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Water supply management approaches using RES on the island of Rhodes, Greece

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Abstract

Desalination powered by renewable energy sources (RES) is presented as an alternative option for the water supply augmentation in the semi-arid region of the island of Rhodes. The case study was chosen as the island relies mostly on the exploitation of groundwater resources and faces serious water shortage problems in an already stressed environment. Alternatives are discussed and compared in contrast to the construction of storage dams to meet urban water needs up to the year 2040. Results may indicate that through the use of financial incentives coupled with holistic water management approaches, desalination powered by RES could be an attractive and environmentally friendly option in an effort to solve problems related to water quantity and quality in semi-arid regions with adequate renewable energy potential.

Keywords: Desalination; Renewable energy sources; Rhodes; Semi-arid regions

1. Introduction

In many southern Mediterranean regions water is used in an unsustainable manner. The landscape, as a whole, is ecologically fragile and seriously endangered by prevailing social and economic trends. 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 [1]. 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. Such conditions are exemplified very accurately in the case of the island of Rhodes.

Desalination, compared to more conventional water supply related interventions, may take an

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advantageous position in terms of economic costs and environmental impact. Amongst the various desalination techniques, reverse osmosis (RO) has been widely used during the last years. Technology advances in the field of energy recovery have managed to reduce, with the use of pressure exchangers, the specific energy consumption at 2.0 kWh/m^3 for seawater desalination [2]. 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 could offer an effective, economic and environmentally friendly solution in water stressed areas where adequate wind potential exists.

The island of Rhodes presents a unique challenge of a semi-arid region where shoddy water resources management and uncontrolled development have led to severe water shortages and environmental stresses. The island with an excellent wind potential seems ideal for the implementation of desalination powered by renewable energy sources (RES) to confront proliferating water resources problems. Such a policy option should be incorporated in an overall management framework in an effort to ensure the long term sustainability of the region.

2. The island of Rhodes

2.1. Physiography, social and economic profile

The island of Rhodes is located in the SE corner of Greece and is one of the largest and most populated of the Aegean Islands, with an area of 1400 km^2. The permanent population of the island was 117,792 inhabitants (NSCG, 2001). The most densely populated and urbanized area is the northern part of the island around the municipality of Rhodes per se and its coastal suburbs. The remainder of the island is mainly rural with decreasing population density from the north to the south.

The predominant economic activity is tourism. Approximately half of the labor force is occupied with tourism related activities, thus strongly contributing to the coastal development schemes. The rural hinterland, which has been affected by tourism development to a far lesser degree, relies still on agriculture and confronts serious depopulation problems.

Despite the fact that agriculture is the second most important economic activity, the local market demand is not satisfied, and agricultural products have to be imported from the mainland. The reasons for such a case as well as the corresponding declining future trend may be attributed to the lack of capital investments, the ageing of the rural population and the shift towards the service sector.

2.2. Water resources issues

UNEP [3] estimates produce an overall annual average rainfall of 586 mm, resulting in 753×10^6 m^3 of potential water volume from which about 70% is lost to evapotranspiration. From the remaining volume, 108×10^6 m^3 (14.4%) and 120×10^6 m^3 (15.9%) constitute the infiltration and the surface run-off, respectively (Table 1). Urban water supplies in the island are still solely obtained from groundwater resources, and in most cases do not require treatment other than chlorination to meet the urban water supply sanitation requirements.

Water supply for irrigation is 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 dam and reservoir (8×10^6 m^3/y).

The strong dependence on groundwater resources along with the large urban population concentration and tourist development in the northern part of the island has led to the depletion and overexploitation of the adjacent, mostly coastal, aquifers. From Fig. 1, it can be deduced

Table 1
Potential average annual water balance of the island of Rhodes (adapted from UNEP [3])

WS	Area, km^2	Rainfall, mm	Rainfall volume, 10^6 m^3	EVT, 10^6 m^3	Run-off, 10^6 m^3	Infiltration, 10^6 m^3
1	132.7	495	65.7	49.6	4.2	11.8
2	106.9	635	67.8	41.9	7.1	18.8
3	194.6	645	125.5	82.3	23.2	20.0
4	73.8	517	38.1	28.7	9.4	0.1
5	144.5	585	84.5	61.1	20.0	3.4
6	447.6	628	281.0	189.6	49.4	42.0
7	185.1	489	90.5	71.8	6.5	12.4
Total/average	1285.2	586	753.2	525	120	108

that safe yield has been exceeded in most coastal aquifers in the northern part of the island and the southern irrigated areas. In addition, the sea intrusion front is advancing or seriously threatening groundwater resources. A foreseeable increase in water demand and the further development of the tourist sector are expected to aggravate the situation and are strongly eliciting the need for the implementation of integrated water resources management efforts.

