Chapter 9

The Use of Renewable Energy for the Provision of Power to Operate Reverse Osmosis Desalination Facilities at Massawa

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Additional information is available at the end of the chapter

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Abstract

The following energy sources, in a various combinations were assessed to provide potable water using seawater reverse osmosis (SWRO) for around 50,000 people in Eritrea: wind power and solar power. Various types of SWRO technology were employed and the cost of scenarios that were able to meet the users' water needs was compared with the costs of the equivalent diesel generator powered scenario over 25 years. The most financially-attractive scenario, a hybridised power plant using solar and wind power was compared with the equivalent conventionally (diesel generator) powered scenario using present and net present value (NPV) methodology. The discount rate used for NPV calculations was found to be pivotal for this comparison, so the logic of the appropriate discount rate was investigated and a discount rate of 3.6% was considered the most appropriate. This resulted in the renewable powered solution for this scenario being financially attractive when compared to the diesel generator powered scenario. This conclusion was mainly due to recent changes in the prices of diesel fuel in Eritrea and solar power generally. Research conducted on this scenario previously, and published in 2014 based on 2010 prices, concluded that this scenario was not financially attractive in comparison to diesel power.

Keywords: reverse osmosis desalination, solar power, wind power, renewable energy economics, discount rate

1. Introduction

Renewable energy is currently considered by many to only have viability for a small portion of energy delivery within a larger system due to intermittency.

This intermittency potentially undermines the environmental and energy security advantages on offer from renewable energy and decentralisation of supply.

This chapter:

- Sets out the investigation of the use of renewable energy sources in such a way that they could be justified for use without reliance on conventional energy sources and to stand alone as an independent and viable power source in their own right; and
- Is a continuation of research initially conducted in 2011 and subsequently published in 2014 [1], to reflect the impact of changes to diesel fuel and solar photovoltaic prices since 2011.

The scenario used to investigate the technical and financial viability of renewable energy was its use to power reverse osmosis (RO) desalination plants to provide water for the personal use of 50,000 people.

1.1. The location

Eritrea was selected due to its susceptibility to droughts, and consequential loss of life. The hypothetical pretext for the need for municipal desalination is that Eritrea has a substantial coastline, and the sea level rise expected due to climate change has the potential to hasten the intrusion of saline water into the fresh groundwater aquifers in the coastal zone. The focus of this research will be the island of Massawa, shown below, which is in a particularly dry part of Eritrea with, typically, less than 200 mm of annual rainfall as shown in **Figure 1**. This is in comparison to the UK, where according to the Metrological Office [2], the minimum rainfall between 1981 and 2010 is around 600 mm.

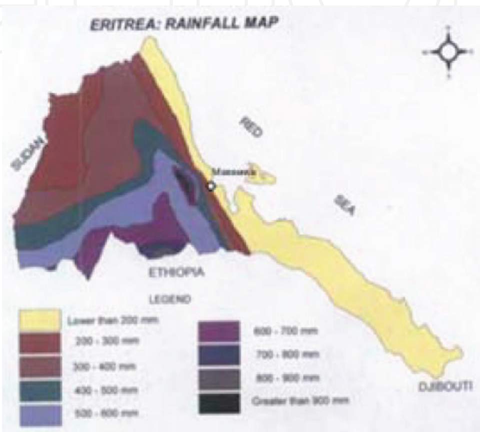

Figure 1. Rainfall map of Eritrea.

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2. The modelling exercise

The modelling exercise was conducted in 3 main stages as shown in **Figure 2**.

2.1. Stage 1

Stage 1 employed Solar PV with the No Brine Stream Recovery (BSR) RO plant only as shown in **Figure 3**.

The methodology used to identify the minimum number of membranes that the RO plant would require is shown in **Figure 4**.

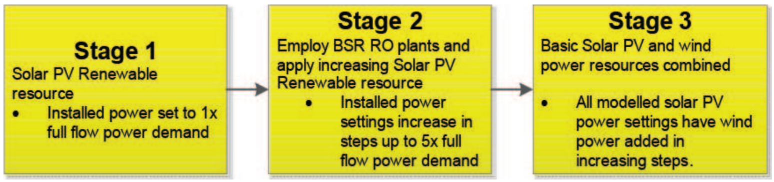

Figure 2. Three stages of modelling exercise.

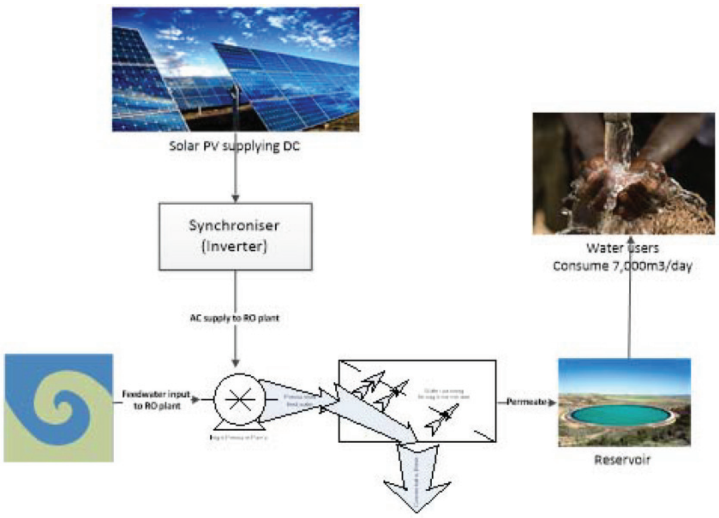

Figure 3. Single source of renewable energy to power RO plant.

