MARKET POTENTIAL FOR DESALINATION PLANTS POWERED BY RENEWABLE ENERGY SOURCES IN THE GAZA STRIP OF PALESTINE

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Abstract

In this study a Geographic Information System (GIS) was applied to analyze water demand, water shortage in the Palestinian Territories (PTs), in terms of the administrative regions in the West Bank (WB) and Gaza Strip (GS).

The total water demand for the PTs is 281.9 MCM, 51% of it is for irrigation, 46% for domestic use, and about 3% are for industry.

The analysis reveals severe shortage problems, in all regions of GS and in some regions of the WB. The total water shortage in the PTs amounts to about 99 MCM, 20 MCM in the GS and 79 MCM in the WB.

Assuming that the Palestinian will have full control on their water resources, in the near future, then there would be no shortage of water in the WB. On the other hand GS rely totally, on its water supply, on ground water pumped from the coastal aquifer. Thus the quality of water, in the GS, is continuously deteriorating, due to over pumping of the ground water, and the intrusion of seawater onto the coastal aquifer. This creates a serious water shortage in the GS.

To this region the GIS tool was applied to locate, design and evaluate various desalination plants, powered by renewable energy source available in GS. Three scenarios were set and investigated to fulfill major part the water demand in Gaza Strip, by seawater desalination. This study reveals that in all cases, the water production costs compete with the present charge for conventional water, which is of deteriorating quality.

Physical Characteristics of the Gaza Strip

The Palestinian Territories are two disconnected areas; the Gaza Strip and the West Bank (See Figure 1). These are the two parts of historic Palestine, which were occupied by Israel during the June 1967 war. The total area of the territories is 6229 km^2. The areas enjoy a Mediterranean type climate, with low rainfall, particularly in GS, where its average is 250 mm/year. Solar radiation is abundant with average annual insulation of 2250 KWh/m^2.day. Wind potential in the Gaza Strip is low [(1)](annual mean speed of 3 m/sec).

1,122000 inhabitants of Gaza Strip[(2)], live in its five administrative regions, North Gaza (Jabalia), Gaza, Deir El-Balah, Khan Yunis and Rafah. The average population growth rate in the GS is 3.5%. The population density in the GS is the highest in the world, 3100 inhabitant /Km^2.

Figure 1: Map of the Palestinian Territories

Water Resources, Demand and Shortage

Table 1 displays the water demand, resources and shortage in the administrative regions of the PTs[3]

Table 1: Water resources, water demand and shortage in the administrative regions of the PTs

Administrative Region (WB)	Domestic Demand (mcm/yr.)	Irrigation Demand (mcm/yr.)	Total demand (mcm/yr.)	Stable Resources (mcm/yr.)	Total Resources (mcm/yr.)	Shortage (MCM/Year)
Jenin	8.74	30.1	40.24	8	126.7	-32.26
Tulkarem	8.87	15.5	25.69	7.1	71.9	-18.57
Nablus	13.43	5.2	20.45	34.7	273.8	14.23
Ramallah	9.42	0.2	10.93	18.9	154.2	7.96
Jericho	1.4	23.3	25.2	8.6	55.5	-16.46
Jerusalem	18.34	0	18.53	7.7	54.5	-10.85
Bethlehem	7.04	0.7	8.43	14.7	98.2	6.26
Hebron	17.32	0.6	21.1	24.3	195.4	3.23
Jabalya	7.84	22.5	30.52	25.5	16	-5.02
Gaza	15.98	13.4	29.85	29	16	-.86
Deir-Al-Balah	6.32	14.3	20.86	13.5	16	-7.37
Khan-Younis	8.57	13.1	21.88	11	16	-10.88
Rafah	5.25	11.4	16.88	21	16	4.1

The total water demand of the PTs is 281.9 MCM, of which 150.3 MCM is for agriculture, 128 MCM for domestic and public uses, including a leakage of about 23 MCM and only 10 mcm for industries of which 8.6 mcm, for the WB. The distribution of the demand per sector in the WB and the GS are displayed in Table 2.

