WATER MANAGEMENT USING RES IN THE ISLAND OF RHODES

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ABSTRACT: A case study of using desalination powered by renewable energy sources in order to enhance the water supply of a semi-arid region is presented. The island of Rhodes which relies mostly on the use of groundwater sources and faces serious problems due to the depletion of aquifers is selected as the target area. Two different alternatives are discussed and compared to the construction of surface storage reservoirs in order to meet domestic demand up to the year 2040. Results indicate that with the use of the proper financial incentives, desalination powered by RES can be an attractive and environmental friendly solution to problems related to water quantity and quality in semi-arid regions with adequate RE potential.

1. INTRODUCTION

In the South European Mediterranean region water is used in an unsustainable manner. The South European Mediterranean landscape, as a whole, is ecologically fragile and seriously endangered by prevailing social and economic trends. In this regard, the future of the region may be threatened by increasing coastal area stress, by expanding differences between tourist areas and the rural hinterlands, and by the sensitivity between the water and soil equilibrium. Most of the population is concentrated in the coastal zone, and increasing tourism causes a strong, seasonal water demand. Thus uneven water demands in both space and time greatly increase the cost of making water accessible.

Desalination, compared to conventional supply-side interventions, can take an advantageous position in terms of economic costs and environmental impacts. Amongst the various desalination techniques, Reverse Osmosis (RO) has been widely used during the last years. Recent technology advances in the field of energy recovery have managed to reduce the specific energy consumption at 2.0 kWh/m^3 for seawater desalination [1]. The low energy requirements are expected to render the particular desalination technology more competitive compared to other desalination techniques and conventional interventions. Under these conditions, wind-powered RO desalination units can offer an effective, economic and environmental friendly solution in cases of areas under severe water stress conditions where adequate wind potential exists.

The island of Rhodes, which has been selected as the target area for the case study presented, presents a characteristic example of a semi-arid region, where poor water resources management and uncontrolled development have led to severe water stress conditions. The island with an excellent wind potential is ideal for the implementation of desalination powered by Renewable Energy Sources for coping with water quantity/quality problems.

2. THE ISLAND OF RHODES

2.1 Physical Characteristics, Socio-Economic Profile

The island of Rhodes is the largest and most populated of the Aegean Islands. It is located in the SE corner of the national territory of Greece and covers an area of 1400 sq km.

The permanent population of the island in the 1991 census was 98,181 inhabitants. The most populated and urbanized area is the north of the island around the city of Rhodes and its coastal suburbs. The rest of the island is mostly rural with decreasing population density as we proceed towards the south.

Tourism is the predominant economic activity of Rhodes employing about half of all the labour force and causing a strong coastal development with intensive use of water resources. The hinterland, which has remained unaffected by tourism development relies mostly on agriculture and faces depopulation.

The second most important economic activity in the island is agricultural production, which however does not meet the local market demand. Lack of capital, advanced age of most of the rural population and development of the service sector (mainly tourism) in favour of agricultural activities inhibit further development.

2.2 Water Supply

Domestic water supplies in Rhodes are still, solely, obtained from underground sources and in most cases do not require treatment other than chlorination to be made potable.

Water supply sources for irrigation are similarly dependent on groundwater except for the case of the southwest part of the island where the possibility exists for the use of surface water impounded from the Apolakkia storage reservoir (7.3 MCM/yr).

The strong dependence on groundwater resources along with the large population concentration and tourist development in the northern part of the island has led to the depletion and overexploitation of coastal aquifers. As it can be depicted from Fig. 1, which presents the main supply sources of the island, safe yield has been exceeded in most aquifers in the northern part of the island and the irrigated areas of the south. The sea intrusion front is advanced or seriously threatening the water resources.

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Population growth and further development of the tourist sector are expected to aggravate the situation and force for a better allocation and conservational management of water resources.

2.3 Water Demand

Total water demand for the year 2000 has been

Figure 2: Water Demand Distribution (2000)

estimated at 32.66 MCM of which 80% is concentrated in the highly urbanised northern part and the tourist coastal zone. Irrigation demand is limited and predominates only in the hinterland and the rural southern and central parts of the island (Fig. 2).

On the basis of a moderate scenario for permanent and seasonal population growth which assumes small and decreasing growth rates for the highly developed areas, domestic water demand is expected to reach 25.15 MCM. by the year 2020 and 32.45 MCM by the year 2040, which accounts for almost 70% of the total water demand (46.23 MCM). Water demand growth and the need for conservation and replenishment of coastal aquifers forces towards the formulation of water supply enhancements alternatives, which will ensure the island’s economic and social growth in the perspective of a sustainable development.