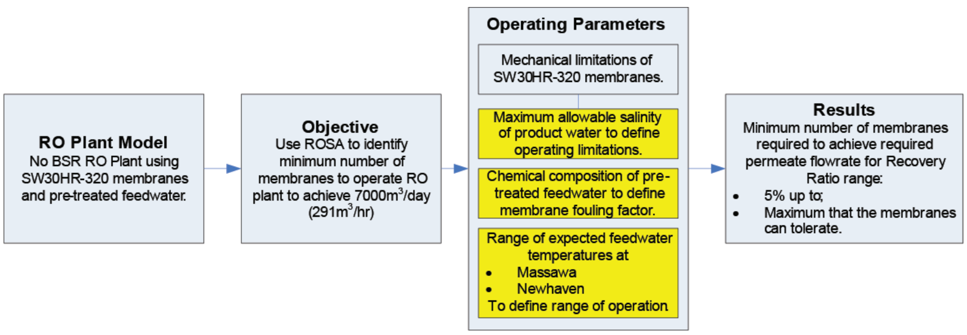

Figure 4. Methodology to identify minimum number of membranes that the no BSR RO plant requires.

2.1.1. Results

The initial results (shown in **Figure 5**) gave the minimum number of membranes required to produce 7000 m^3/day, if the plant were run for 24 h continuously at each recovery ratio.

It was decided that the RO plant would operate where the minimum number of membranes required was consistent between 15 and 24% recovery ratios, as shown in **Figure 5**.

A schematic diagram of the No BSR plant employed for the modelling within this research is shown in **Figure 6**.

The resulting No BSR RO plant operating profile, including impacts on efficiency as load changes as expected due to intermittent power as indicated in the US DOE Tip sheet 2 [3], is shown in **Figure 7**.

This surface was mapped mathematically using polynomial equations and the method used to calculate the amount of water produced, was a 'for' loop in Matlab, as shown below:

$$\begin{aligned}&\text{for } i = 1{:}rwr\\&\quad newwater1(i) = polyval(ppolycoef(index(i),:), Pg1(i,:))\ ;\\&\text{end}\end{aligned} \tag{1}$$

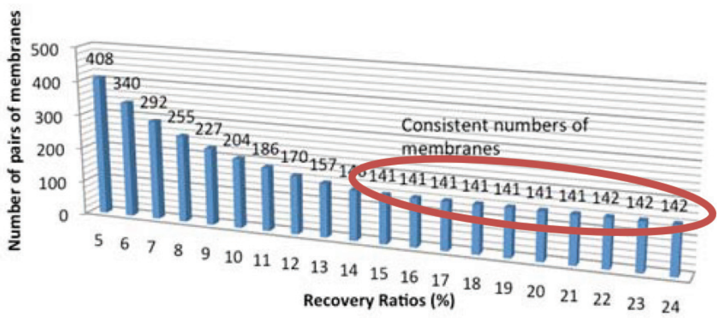

Figure 5. Minimum number of pairs of membranes at each site for maximum temperature at various recovery ratios.

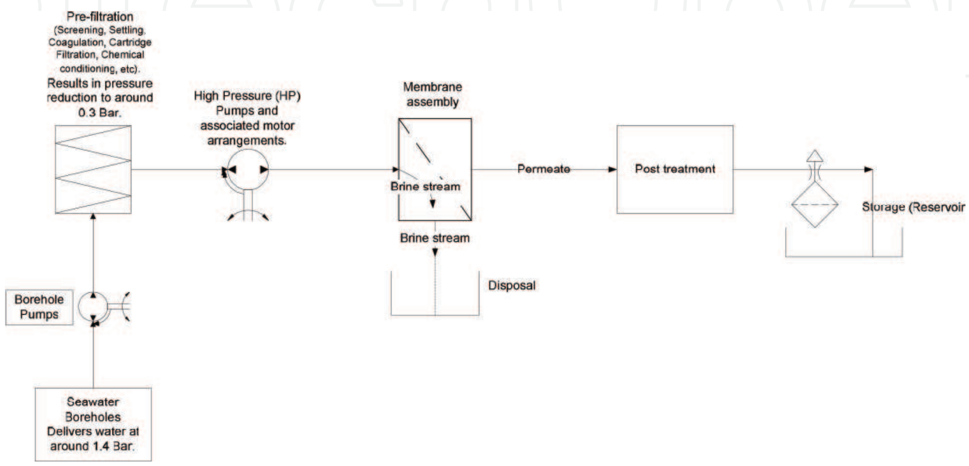

Figure 6. No BSR RO plant.

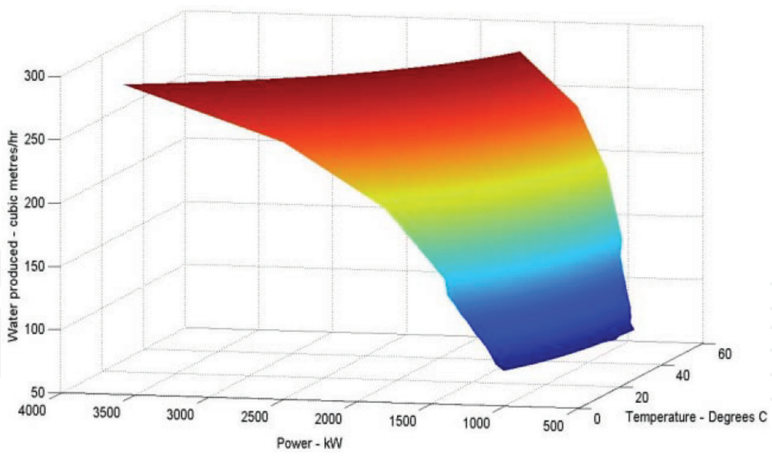

Figure 7. No BSR RO plant water production profile at varying power and feedwater temperature.

where *Pg 1* = the power available to operate the RO plant at each hour during the year; *index(i)* identifies the location of the prevailing seawater temperature for each hour of the year; *ppolycoeff* is a file that contains all the polynomial equations relating to each 0.01°C step from 3 to 42 °C; *i=1:rwr* defines the number of times that the calculation should be conducted before stopping; *i*=the number of the calculation being conducted, in this case, conducted in sequence from 1 – (rwr) the max number of which is 8760 (the number of hours in a year); *Polyval* is the matlab function that then evaluates the polynomial equation identified by *(index(i))* making the corresponding *Pg* at *(i)* the subject.

