis showed that the minimum acceptable rate is 12 percent for the total capital, and 20 percent for the investor. Furthermore, the results indicate that NPV for all the above rates is negative, which imply that execution of the project under discussion is non-economic.

Internal Rate of Return (IRR)

Results from Comfar analysis indicated that the investment internal rate of return is -19.82 percent and Investment Rate of Return is -22.69 percent.

Net Present Value (NPV)

Net present value is displayed by Comfar as Fig. 1. As can be indicated, Fig. 1 shows NPV variations in proportion to different discount rates. (NPV sensitivity in proportion with discount rate) Curve intersection with the x-axis represents the project's IRR.

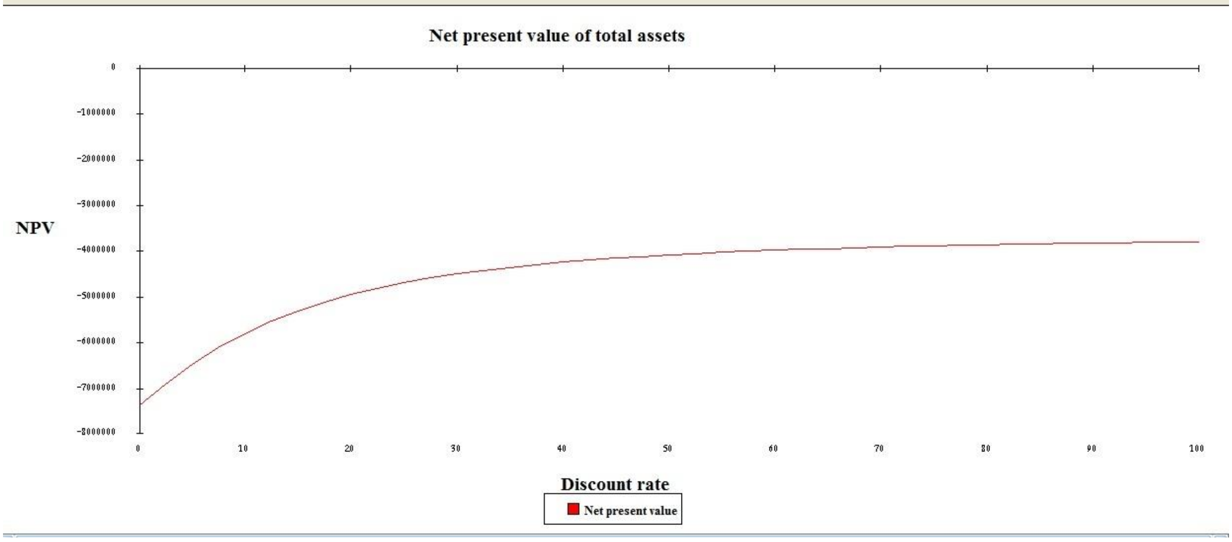

Figure 1. Total Capital NPV (per one-tenth dollar)

As observable in Figure 1 the total capital's NPV with the rate of return of 12%, is -557789.4 dollar. The negative amount implies that the project is economically feasible. Moreover, the investor's NPV with the rate of return of 20%, equals -403716.7 dollar which yet again indicates the economic undesirability of the project.

Sensitivity Analysis

Figure 2 depicts sensitivity as well as variations of IRR in proportion to three factors of sales income, fixed capital expenditure, and operational expenditure.

The results show that the project is not sensitive in terms of fixed investment and that a 20 percent increase in the fixed capital, does not render the investment undesirable.

However, the mentioned project is sensitive in terms of operational expenditure and sales income in such a manner that on the occasion of a 20 percent decline in sales income or a 20 percent rise in operational expenditure the project will no longer maintain investment desirability.