2.4 Identified prospects

Table I presents the water supply balance of the island as it has been estimated by the UNEP Water Resources Master Plan. The significant quantity of surface run-off, is favourable towards the construction of surface storage reservoirs for the fulfilment of domestic water needs. It should be noted that with the exception of the Apolakkia dam, all surface run-off is currently lost as outflow to the sea.

Table I: Approximate water supply balance

WS	PPT (mm)	EVT (MCM)	Run-Off (MCM)	Infiltration (MCM)
1	495	49.6	4.2	11.8
2	635	41.9	7.1	18.8
3	645	82.3	23.2	20.0
4	517	28.7	9.4	0.1
5	585	61.1	20.0	3.4
6	628	189.6	49.4	42.0
7	489	71.8	6.5	12.4

On the other hand, the wind potential of the island is excellent with an average wind speed reaching 8 m/s.

Figure 3: Potential Wind Park Sites

Figure 3 presents the sites favourable for wind park construction. The presented sites are far from areas of special interest (coastal zone, archaeological sites), near the local electricity grid and with a relative low altitude (<800 m) in order to ensure easy access.

Wind potential makes it also possible for the formulation of alternatives of construction of desalination units in order to meet the expected domestic water demand.

3. POSSIBLE SUPPLY ENHANCEMENTS

3.1 Construction of surface storage reservoirs

The UNEP Water Resources Master Plan which has been formulated for the island, focuses on the exploitation of surface run-off for the coverage of the domestic water demand. It proposes the construction of 2 surface storage

Figure 4: UNEP Water Resources Master Plan

reservoirs, in Kritinia and Gadouras areas and the use of the existing Apolakkia reservoir for the coverage of domestic water needs of the neighbouring areas (Fig 4).

The Gadouras dam with a total annual capacity of 30 MCM/yr will cover the domestic demand of the northern part of the island, the south and the tourist areas of Lindos and Gennadi up to 2040. The smaller dam of Kritinia with a capacity of 2.5 MCM/yr will cover the needs of the villages of Kritinia and Emponas while the central part of the island and irrigation will be supplied through the existing boreholes. The southeast part of the island (the area of the Apolakkia dam) will rely for domestic supply on the existing dam.

The proposal as a whole is expected to cost 96.9 10^6 USD of which about 98% will be allocated for the construction of Gadouras dam and the extensive waterworks needed. Table II presents the analytical cost estimation for the particular storage reservoir.

Table II: Cost estimation for Gadouras Storage Reservoir

	Cost (10^6 \$)
Investment Cost	94.981
O & M Costs	2.849 (per year)
Replacement of equipment	0.06 (at 25 yrs)
Pump Replacement	0.012 (at 25 yrs)

3.2 Desalination powered by Renewable Energy Sources

The present study focuses on the construction of desalination units powered by RES in order to cope with the increasing water demand of the island with the exception of the area near the Apolakkia reservoir. Due to its very low energy requirements, the desalination process selected is Reverse Osmosis and because of the island potential, wind is proposed as a renewable energy source. Two different alternatives where examined.

Alternative A proposes the construction of one large desalination unit near the village of Massari, in the East coast of the island. Alternative B proposes the construction of 6 desalination units, in order to meet the water demand of nearby areas. The spatial distribution of desalination units will be as follows:

- 1 unit for the northwest coast
- 1 unit for the southeast coast
- 1 unit for the east coast
- 3 units for the northeast coast and the capital of Rhodes

In both alternatives the desalination units will be rebuilt every 15 years with increasing capacity in order to ensure the coverage of domestic demand up to 2040 while wind turbines in each case will be replaced after 20 years of operation. Figure 5 presents the total capacity of desalination units for the Alternative B, while total power installed for both alternatives is presented in Figure 6.