2.2. Solar power

Massawa is one of the hottest inhabited places in the world, so solar PV was adopted.

HOMER (energy modelling software for renewable energy systems) was employed to derive the solar irradiance on an hour-by-hour basis based on the monthly averages from [4], as shown in **Table 1**.

2.2.1. Renewable energy system employed within model

The solar array for this process assumes that 10% of the available radiation, at any time when the sun is shining, is captured and converted to usable DC electrical power. This DC power is then be converted, by an inverter, to AC power, suitable for use by the RO plant. The efficiency of this power conversion was taken as between 90 and 95%.

Sufficient solar photovoltaic power was installed so that the maximum power output during the year from the solar PV would achieve the maximum flowrate of the RO plant. Additional power was then added in discrete levels, up to (and including), the power required to achieve five times maximum flowrate of the RO plant.

2.3. Stage 2

Stage 2 employed the same methodology as Stage 1 (application of solar PV only), but for the BSR RO plants (Pelton wheel and Pressure exchanger).

Month	Original monthly average (W/m²/day during that day)	Conversion to kW/h	Clearness index* applied by HOMER
Jan	303	7.272	0.895
Feb	357	8.568	0.954
Mar	366	8.784	0.884
Apr	376	9.024	0.855
May	337	8.088	0.754
Jun	306	7.344	0.686
Jul	300	7.2	0.674
Aug	301	7.224	0.684
Sep	330	7.92	0.784
Oct	319	7.656	0.830
Nov	308	7.392	0.891
Dec	295	7.08	0.905

*The 'clearness index' is a dimensionless number between 0 and 1 indicating the fraction of the solar radiation at the top of the atmosphere that is able to pass through the atmosphere to the Earth's surface.

Table 1. Average monthly irradiance.

2.3.1. Pelton wheel

The Pelton wheel RO plant system modelled is shown in **Figure 8**.

As shown in **Figure 8**, the Pelton wheel BSR RO plant design utilises the brine/concentrate stream to power a Pelton wheel turbine, which is mechanically linked to a high pressure pump arrangement and partially pressurises the incoming feedwater. This reduces the external power required to raise the feedwater pressure. The resulting Pelton wheel BSR RO plant water production profile, at varying input power and feedwater temperatures, is shown in **Figure 9**.

2.3.2. Pressure exchanger

The pressure exchanger RO plant system modelled is shown in **Figure 10**.

As shown in **Figure 10**, the pressure exchanger BSR RO plant uses the brine/concentrate stream to pressurise a hydraulic chamber. This hydraulic chamber acts on a piston arrangement, which in turn is used to partially pressurise the incoming feedwater. A booster pump then raises the now partially pressurised feedwater to the correct pressure to combine with the feedwater pressurised by the high pressure pump for desalination by the RO plant membranes.

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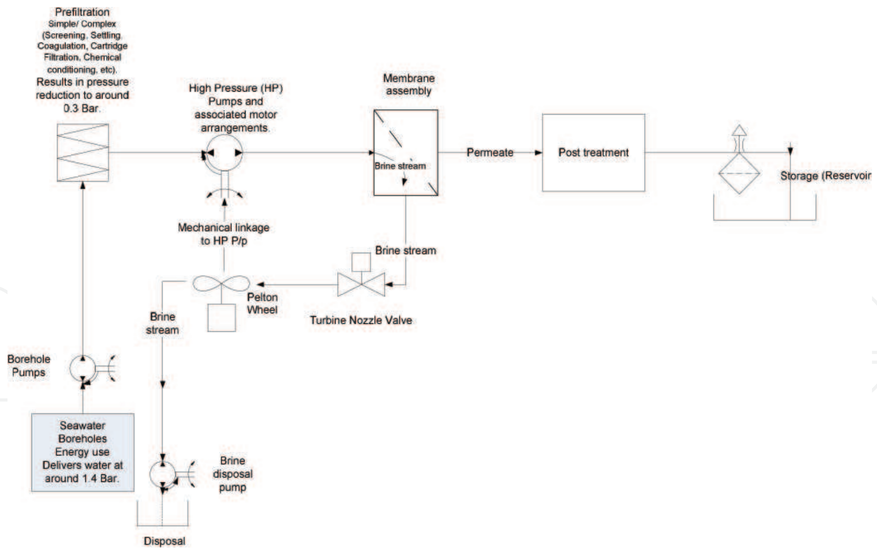

Figure 8. Pelton wheel BSR RO plant.