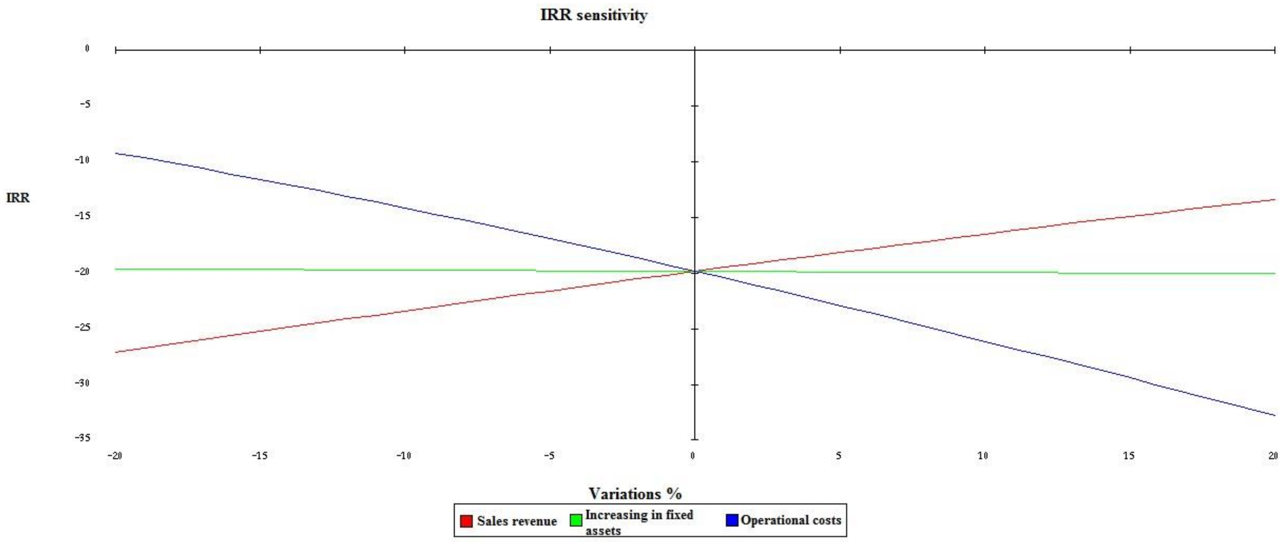

Figure 2. IRR Sensitivity (per one-tenth dollar)

Results of the Produced Reports by COMFAR 3 (MEH)

Results from software analysis showed that the minimum acceptable rate is 12% for the total investment, and 20% for the investor. Furthermore, the results indicate that NPV for all the above rates is positive, which imply that execution of the project under discussion is economic.

Internal Rate of Return (IRR)

Results showed that the investment internal rate of return is 20.91% and Investment Rate of Return is 30.34%.

Net Present Value (NPV)

Fig. 3 shows NPV variations in proportion to different discount rates. (NPV sensitivity in proportion with discount rate) Curve intersection with the x-axis represents the project's IRR.

As observable in the diagram the total capital's NPV with the rate of return of 12%, is $280729.4. The positive amounts imply that the project is economically desirable. Moreover, the investor's NPV with the rate of return of 20%, equals $105303 which once again indicates the economic desirability of the project.

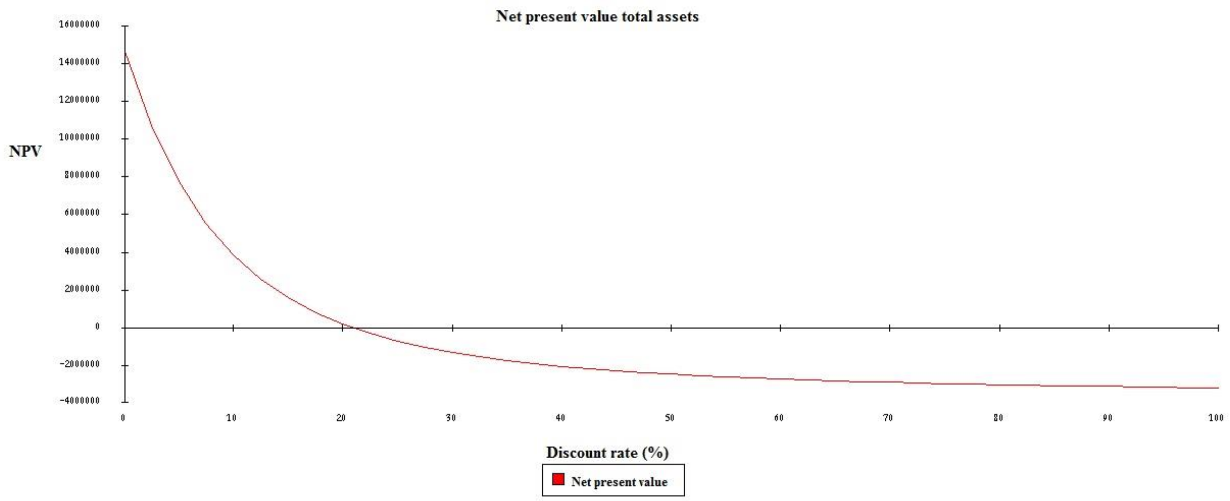

Figure 3. Total Capital NPV (per one-tenth dollar)

Sensitivity Analysis

As can be seen in Fig. 4 depicts sensitivity as well as IRR variations in proportion to three factors of sales income, fixed capital expenditure, and operational expenditure. The results show that the project is sensitive in terms of sales income, fixed investment and operational expenditure in such a manner that with a 20 percent decline in sales income or a 20 percent rise in operational as well as fixed expenditure the project will no longer maintain investment desirability. The project shows less sensitivity regarding operational expenditure.