Table 2: Water demand per sector per region in the PTs

Region	Domestic Demand MCM/Year	Irrigation Demand MCM/Year	Industrial Demand MCM/Year	Total (MCM/Year)
West Bank	84.6	70.1	7.2	161.9
Gaza Strip	43.9	74.7	1.4	120
Total	128.5	144.8	8.6	281.9

Irrigated agriculture is one of the major consumers of water. Seasonal population consumption of water is nearly negligible (0.15 mcm/year).

Solutions for Water Shortage in the Gaza Strip

The water shortage in the West Bank is about 79 MCM and in Gaza Strip is 20 MCM. The water quality in the West Bank is good and conforms to the WHO standards, while the water quality in the Gaza Strip is continually deteriorating, as already mentioned(4). The traces of some elements and compounds such as; K, Ca, Na, and NO_3, reach 1850 mg/l, about twice the WHO standards of 1000 mg/l. The concentration for Cl is 846 mg/l, three times; greater than the value allowed by the WHO standard of 250 mg/l, while for the nitrate it is 106 mg/l compared with 4 mg/l set by the WHO standard.

The time the Palestinians will take over the responsibility for their water resources, they would encounter no water shortage problem in the West Bank and the water quality is good, while for Gaza Strip the situation is catastrophic due to:

a- Bad water quality.
b- High rate of pumping of the coastal aquifer.
c- Scarcity of fresh water resources.
d- Dependence on ground water.
e- High density of population and high population growth rate.

On the other hand, it would be wise, clever and responsible to give time for the coastal aquifer to rehabilitate and to be replenished over the following two decades with fresh water.

Renewable Energy Status in the Gaza Strip

Desalination by renewable energy of seawater in Gaza Strip is an attractive solution to the problem, and can provide water of good quality to the population. For environmental protection and due to non-existence of any kind of conventional energy resources, renewable energy for seawater desalination is a good opportunity for the

Palestinians to practice and contribute their part for a clean, green and healthy environment.

Average annual wind speed in Gaza Strip is 2.9 m/sec[1], making it impractical to use wind turbines to operate the plants. Solar radiation, however is abundant, insulation is 2245 KWH/year/square meter[5], and it would be possible to use Photovoltaic panels to power the desalination plants, but owing to scarcity of land due to the high population density in Gaza Strip, these panels require 6.7 m^2 / KW_p, so that for 10 MW plant that can produce about 12 mcm/year (10% of demand), the plant would occupy quite a large area of 6.7 hectares, if it would be totally powered by photovoltaics. It is suggested that few percentage, such as 10%-20% of the energy needs, to be covered by these photovoltaic panels and the rest should be supplied by the electricity grid.