Total water demand for the year 2000 is estimated at 29.5×10^6 m^3, of which 13.8×10^6 m^3 (about 47%) are attributed to irrigated agricultural and animal breeding activities and 15.7×10^6 m^3 (53%) constitute urban water demand (permanent, seasonal population and conveyance losses). Almost 85% of the urban water demand is concentrated in the urbanized northern part and the tourist coastal zones. Irrigated agriculture is the predominant water consuming activity in the rural southern and central parts of the island.

Following a moderate scenario for the permanent and seasonal population increase, which assumes small and decreasing growth rates for the highly developed areas, urban water demand is expected to reach 21.3×10^6 m^3 by the year 2020 and 28.1×10^6 m^3 by the year 2040, which accounts for almost 70% of the total water demand (41.9×10^6 m^3). Water demand growth

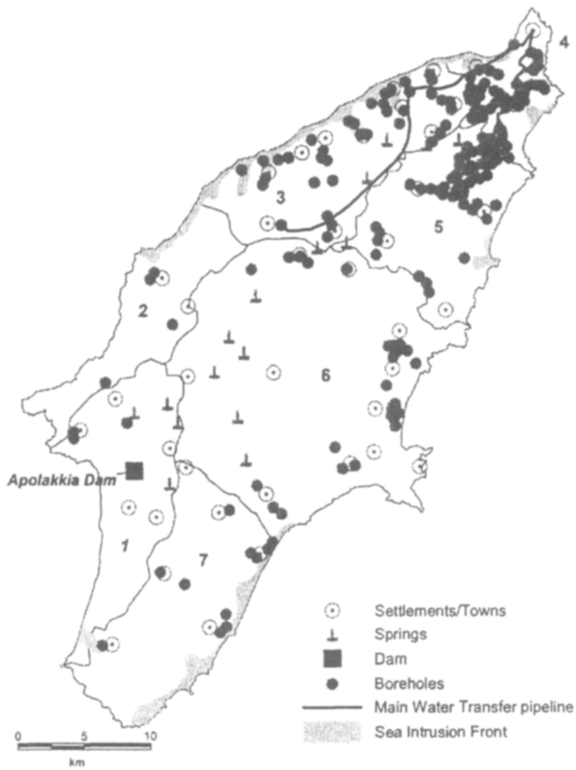

Fig. 1. Water supply sources in the island of Rhodes

and the need for sustainability of the water resources point towards the necessity for the application of water supply policy alternatives in an effort to ensure the island's future economic and social growth.

2.3. Water resources management approaches

In order to delineate alternatives confronting the severe water supply problems in the island of Rhodes, it is important to understand the broader context of Greek water resources management. The most pressing issue is the existence of many government departments dealing with water problems with compartmentalized and uncoordinated activities [4]. Added to this is a water law system which is not responsive to modern issues of an urbanized society and a fast changing socioeconomic environment. Furthermore, there are problems of fragmented authorities and overlapping jurisdictions, as well as widely scattered regulations, thus permitting overlapping functions, multiple advisory bodies and insufficiently decentralized management responsibilities. The most striking element in the description of water resources management in the island of Rhodes is that a continuous air of crisis seems imminent regarding water supplies and their usage. Such a crisis, present also in other similar parts of the world, converges into: (a) a vulnerable ecosystem where the annual natural fluctuation of water supply is exacerbated by periodic droughts or floods, intensified due to haphazard development; (b) a lack of adequate water supply (both in terms of quantity and quality) as a result of water-intensive lifestyles and tourist uses; (c) a rapid water consumption increase and highly consumptive, competing and conflicting water demands; (d) an absence of long-range planning, as well as an absence of public participation or input; (e) decreasing groundwater availability and contaminated aquifers; and (f) increasing ecosystemic considerations, including natural changes and the entire gamut of anthropogenic impacts in the surrounding environment. Hence, Table 2 presents on-going (real) conditions vs. alternative (ideal) target characteristics for water infrastructure and management in the island of Rhodes.