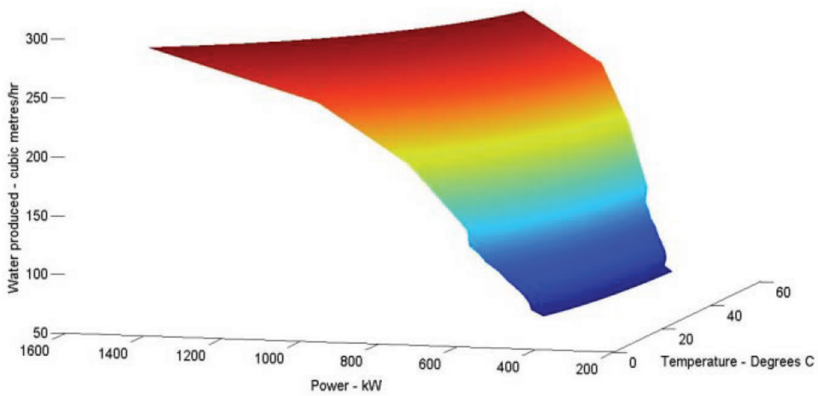

Figure 9. Pelton wheel BSR RO plant water production profile at varying power and feedwater temperatures.

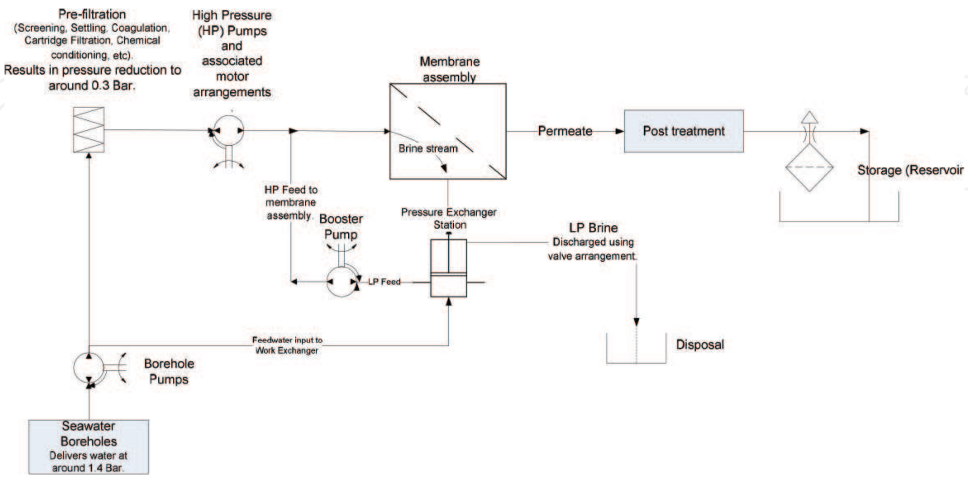

Figure 10. Pressure exchanger BSR RO plant.

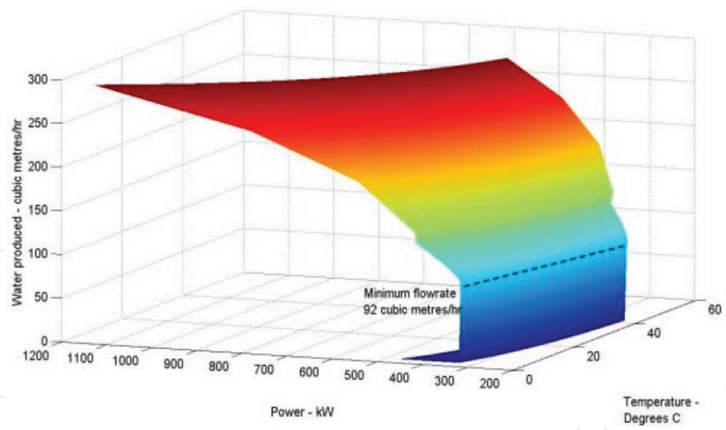

Figure 11. Pressure exchanger BSR RO plant water production profile at varying power and feedwater temperatures.

The resulting pressure exchanger BSR RO plant water production profile, at varying input power and feedwater temperatures, is shown in **Figure 11**.

As was the case in Stage 1, additional solar PV power was added in discrete levels up to (and including) the power required to achieve five times maximum flowrate of each of the RO plants.

2.4. Stage 3

Stage 3 modelled the addition of wind power in an attempt to make the renewable powered scenario competent to produce the correct amount of potable water for the Massawa residents.

2.4.1. Wind resource available Massawa

The monthly average wind speed data at Massawa was taken from monthly average data over 4 years based on local weather reports [5] and applied to HOMER to derive the wind speed for each hour of the year, shown in **Figure 12**.

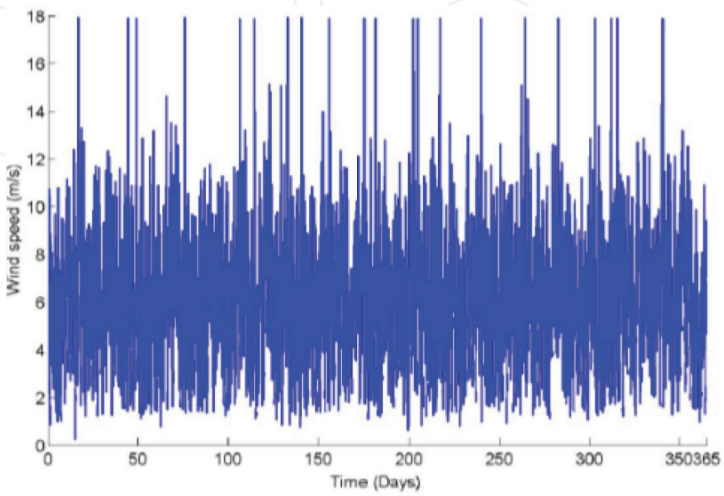

Figure 12. Wind speeds at Massawa over 1 year.

As was the case in the previous Stages, additional wind power was added in discrete levels up to (and including) the power required to achieve five times maximum flowrate of each of the RO plants.