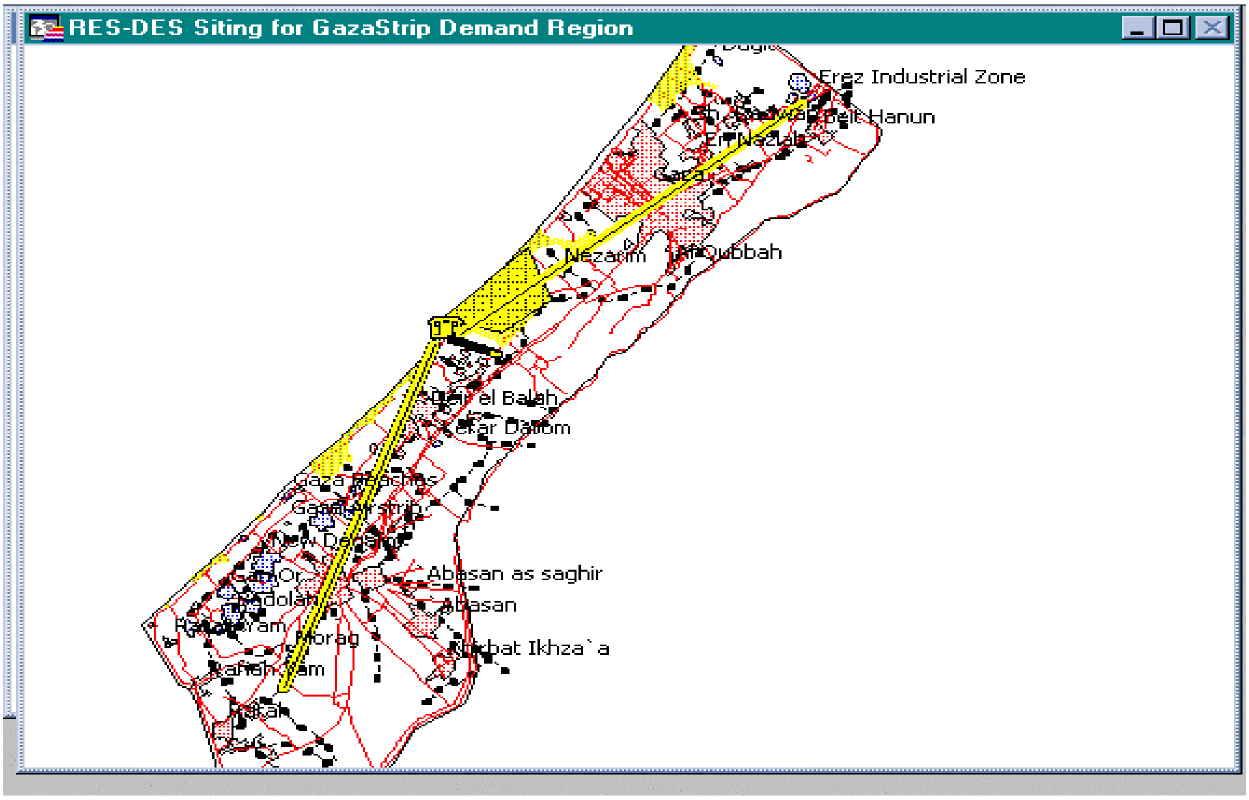

Figure 2: All possible sites as selected by the GIS –tool, in the Gaza Strip

When the GIS tool was advised to find out the probable desalination sites, it gave the ones that appear in Figure 2. It is suggested, that large scale desalination plant should be built on the large site, on the median coast opposite to Deir al Balah City. One such plant is shown in the figure, with the two pipelines supplying water, to all places across the strip.

Desalination Techniques

The GIS tool, electrodialysis, and reverse osmosis and vapor compression provide three techniques. The desalinating cost per one cubic meter is 8.5, 7.2 and 9.3 Euro/ m^3, respectively.
The three technologies were compared by the selling price of one cubic meter for various desalinating plant capacities expressed in percentage of the total demand (total demand is 125 mcm/yr), assuming:
1- 0.2 for the profitability index.
2- 50% coverage of the desalinated power by photovoltaic panels.
3- 15 years is the investment lifetime.
4- 8% is the investment discount rate.
5- Operation and maintenance costs are included.
6- Included, too, the cost of the electric cable connecting the plant to the grid, and the cost for two pipelines, one to the northern part of GS and the other to the southern part of GS, as seen in the sitting figure (Figure 2).

The results are displayed in Figure 3.