By comparing the "ideal" with the real water resources management situation, it may be deduced that the existing framework deviates from the ideal one. Such a divergence may question the efficiency and effectiveness of the applied policy actions. Thus, the primary task of a holistic water resources management policy would be to bridge the gap between the ideal and the real conditions, concentrating on its minimization before it becomes chasmic through time. Such an effort should be based on reasonable policy actions emanating from and corresponding to the particular environment. The term "reasonable" should be interpreted as describing those actions that would consent in generating appropriate steps for effective water resources management, in the context of the area, according to a time framework. Therefore, while the above arguments summarize, more or less, the character of water resources management policy options

Table 2
Comparison of ideal to real water resources management conditions in the island of Rhodes

Real	Ideal
• Vulnerable to natural hazards and poorly maintained infrastructure	• High level well maintained infrastructure decreasing vulnerability to environmental vagaries
• Scattered authorities and regulation	• Well structured and coordinated organizational and administrative schemes
• Crisis management	• Risk management
• Centralized decision-making	• Structured and decentralized decision-making
• Poorly informed public	• Public involvement and participation

for the area, emerging water supply policy options are demarcated in the following section.

2.4. Emerging water supply policy options

A series of water supply policy options focus on the development of the potential surface water resources. In this context, Table 1 presents the average annual water balance for each watershed (WS) presented in Fig. 1. The presented average annual surface run-off with a total of 120×10^6 m^3 may initially point towards the construction of reservoirs in an effort to satisfy the increasing water supply needs. It should be noted that with the exception of the Apolakkia dam, all of the potential surface run-off is currently lost as outflow to the sea. However, as in every surface water resources development effort, additional site-specific constraints are present such as geology, morphology, environmental requisites, etc., which may render the overall effort extremely difficult.

Another series of water supply options are coupled with recently developed technologies guided by the sustainability concepts. In this regard, the construction of desalination units is examined.

Besides conventionally powered desalination, the excellent wind potential of the island points towards the possibility of coupling reverse osmosis with wind energy. Fig. 2 presents the sites favorable for wind park construction. Criteria used for appropriate site selection are adequate wind potential (average wind speed >7 m/s), minimum distance (1,000 m) from areas of special interest (coastal zone, archaeological sites, inhabited areas), proximity to the local electricity grid (1,000 m) and relatively low altitude (<800 m), to ensure easy access.

In order to formulate viable water supply augmentation responses on the island of Rhodes, the presented policy options have to be examined through well articulated standards and criteria. Such criteria ideally incorporate: technical

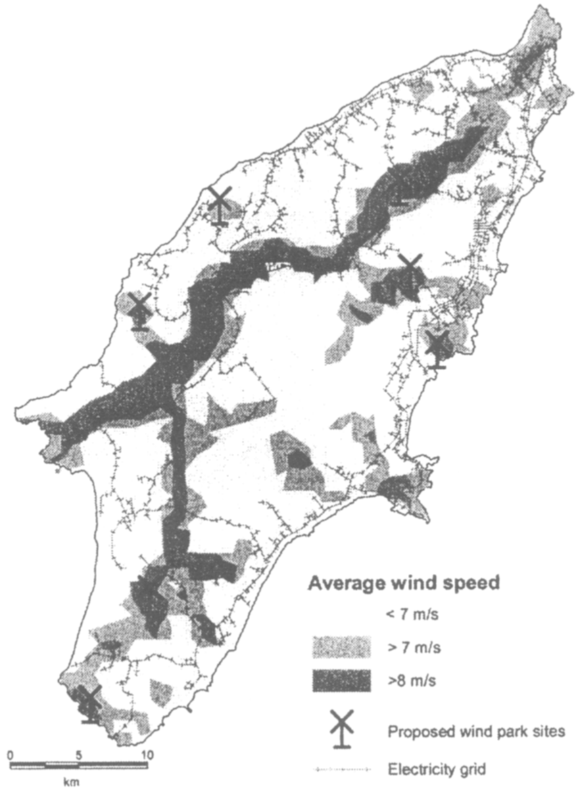

Fig. 2. Potential wind park sites.

feasibility, economic efficiency, ecological sustainability, and social equity. However, the present approach strictly concentrates on technical and economic considerations.