2.5. Scenarios modelled and scaling of renewable energy scenarios

Sixty scenarios were modelled with BSR and No BSR RO plants limited to 7000 m^3/day output capacity with varying installed solar PV and wind capacity.

There was limited success in identifying scenarios that were able to meet the water demands of the local population without increasing the capacity of the RO plant to compensate for intermittency.

So, each of the RO and Power plant scenarios were scaled up by the ratio of water shortfall, i.e. if the combined RO plant and Power scenario made 50% of required water, both the RO plant and installed power are doubled in size to fully meet the water demand requirements.

3. Costs

Prices are based on exchange rate of $1–£0.636 as was the case in 2011, when much of the original research was conducted.

3.1. RO plant and reservoir costs

Table 2 shows the CAPEX and OPEX costs associated with the unscaled RO plants employed based on [6–10].

Reservoir costing was taken as £82,115,200 based on extrapolation of various reservoir costs from [11] to meet the required holding capacity.

3.1.1. Impacts of intermittency

Intermittent operation of desalination plants is possible and has already been realised in smaller systems as shown in [12, 13]. According to Rizzuti [14], however, it is understood that for large-scale seawater desalination plants, the plant's lifetime could be reduced by increased scaling, fouling and corrosion.

This said, there is potential for the mechanical wear aspects on the plant to be reduced due to the increased size of the scaled up renewable RO plant, as the components will not experience

(£x10^6)	No BSR	Pelton wheel	Pressure exchanger
Capital costs	9.27	10.38	11.12
Total costs over 25 years	48.8	79.1	56.0

Table 2. Capital, O&M and total costs over 25 years for RO plants.

the stress of operating at full load for as much of the time. It was considered reasonable to conclude that the impact on RO plant operation and costs will vary based on the power supply intermittency. The degree of this impact is not well understood and is worthy of further investigation, but based on the research conducted, it is considered appropriate to increase O&M costs to acknowledge the impact of intermittency. Therefore, in the light of the lack of information to support accurate estimates, a pessimistic assumption was employed for intermittent operation that annual O&M costs increase by 100% over those of a continuously operated plant on a per m^3 of water produced basis increasing the costs as shown in **Table 3**.

3.2. Renewables

Table 4 shows the CAPEX and OPEX costs associated with the renewable energy sources employed including the reduction in the price of solar PV between 2010 and 2016.

3.2.1. Reduction in solar PV price in 2016

Figure 13, taken from the National Renewable Energy Laboratory (NREL) report on solar costs [17], shows how costs for solar PV has reduced significantly since 2009.

The costs employed for 2017 were based on the 'utility scale PV, fixed tilt (100 MW) as shown on the right hand side of **Figure 13**. \$1.42/W = £903/kW.

This was considered to be an optimistic price due to Massawa's relatively remote location and limited market potential and so the supply chain cannot be relied upon to be developed to a stage where it provides competitive pricing. The NREL webpage [18] shows deviation of +/− \$694/kW about a mean cost of \$2025/kW, which would make the worst case cost \$2719/kW (£1729/kW).

So for the purpose of this report the CAPEX for the plant was taken as £1700/kW, which assumes that the PV costs are at the higher end of the range.

Operating cost for	No BSR (£)	Pelton wheel BSR (£)	Pressure exchanger BSR (£)
Continuous operation (£/m^3)	0.62	1.08	0.70
Intermittent operation (£/m^3)	1.24	2.16	1.40
Intermittent operation/ year (£x10^6)	3.16	5.52	3.58
Intermittent operation over project life (£x10^6)	79	138	90

Table 3. Continuous and Intermittent O&M costs for the BSR and no BSR RO plants.

	Solar (2010) [15]	Solar (2016)	Wind [16]
Capital costs (£/kW installed)	3000	1700	1200
O&M costs (£/kW/annum)	15	16	37

Table 4. Capital and O&M costs of renewable energy sources.

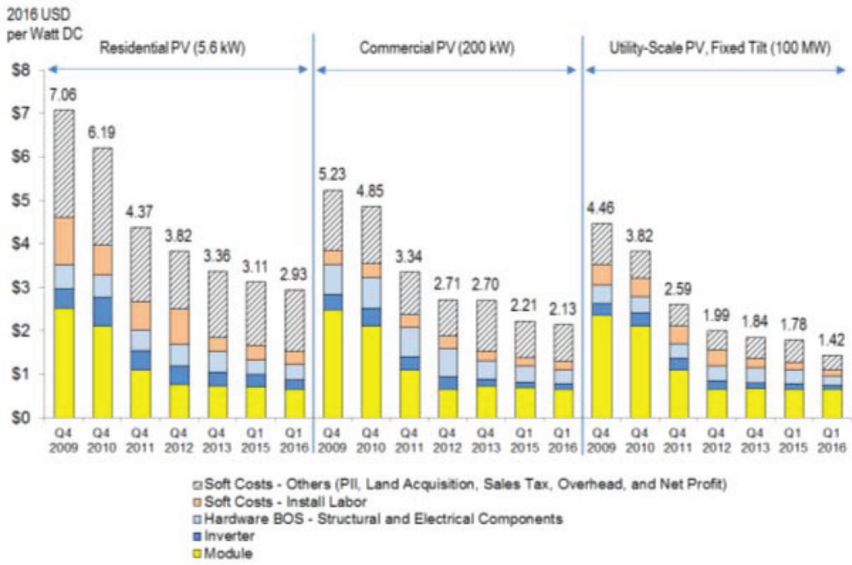

Figure 13. Residential, commercial and utility scale PV system cost reduction since 2009 [17].

3.2.2. Operations and maintenance costs

The NREL webpage [18] indicates the O&M costs for a PV system between 1 and 10 MW are $16 +/−$9/kW, which equates to a high end cost of $25/kW (£15.90/kW).