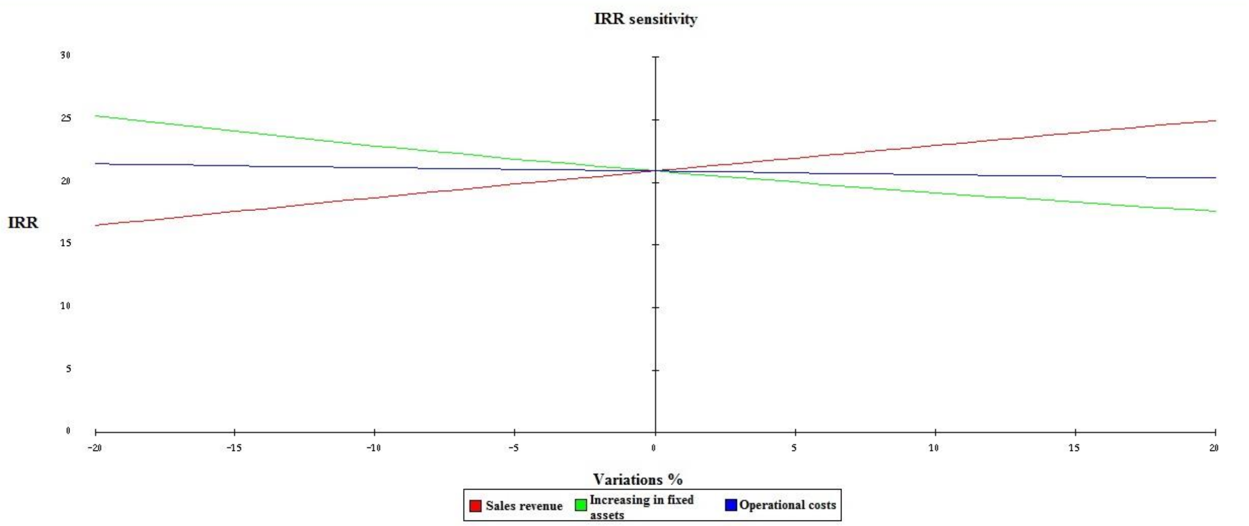

Figure 4. Sensitivity Analysis due to IRR Sensitivity (per one-tenth dollar)

Conclusion

Numerous factors influence investment expenditure of desalination units: capacity, system type, location of establishment, accessibility to saltwater, inlet water quality, labor, energy supply, financing, manner of dumping the remaining condensation wastes, quality and quantity of the produced water, and safety coefficient of the installed set, to name a few.

The economic evaluation of the price of water offered to the customers needs to take into consideration all of the above.

Another important and effective agent in the investigation of desalination unit expenditure is, undoubtedly, energy supply and pertinent expenditure.

Depending on the type of desalination units, a source of thermal energy is required which entails 50-70% of implementation and exploitation expenses. The existing sources of energy and their respective environmental effects also influence water treatment expenditure, as national and regional-dependent expenses are effective in the actual prices.

The total capital's NPV of the MEH with the rate of return of 12%, is $280729.4. The positive amounts imply that the project is economically desirable. Moreover, the investor's NPV with the rate of return of 20%, equals $105303 which once again indicates the economic desirability of the MEH project. On the other hand, the total capital's NPV of RO with the rate of return of 12%, is -557789.4 dollar. The negative amount implies that the project is economically feasible. Moreover, the investor's NPV with the rate of return of 20%, equals -403716.7 dollar which yet again indicates the economic undesirability of the RO project. To sum up, the water produced by RO can be purchased at 0.02 $/lit, and by solar MEH unit (Respect to introduced characterization), at 0.032 $/lit.

A comparison of the two units suggests that RO is not economically justifiable in regions where the power grid is accessible while, in remote areas where local power grid is not available or where the required power is generated by exported natural gas and the solar irradiation is adequate it can be justifiable in the long run.

This, of course, will entail providing the proper groundwork concerning enactment of regulations, standards, and investments in the area. As for MEH system, the more the capacity of the unit, the less the price of the produced water, and since the source of energy is the sun, it is economically justifiable in remote regions benefitting from high solar irradiation.

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