3. Construction of storage dams

The UNEP Water Resources Master Plan, which has been formulated for the island, focuses on the exploitation of the surface run-off for the satisfaction of the urban water demand and the protection of coastal aquifers from over-abstraction and salinization. It proposes the construction of two dams, in Kritinia and the Gadouras areas, and the use of the existing Apolakkia reservoir for the service of urban water needs of the neighboring areas (Fig. 3).

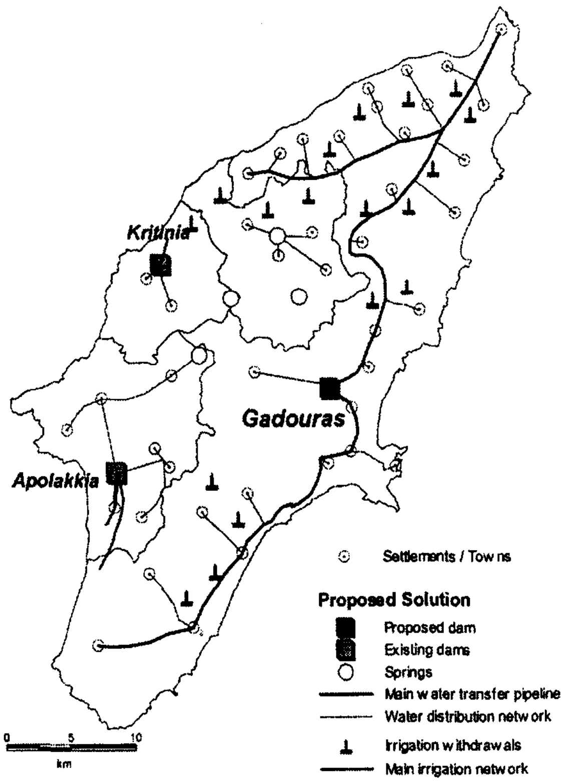

Fig. 3. Construction of surface storage reservoirs.

The Gadouras dam with a total annual storage capacity of 30×10^6 m^3/y should cover, when finished in the year 2005, the urban water demand of the northern part of the island and the south and eastern tourist coastal zone up to 2040. The smaller dam of Kritinia, currently in the final stage of construction, with a capacity of 2.5×10^6 m^3/y will cover the irrigation and potable water needs of two nearby villages. In the proposed scheme, the central part of the island and all local irrigation needs will be supplied through existing boreholes and springs. The Apolakkia dam (capacity of 8×10^6 m^3/y), which is currently only used for irrigation purposes, will primarily meet the urban water needs of the southwest part of the island.

For Gadouras dam almost 98% of the total cost will be allocated for the construction of the dam per se and the related waterworks. The analytical cost estimation for the pertinent dam and reservoir is presented in Table 3. Annual operation and maintenance costs of all project facilities are equal to 3.33 million €/y while for replacement of pumps and treatment plant equipment in year 2030 is expected to cost 0.08 million €.

Table 3
Installation costs estimation for Gadouras dam and reservoir [6]

	Cost (million €)
Dam, spillway, outlet work	47.666
Open channel	2.026
Tunnels	4.867
Pipeline (and related earthwork)	37.967
Treatment plant	7.886
Pumping stations	1.448
Total installation cost	101.9

Environmental impact and costs are only discussed and not quantified in the analysis. Dam construction is expected to decrease the natural recharge of the alluvial aquifer of the region, resulting in deterioration of water quality due to the facilitated sea intrusion and the intensive pumping practiced.

4. Desalination

Another series of water supply policy options may focus on technology alternatives, namely desalination. In this cluster of supply augmentation responses two different options are discussed and evaluated: (a) conventional desalination and (b) desalination powered by RES. Additionally, two alternative schemes are examined. The first one concentrates on a single central unit providing water to the whole area to be served by the Gadouras dam, while the second one is based on peripherally distributed small units.

4.1. A centralized desalination supply scheme

Due to the very low energy requirements and the experience in similar units offered in the pertinent literature [5–8], reverse osmosis (RO) was selected as the optimal desalination process. With respect to recent technology developments, a conservative estimate of 3.5 kWh/m^3 of water produced for overall energy consumption is considered. The initial capacity is estimated at 52,500 m^3/d and the unit will be rebuilt in 2016 (63,000 m^3/d) and 2031 (70,200 m^3/d). The capacity of the unit for each option ensures that urban demand of the target area will be met up to the year 2040. The desalination unit for both alternatives is placed near the village of Massari and the length of distribution network needed is estimated at 116 km.