The Operation and Maintenance (O&M) costs for the plant were taken as £16/kW, which assumes that these costs are, once again, at the higher end of the range, due to the expected lack of a competitive local market.

3.3. Conventional power costs

Table 5 shows the CAPEX and OPEX costs associated with the diesel generator power plant modelled at Massawa, which is based on various sources.

3.3.1. Increase in diesel fuel prices in Massawa

The history of the diesel fuel price is shown in **Table 6** based the following internet sources [21–23].

	Diesel generator costs for 25 years based on 2010 fuel price				Diesel generator costs for 25 years based on 2016 fuel price	
	Installed power costs (£) [19]	Fixed O&M costs (£) [19]	2010 fuel costs (£×10^6) based on £0.71/l [20]	Total scenario costs (including RO plant and reservoir) (£×10^6)	2016 fuel costs (£×10^6) based on £1.75/l	Total scenario costs (including RO plant and reservoir) (£×10^6)
No BSR	380,000	40,000	100.2	232	260.1	392
Pelton wheel	160,000	27,500	43.4	205	114.8	276
Pressure exchanger	125,000	22,500	32.8	171	87.5	226

Table 5. Capital and O&M conventional power plant scenario costs.

Date	Price ($)	Price (£)
2017 (estimated)	2.75	1.749
2014	3.00	1.908
2012	1.71	1.08756
2010	1.07	0.68052
2008	1.07	0.68052
2006	0.81	0.51516
2004	0.40	0.2544
2002	0.25	0.159
2000	0.33	0.20988
1998	0.23	0.14628
1995	0.19	0.12084
1992	0.29	0.18444

Table 6. Historic and estimated diesel fuel cost in Eritrea.

As can be seen from **Table 6** the price of diesel fuel in Eritrea has increased 10 fold between 1992 and 2014, the latest date that price information is available from the sources used. 2014 was a relatively high price point when in the UK diesel fuel was around £1.29/l, but by June 2017 the price of diesel fuel in the UK had fallen to £1.18/l, a reduction of 8.5% due, in part, to the fall in crude oil prices. Although the influences in the price of retail diesel fuel are affected by different variables in the UK and Eritrean economies, for the purposes of this research a reduction of 8.5% of the 2014 price has been adopted for the price of diesel in Eritrea to account of the fall in crude oil price. This results in an estimated price for 2017 of $2.75/l (1.75/l) as shown in **Table 6**.

4. Results

Shown in **Table 7** are the results for the costs of the most financially attractive scenarios for each stage of modelling power source and RO plant type in comparison with the diesel generator powered plant.

Scenarios that have become financially viable (are cheaper than the diesel generator powered equivalent), due to the application of latest diesel fuel and solar PV prices are highlighted in yellow and the most financially attractive is in 'bold' font.

The changes in solar PV and diesel fuel prices have made the renewable powered scenario much more financially attractive than in 2010, but only the renewable powered No-BSR RO plant scenarios have actually become financially attractive in comparison to the diesel generator powered scenario (**Table 7**). The most financially attractive scenario is estimated to cost 77% (around ¾) of the cost of the conventionally powered plant over the project's 25-year life.

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Stag e	Type of RO plant	Solar Power (MW)	Wind Power (MW)	Ratio of renewable scenario cost against Conventional based on 2010 fuel and solar PV prices	Ratio of renewable scenario cost against Conventional based on 2017 fuel and solar PV prices	Percentage difference (%)
1	No BSR	26.34	0	1.72	0.93	46.01
2	No BSR	37.2	0	1.63	0.84	48.39
	Pelton Wheel	21.3	0	2.02	1.40	30.69
	Pressure Exchanger	17.4	0	1.90	1.34	16.43
3	**No BSR**	**17.37**	**9.93**	**1.39**	**0.77**	**45.02**
	Pelton Wheel	10.24	10.54	1.69	1.21	28.6
	Pressure Exchanger	3.76	9.67	1.46	1.09	25.8

Table 7. Technically competent and most financially viable scenarios at Massawa when latest diesel and solar PV prices are applied.

5. NPV

The net present value (NPV) is a central tool in discounted cash flow (DCF) analysis, where each cash inflow/outflow is discounted back to its present value (PV). Then they are added together. So, NPV is the sum of all the terms:

$$Rt/(1+i)^t \qquad (2)$$

where t - the time of the cash flow; i – the discount rate (the return that could be earned on an investment in the financial markets with similar risk.); the opportunity cost of capital; Rt - the net cash flow (the amount of cash, inflow (value of water sold) minus outflow (the cost to maintain the power source and RO plant) at time t.

The next two sections will derive the following to allow the NPV to be calculated.

- Price of water
- Discount rate

5.1. Price of water

As part of an informal telephone conversation, Tesfai [24] stated that municipal water in Eritrea costs less than 5p/l, and bottled drinking water costs less than 10p/l.

The Munich Re Foundation [25] also states that:

'Water from tank trucks costs 15 Nakfa or about €0.90 per 20-litre canister'.

This equates to 3.8p/l or £38/m^3, which is in keeping with Tesfai's estimate of less than 5p/l or £50/m^3.

The situation described above is borne out by Awate [26], which reports rationed water being delivered by bowser in Asmara, the capital of Eritrea in 2017, and the quality of the water provided being saline/brackish and requiring disinfection before consumption, which in turn, due to incorrect disinfection dosing, could have longer term health effects.

For the purposes of this research, the cost of water to the end user at Massawa will be taken as £38/m^3 based on the estimate from the Munich Re Foundation [25], but as the RO plant will, in effect, only be a different water supply point for the tankers to collect their water from, cannot be given credit for the full £38/m^3 that the end user pays.