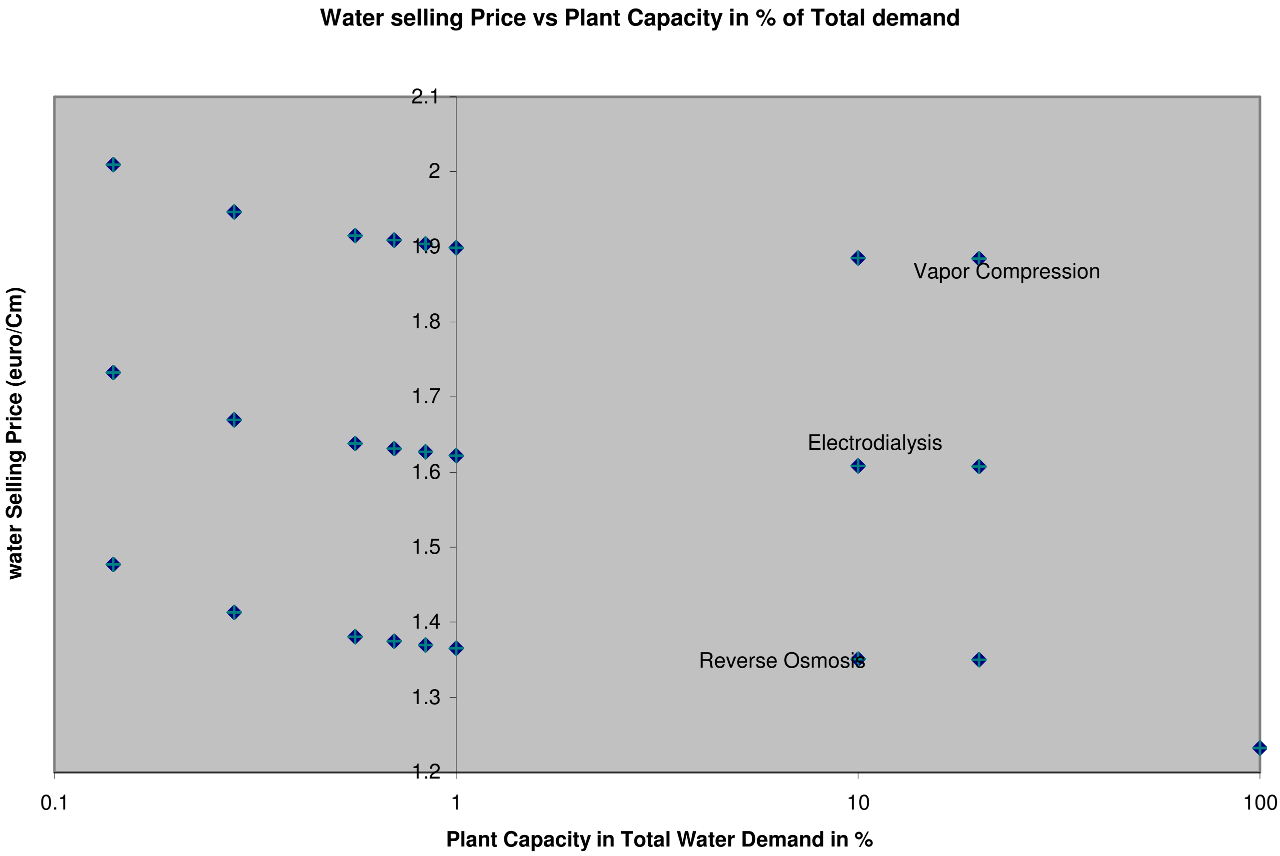

Figure 3: Selling prices of desalinated water versus desalination plant capacity

It is obvious from Figure 3, that water cost decreases as plant capacity increases, and it becomes steady over capacities of 10% of the total demand (accounting to

12 mcm/yr). This trend of price to decrease with plant capacity is general to any other coverage percentage of the energy by photovoltaics.

Reverse osmosis technique, has been selected for the entire study owing to:

1- Its low cost and since continual decrease in cost should be anticipated, due to tremendous advancement and development of membrane technology [(6)],
2- Easier procedures for operation and maintenance,
3- Its modular structure,
4- Short implementation time.

Economy of the Combination of Photovoltaics with Reverse Osmosis Desalination

As it was mentioned earlier, Gaza Strip is highly populated and land is very expensive and very scarce to try to power large-scale desalination plants mainly by photovoltaic. Yet, it is recommended, due to environmental impacts to cover 10-20% of the energy demand by photovoltaics.