As mentioned, energy requirements for the second option will be covered through the exploitation of the local wind potential. The wind turbine selected has a nominal power of 600 kW and an estimated lifetime of 20 years. The wind park is proposed to be constructed in the southern part of the island, in the greater area of Kattavia village (average yearly wind speed of 9.1 m/s), and the installed power, escalating with the desalination unit capacity, is presented in Table 4. The desalination unit will be grid-connected and energy requirements in periods of low energy production will be covered by the local electricity grid at the price of 0.066 €/kWh. On the other hand, excess energy produced can be sold to grid for 0.044 €/kWh. Additional electricity is estimated through the yearly energy balance of the desalination unit under the assumption that all excess energy produced can be absorbed by the local electricity grid.

Table 5 presents data used for the analytical cost estimation for both alternatives. The study of the economic feasibility of each desalination project is conducted through the estimation of the water production cost and the internal rate of return of the investment.

Fig. 4 presents the net present value for all supply augmenting options that have been considered so far. Economic benefits (volume of

Table 4
Installed power for centralized desalination supply scheme

Year	Installed power, MW	Wind turbines
2001	13.2	22
2016	15.6	26
2031	17.4	29

Table 5
Desalination and wind park costs

Desalination unit capacity, m^3/d:		Capital cost, €/m^3 d	O&M costs, €/m^3 produced
Small (<5,000)		1275	0.425
Medium (<15,000)		1105	
Large (>15,000)		935	
	General costs, €	Specific costs, €/WT	O&M costs, €/WT/y
Wind park	74,000	711,000	17,000

water sold), which are the same for all three projects, are estimated assuming a fixed over time water selling price of 1.20 €/m^3. Such a premise is undertaken due to the fact that water prices are decided by the local authorities and do not usually reflect elements as recovery of costs or free water market principles.

It may be educed from the previous argument that the construction of the proposed surface reservoir appears to be the most economically attractive option. However, the extreme fluctuations of rainfall patterns, particularly in the recent years (1990, 1993 and 2001 with severe droughts), compounded by significant evaporation losses, may fail to supply the designed water volumes. In addition, with a given storage capacity, the dam may neither efficiently adjust to increased water demand nor timely and adequately respond to unexpected seasonal demand fluctuations, particularly under extreme and

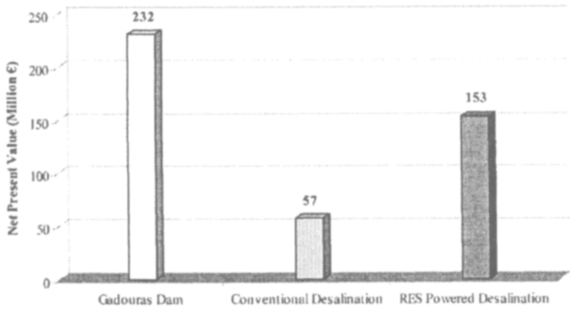

Fig. 4. Net present value for Gadouras dam, conventional and RES-powered desalination units.

stressed meteorological conditions. Two additional constraints refer to the long construction period (at least 5 y) in comparison to the lesser time period (1–2 y) for desalination units as well as the potential environmental impacts in the area of dam and reservoir that have been presented.

Desalination units can more closely follow demand variations. Specifically, desalination powered by RES, as opposed to conventional desalination, may be an attractive solution in terms of profitability (Fig. 4) and induced environmental impact due to lower grid electricity consumption. However, the scheme of one desalination unit in order to meet the urban water needs of the entire area should pose significant problems in cases of failure to supply the designated water volume or regular shut-downs required for maintenance purposes. The high capital and O&M costs of the unit would also discourage private involvement. To confront the problems presented and to encourage private sector involvement, a decentralized desalination supply scheme should be considered.