The overall cost for the most financially viable renewable powered scenario in 2010 based on comparison to the equivalent diesel powered scenario is around £325 million over 25 years, and to break even each cubic metre of water delivered by the RO plant would need to be priced at £5.05, which incidentally is more than 3 times the cost of water in the UK [27].

For the purposes of this research, the cost of the water delivered at Massawa will be £5.05/m^3.

5.2. Discount rate

The normal method for calculating the discount rate for UK government financed infrastructure projects, according to the UK Treasury [28], is 3.5% above the inflation rate.

The inflation rate has varied considerably in the UK over the last 10 years as indicated by the graph on the 'Inflation EU' Website [29] which shows an average high of 4.8% in 2011 and a low of 0.05% in 2015. This gives an average of 2.375% average inflation over the last 10 years. The inflation rate adopted for this calculation is 3.5% to include a margin for the inflation risk over the 25-year term of this project. This figure is in keeping with the long-term rate described in the UK Treasury's 'Green Book' [28] on p. 26.

For the purposes of this research, the discount rate was taken as the sum of these two parts (7%).

5.3. NPV results

Shown in **Figure 14** are the accumulated costs for the most financially attractive renewable powered scenario at Massawa (Solar plus Wind power), and the equivalent No BSR RO plant Diesel Generator-powered scenario.

Having set the price of the water revenue at the cost for the break even of the renewable powered scenario, it is shown to break even at the 25 year point, and the diesel generator powered scenario makes a profit of over £50 million over the life of the project.

When the scenario is updated to reflect diesel fuel and solar PV prices in 2016/7 the scenario changes significantly as shown in **Figure 15**.

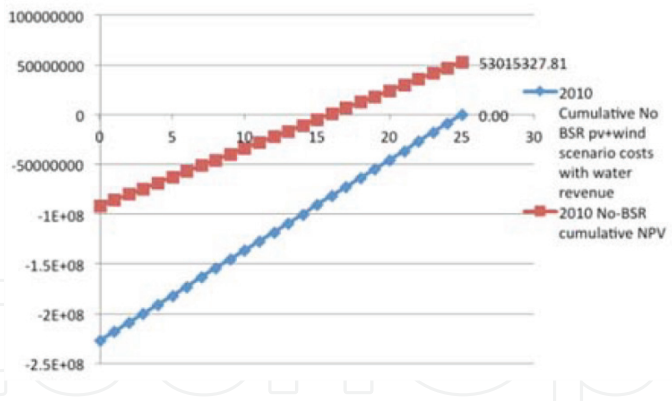

Figure 14. Comparison of cumulative cost for most financially viable renewable and diesel generator-powered scenario in 2010.

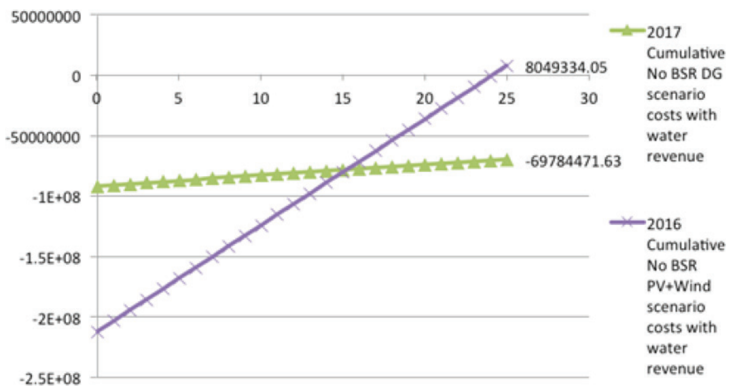

Figure 15. Comparison of cumulative cost of the solar and wind scenario with diesel generator with 2016 prices for diesel fuel and solar PV applied.

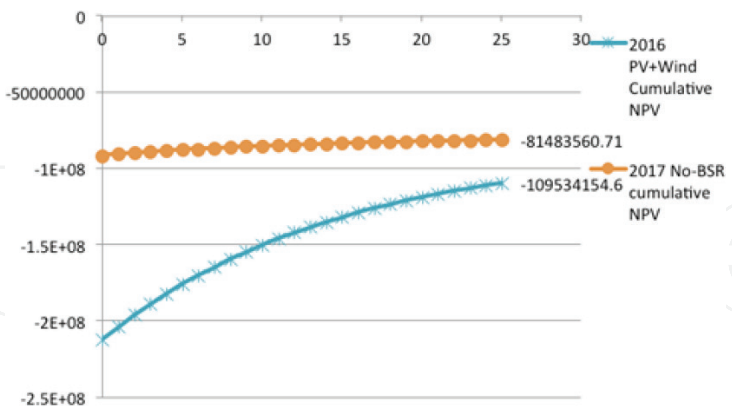

Figure 16. Comparison of the NPV cumulative cost using discount rate of 7% of the solar and wind scenario with diesel generator with 2016 prices for diesel fuel and solar PV applied.

As can be seen from **Figure 15**, the updating of diesel and solar PV prices alters every aspect of the financial viability of the most financially attractive renewable powered scenario, in that:

- It now breaks into profitability;
- It is significantly more financially viable than the diesel generator scenario; and

- The end of life profit for the diesel generator scenario of more than £53 million has now turned into a loss of almost £70 million.

Figure 16 shows the difference that applying the 7% discount rate makes to the financial attractiveness of the scenarios.

As can be seen from **Figure 16**, the application of the 7% discount rate means that neither scenario is now profitable, and further that the renewable powered scenario (PV + Wind) is now more than £28 million less financially attractive than the diesel generator powered scenario.