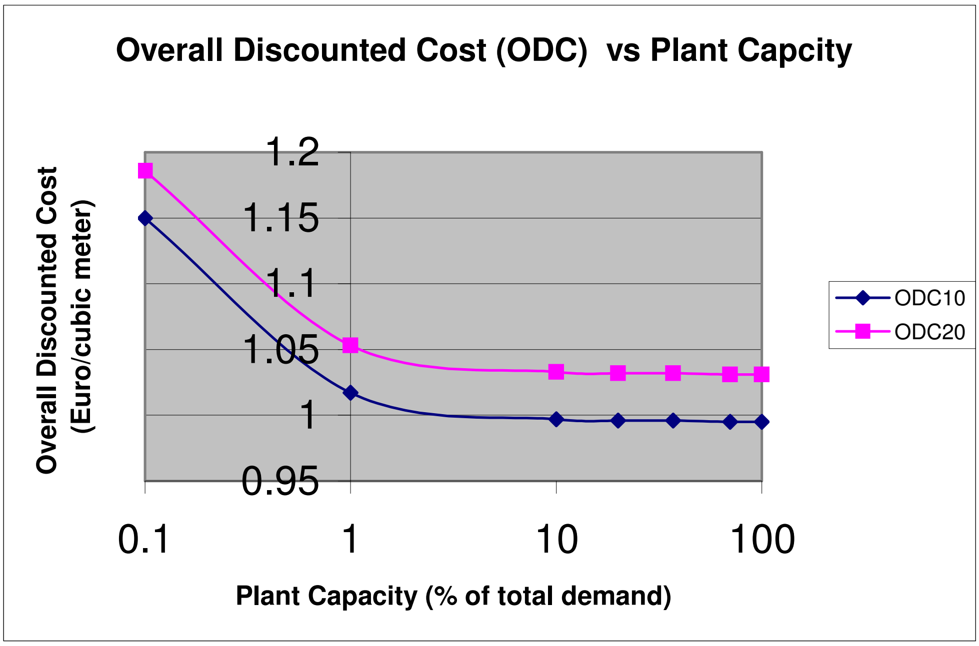

Figure 4: Overall discounted cost of reverse osmosis desalination versus plant capacity expressed in percentage of the total demand (120 mcm) for two coverage percentages of the energy needs by photovolataics (10%-ODC10 and 20%-ODC20%)

It is obvious from Figure 4 that:

1- The cost for seawater desalination increases as the percentage of energy coverage by photovoltaics increases.
2- The water cost decreases as plant capacity increases, and it becomes steady over capacities of 10% of the total demand.

Table 4-A and 4-B, show the results of the design and cost assessment of desalination plants, such as power, land requirement, cost of photovoltaic panels,

reverse-osmosis desalination unit, total investment (in Meuro= 1 million Euro), and cost per cubic meter desalinated for coverage of the energy needs of A-10%, and ***B***-20%, by photovoltaics, as function of the capacity of the plant in % of the total demand of the Gaza Strip (120 mcm).

Table 4: Power, land requirement, cost of photovoltaic panels, reverse-osmosis desalination unit, total investment (in Meuro= 1 million Euro), and cost per cubic meter desalinated for coverage of the energy needs of A-10%, and B-20%, by photovoltaics

Table 4-A

Capacity in % of total demand	100	70	37	20	10	1	0.1
Nominal PV converter power (KW-peak)	4755.2	3326.5	1758.3	950.4	475.2	47.53	4.76
Land required for PV panels (hectare)	3.168	2.218	1.172	0.634	0.317	0.0317	0.00317
Photovoltaic installment (Meuro)	83.72	58.63	31.03	16.81	8.44	0.917	0.165
Desalination Plant Installment(Meuro)	614.61	430.23	227.41	122.92	61.46	6.15	0.615
Total Investment (Meuro)	698.42	488.94	258.52	139.82	69.99	7.15	0.795
Overall discounted cost (Eu/cubic.m)	0.995	0.995	0.996	0.996	0.997	1.017	1.15

Table 4-B

Capacity in % of total demand	100	70	37	20	10	1	0.1
Nominal PV converter power (KW-peak)	9504	6653	3517	1901	950	95	9.5
Land required for PV panels (hectare)	6.336	4.435	2.344	1.267	0.634	0.0634	0.0063
Photovoltaic installment (Meuro)	167.37	117.18	61.97	33.62	16.81	1.75	0.248
Desalination Plant Installment(Meuro)	614.61	430.23	227.41	122.92	61.46	6.15	0.614
Total Investment (Meuro)	782.06	547.49	289.47	156.54	78.36	7.99	0.88
Overall discounted cost (Eu/cubic.m)	1.031	1.031	1.032	1.032	1.033	1.053	1.186

From this table the following results could be drawn, for desalination systems producing over few percents of the total demand:

1- Total investment is 7 and 7.82 million Euro for each percent of the total demand for 10% and 20% coverage of the energy needed by photovoltaics, respectively.
2- Area of 6.7 square meters is required to install one KW_p of photovoltaic panels.