4.2. A decentralized desalination supply scheme

In this scheme, the construction of smaller decentralized desalination units, located near the water demand sites, would present fewer operational problems and favorably confront the risk of failure. Therefore, the construction of six

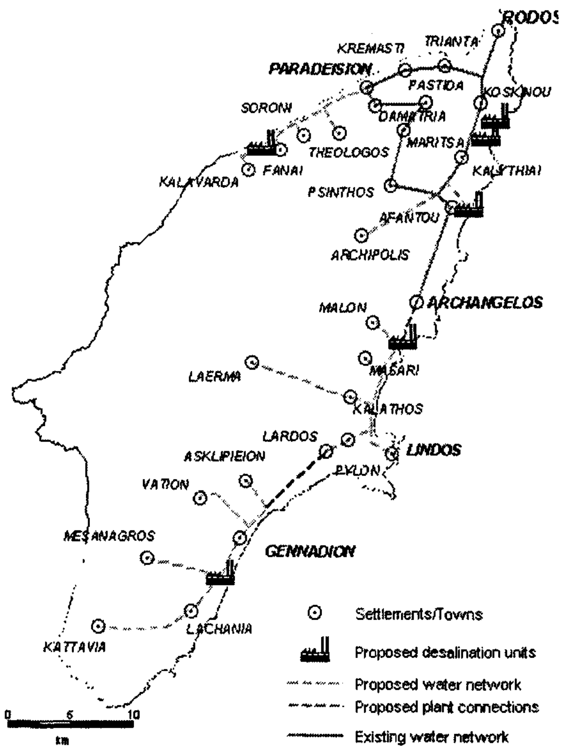

Fig. 5. Spatial distribution of small-scale desalination units.

desalination units with the appropriate individual capacity, instead of one for the total may be proposed. The spatial distribution of the units is presented in Fig. 5 and explicitly in the following:

- one unit for the northwest coast (Paradeisi–Kremasti)
- one unit for the southeast coast (Gennadi–Kattavia)
- one unit for the east coast (Lindos area)
- three units for the northeast coast (Koskinou–Archangelos) and for the city of Rhodes.

The total capacity of the six desalination units is presented in Fig. 6. Supply network length is estimated at 116 km (105 km for connections of desalination units to demand points and 11 km for plant interconnections).

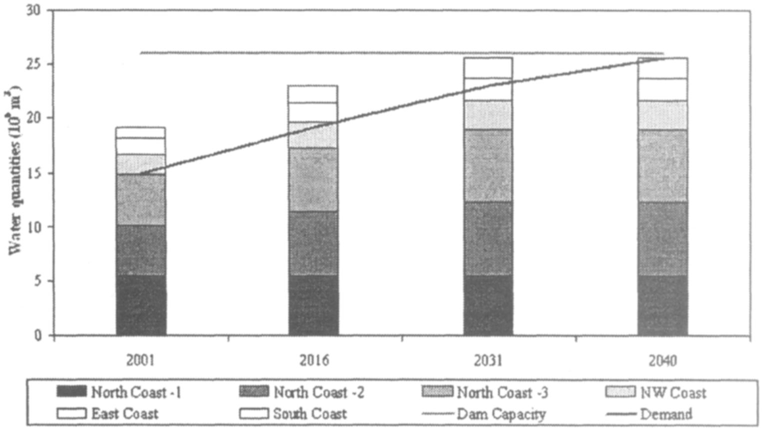

Fig. 6. Capacity of small-scale desalination units.