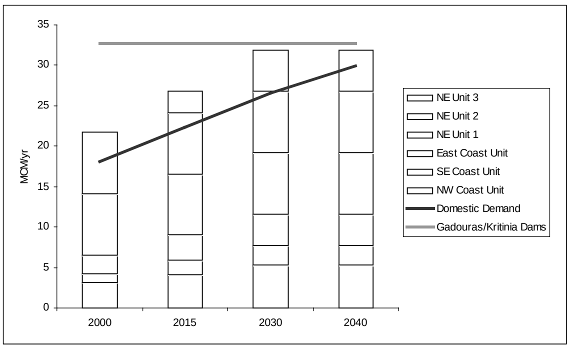

Figure 5: Desalination Unit Capacities (Alternative B)

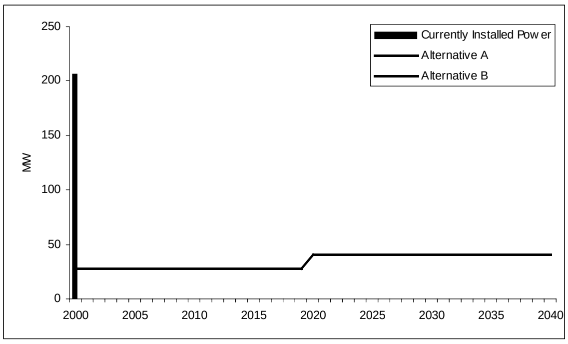

Figure 6: Total power installed

3.3 Cost-Benefit Analysis

The specific costs for the estimation of the annual expenses for the desalination units and the wind park are presented in Tables III and IV.

Table III: Desalination unit specific costs

Plant Capacity (m³/d)	Capital Cost ($/m³)	O&M Costs ($/m³/d)
Small (<5000)	1275	0.425
Medium (<15000)	1105	0.425
Large (>15000)	935	0.425

Table IV: Wind Park specification

	Cost
Nominal Power (kW)	600
Capital Cost ($/WT)	531500
Other Capital Expenses ($)	68900
O & M Costs ($/WT/yr)	14450

Due to capacity increase and replacement of equipment, capital costs for Alternative A and B are distributed throughout the lifetime of the project whereas for the storage reservoirs construction, most capital investment is to be paid at the beginning of the construction period. The resulting average water production cost for all schemes examined is presented in Figure 7.

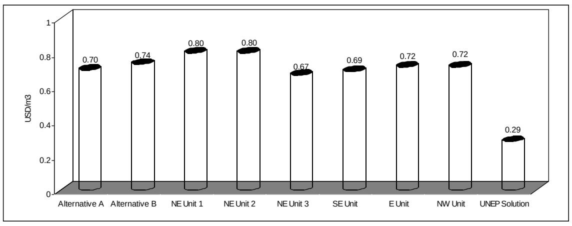

Figure 7: Water Production Cost

The Net Present Value for Alternative A, each desalination unit included in Alternative B and the Gadouras surface storage reservoir proposed by UNEP has been estimated assuming a water selling price of 0.92 $/m^3$ for 40 years (2000-2040) and is presented in Table V.

Table V: Net Present Value

	NPV (10^6 $)
Alternative A	15.9
Alternative B	14.2
NW Unit	0.05
NE Unit 1	6.5
NE Unit 2	6.5
NE Unit 3	1.5
SE Unit	0.01
E Unit	0.06
Gadouras Storage Reservoir	35.2

4. CONCLUSIONS

Due to economies of scale, Alternative A presents a lower production cost and a higher Net Present Value than all the schemes included in Alternative B. However the realisation of a centralised solution involves high investment and operational risks and high capital costs. On the other hand, Alternative B as a whole presents a high water production cost. The implementation however of smaller units ensures lower operational and maintenance costs and can attract more than one investors.

As opposed to the solution of surface storage reservoir construction, both alternatives have the advantage of following the water demand growth. The proposed surface storage reservoirs have a fixed volume and are oversized (a capacity of 32.5 MCM in order to meet a final demand of 25 MCM) in order to account for evaportranspiration and other losses. Furthermore, the acquisition of the promised water supply involves high risks since it is susceptible to droughts. The construction period is long and it may take more than 5 years for full operation while environmental impacts in the entire area of construction are significant.

It can therefore be concluded that desalination with the use of renewable energy sources can be an attractive solution in cases of arid or semi-arid regions which experience severe water stress conditions. It offers a reliable water supply which is also adjustable to water demand growth patterns while it is an environmental friendly solution. The further reduction of the specific energy consumption of the Reverse Osmosis desalination process is expected to lower significantly water production costs. With the use of appropriate financing mechanisms desalination powered by RES is expected to be fully economically competitive with conventional supply-side interventions.

REFERENCES

[1] J. P. MacHarg, The International Desalination & WaterReuse Quarterly **11/1**, **(**2001**)** 42.

[2] Water Resources Master Plan of the Island of Rhodes, UNEP 1995.