SCENARIOS FOR DESALINATING SEAWATER IN THE GAZA STRIP

This study reveals the following facts and results:

1- The region is very small in area, so that there is no need to think of small desalination units (no remote resorts, or hotels).
2- The desalination plants must be centralized regional plants, with productivity in the range of 4-40 MCM.

3- The cost of water is minimal for reverse osmosis plants, and it becomes steady for productivities in the 4-40 mcm range.
4- Due to scarcity of lands, it is wise to power the plant, only partially by photovoltaic panels.
5- Due to limitations on site selection a proper site for any scenario is that near Deir Al Balah City (See Figure 2).

Three scenarios are set to solve the water crisis in Gaza Strip by seawater desalination:

- **Scenario 1**: (High Scenario) Construction of a central large desalination unit using 10% photovoltaics, to cover the total demand of Gaza Strip (120 mcm)
- **Scenario 2**: (Minimal Scenario) Construction of one desalination plant using 10% photovoltaics to fulfill the domestic needs of GS of 44 mcm.
- **Scenario 3** (Medium Scenario) Construction of any desalination units using 10% photovoltaics to fulfill a demand between the former two extreme scenarios.

Note: Some results of small desalination plants for small communities, hotels or recreation centers are also included.

SPECIFICATIONS of the Desalination Plants

Common factors for the three scenarios:

Location: On the seashore of Deir Al Balah (median coast), as shown in Figure 2.
The plant is 10% powered by photovoltaic energy.
Insulation is 2245 KWh/year/sq. meter
Investment lifetime is 15 years.
Investment discount rate is 8%.
The cost for two water pipelines crossing along the GS is included.

Overall discounted cost (ODC) is 0.996 Euro/ m^3 (it decreases while plant capacity increases but becomes steady for plant capacities over 1 mcm/year).
Table 5 illustrates the main characteristics and cost of the various components for the desalination plants for the two main scenarios.

Table 5: Characteristics and main features of the desalination plants for the two main scenarios

Specifications	Scenario 1 (High)	Scenario 2 (Minimal)
Desalination Plant/s capacity (m^3/day, mcm/yr.)	328767, 120	120548, 44
Nominal PV power converter (KW_p)	4752.2	1758.3
Area covered by PV Panels (m^2)	31680	11722
Operation and Maintenance (Euro/Year)	151,000	61,322
Desalination unit cost (Euro)	614,696,705	198,201,848
Photovoltaic Panels cost (Euro)	83,720,160	30,971,459
Total Investment (Euro)	698,416,865	229,181,307

CONCLUDING REMARKS

The following facts make the alternative of seawater desalination a must:

1- Provision of potable water of good quality to all inhabitants in Gaza Strip.
2- Give time for the coastal aquifer to rehabilitate and improve its water quality.
3- Be independent on water supply from outside the Gaza Strip.
4- Production cost is competitive with the present charging cost. Additionally desalinated water is of good quality.
5- Total cost (excluding land price) for the largest project, providing 120 MCM/year, is around 700 MEURO.
6- Desalination process is a high consumer of energy. Energy consumption per capita in the Gaza Strip is 336 KWh/year, meaning that generation of energy should reach around 50 MW. The power required for desalination is 100 MW and 37 MW, respectively, for the high and minimal scenarios. Electricity is presently imported from Israel. There are plans to implement power stations in Gaza Strip. The energy requirements for desalination must be taken into account in such plans.
7- In cases of small-scale desalination plants, which may be used to fulfill the water demand of small cities and large hotels amounting to 1% and 0.1% of the demand, the results are displayed in table 3:

Table 6: Specifications of seawater desalination projects for small communities

Specifications	**1% Capacity**	**0.1% Capacity**
Desalination Plant/s capacity (m^3/day, mcm/yr.)	3287, 1.2	329, 0.12
Nominal PV power converter (KW_p)	47.5	4.76
Area covered by PV Panels (m^2)	316.8	31.7
Operation and Maintenance (Euro/Year)	9251	8242
Desalination unit cost (Euro)	6,146,147	614,612
Photovoltaic Panels cost (Euro)	917,464	164722
Total Investment (Euro)	7,069,089	784,812
Overall discounted cost (Euro/ m^3)	1.01	1.14

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