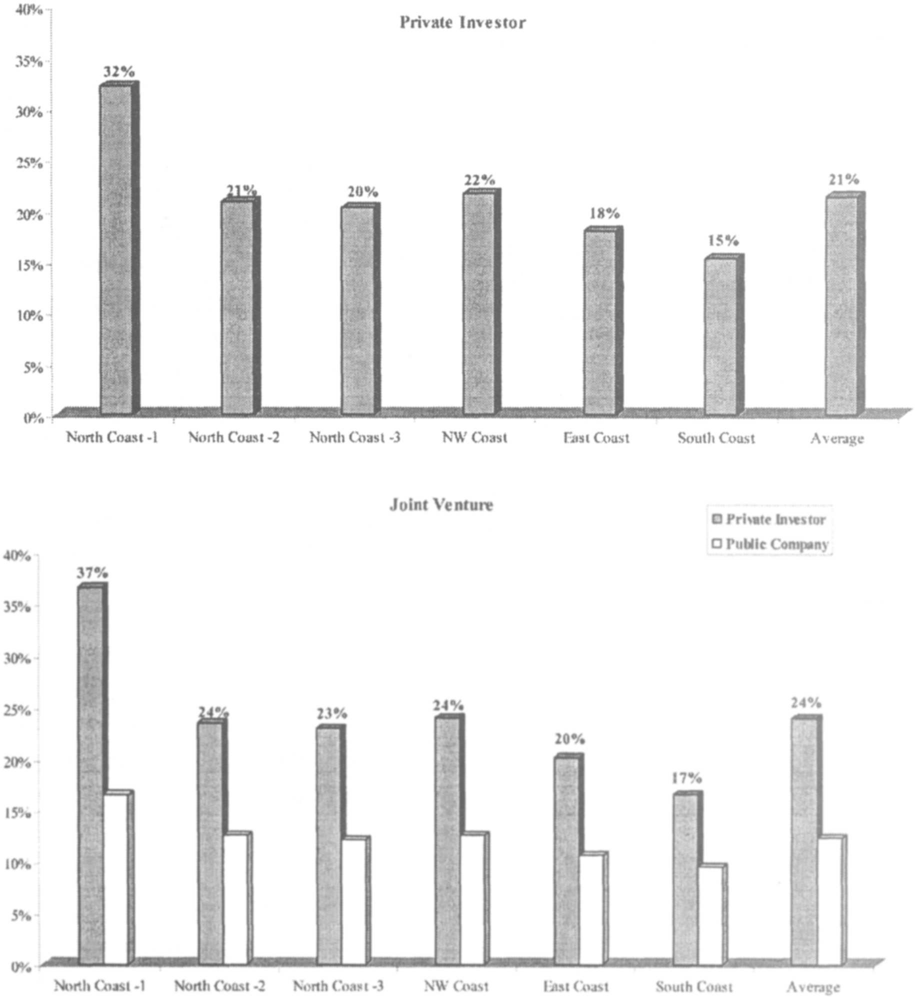

Fig. 7. Internal rate of return (IRR) for small-scale desalination units.

For the cost benefit analysis of the proposed scheme, two different alternatives are evaluated, differing on the degree of involvement of the public sector.

In the first alternative (private investor), the investment is a completely private one. Financing for capital costs is as follows:

- Desalination unit: 50% loan of the total cost, with an interest rate of 6% and a payback period of 10 years;
- Wind Park: 40% grant of the total cost (European Union funds).

In the second alternative (joint venture), the financing parameters for the private investor are identical. However, the public sector, in the form of the municipal water supply utility, assumes 40% of the total capital cost, 50% of the O&M expenses and receives 40% of the water sales.

To reflect the opportunity cost for capital investment, the discount rate is set at 10% for the private company in both alternatives and at 4% for the public company. Results are presented in Table 6 and Fig. 7.

Due to economies of scale, water production cost is higher in the case of small desalination nits. However, the construction of smaller scale units near the demand sites ensures lower distribution network operational costs. The investment cost is lower and private investment risks are almost eliminated. Results indicate that the joint venture scheme seems to be the most attractive option for both the private investor and the public water utility.

Table 6
Water production cost for small-scale desalination units (€/m^3)

Unit	Private investor	Joint venture
Average	0.797	0.812
NW coast	0.773	0.806
East coast	0.824	0.843
South coast	0.728	0.770
North coast 1	0.858	0.862
North coast 2	0.751	0.796
North coast 3	0.764	0.795

5. Conclusions

Under the present conditions, surface water storage schemes are the most attractive and reliable option for the water supply development in the island of Rhodes. In this regard, desalination seems as only a complementary solution in time and space. However, desalination coupled with RES may offer a reliable enough alternative option, in the overall responses framework.

Furthermore, desalination with the use of RES may be an attractive solution in cases of arid or semi-arid regions in other parts of the world that experience severe water stress conditions. It offers a reliable water supply that may also adjust to water demand fluctuation and increases, while it offers little environmental impact. The forecasted further reduction of the specific energy consumption of the reverse osmosis desalination process is also expected to lower water production costs significantly.

In comparison to centralized desalination solutions, small-scale desalination units located near demand sites present a rather increased water production cost. However, with the use of appropriate financing mechanisms and the active involvement of the public sector (i.e., joint venture schemes), the financial risk may be diminished, the profitability of the investments can be increased and the option may be fully competitive with conventional supply-side interventions.

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