In selecting the appropriate discount rate for long-term public policy decisions, economic theory tends to distinguish between two components.

- The rate of pure time preference is the discount rate that would apply if all present and future generations had equal resources and opportunities.
- In addition, there is a wealth-based component of the discount rate, reflecting the assumption that if future generations will be richer than we are, then there is less need for us to invest today in order to minimise the financial burden on those that follow.

In the notation of 'The Stern Review' [29], the discount rate, r, is the sum of these two parts:

$$r = \delta + \eta g \tag{3}$$

where δ (delta) is the rate of pure time preference; g is the growth rate of per capita consumption. If per capita consumption is constant, implying that $g = 0$, then the discount rate $r = \delta$; η (eta), determines how strongly economic growth affects the discount rate. A larger value of η implies a larger discount rate, and hence less need to provide today for future generations (as long as per capita consumption is growing).

Stern takes the position that all future generations should be treated equally, except that there is a small probability that future generations will not exist – for example, if a natural or man-made disaster destroys most of, or the entire human race. The probability of destruction of humanity is taken by Stern as 0.1% per year; pure time preference (δ) is therefore set equal to 0.1%. That is, we are only 99.9% sure that humanity will still be here next year, so we should consider the well-being of people next year to be, on average, 99.9% as important as people today. Stated simply, the only reason that the current generation should not consider the needs of those in the future is due to the small possibility that the future generation will not exist, not because the future generation will be rich enough to manage the previous generation's impact on the environment.

To calculate the discount rate, Stern estimates that the growth of per capita income will average 1.3% per year, and sets $\eta = 1$ to indicate that future generations are not richer than the current generation. Therefore, the Stern Report discount rate is:

$$r = \delta + \eta g = 0.1\,\% + (1 \times 1.3\%) = 1.4\% \tag{4}$$

http://dx.doi.org/10.5772/intechopen.76837

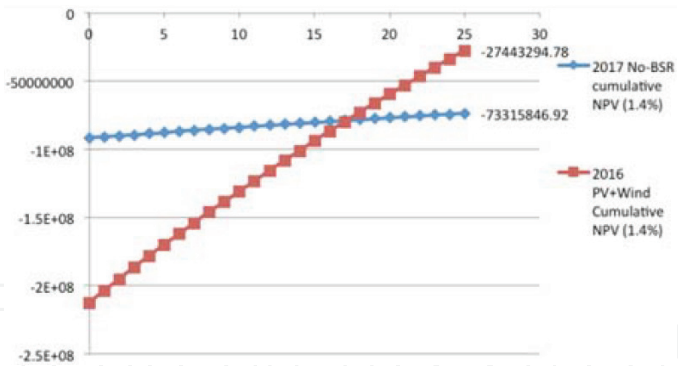

Figure 17. Comparison of the solar and wind with diesel generator no BSR scenario with discount rate of 1.4%.

This makes a marked difference to the viability of the renewable powered scenario, as shown in **Figure 17**.

As can be seen from **Figure 17**, the reduction of the discount rate means that, although neither scenario is financially viable, the renewable powered scenario is now more than £45 million more financially attractive than the diesel generator powered scenario.

5.4. An alternative point of view

Taking the Stern position that this generation can only apply 0.1% to the discount rate, it does not seem entirely unreasonable to suggest a discount rate of 3.6% based on:

Long-term view of inflation (3.5% as derived previously) + 0.1% based on probability that next generation will not be here

This would give appropriate recognition to the fact that this project represents a significant CAPEX investment to:

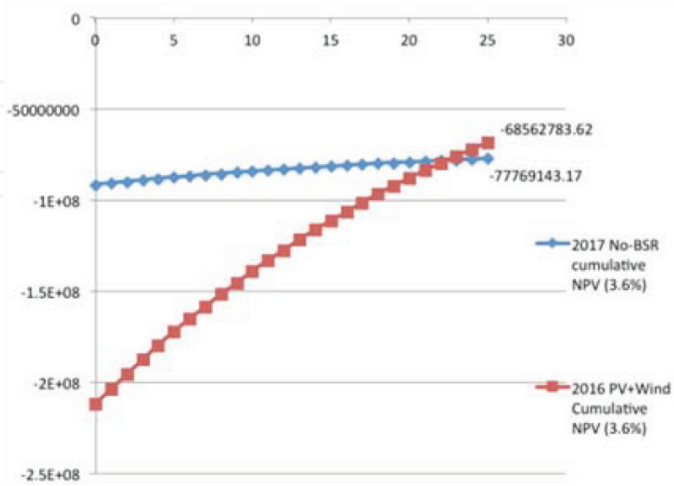

Figure 18. Comparison of the solar and wind with diesel generator powered no BSR RO plant scenario with discount rate of 3.6%.

- Improve the quality of the lives of users, and in so doing;
- Minimises the impacts of climate change and the associated potential costs for future generations, whilst;
- Acknowledging a realistic view of inflation over the longer term of project's of this type for the current generation.

Figure 18 shows the comparison of the renewable and diesel generator powered scenarios.

As can be seen from **Figure 18**, the 3.6% discount rate does not make either option financially viable, but does make the renewable powered scenario around £9.2Million more financially attractive than the diesel powered scenario.

6. Conclusion

Overall conclusions are that:

- It is technically possible to desalinate water for human consumption at Massawa using renewable energy.
- This is financially viable in comparison to the use of diesel generators, but only recently due to the changes in solar PV and diesel fuel prices; but
- The NPV methodology for evaluation of renewable energy projects has a significant impact on the financial viability of such projects; and
- The operational impacts of using intermittent power sources on municipal RO plants needs to be better understood.

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