Water supply management approaches using RES in 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 the South Mediterranean region 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 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. 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 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

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.

Water resources issues

UNEP estimates [3] produce an overall annual average rainfall of 586 mm, resulting in 753 x 10^6 m^3 of potential water volume from which about 70% is lost to evapotranspiration. From the remaining volume, 108 x 10^6 m^3 (14.4%) and 120 x 10^6 m^3 (15.9%) constitute the infiltration and the surface runoff 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 x 10^6 m^3/yr).

Table 1
Potential average annual water balance of the island of Rhodes (adapted from UNEP, 1996).

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

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 Figure 1, it can be deduced 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 x 10^6 m^3, of which 13.8 x 10^6 m^3 (about 47%) are attributed to irrigated agricultural and animal breeding activities and 15.7 x 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.

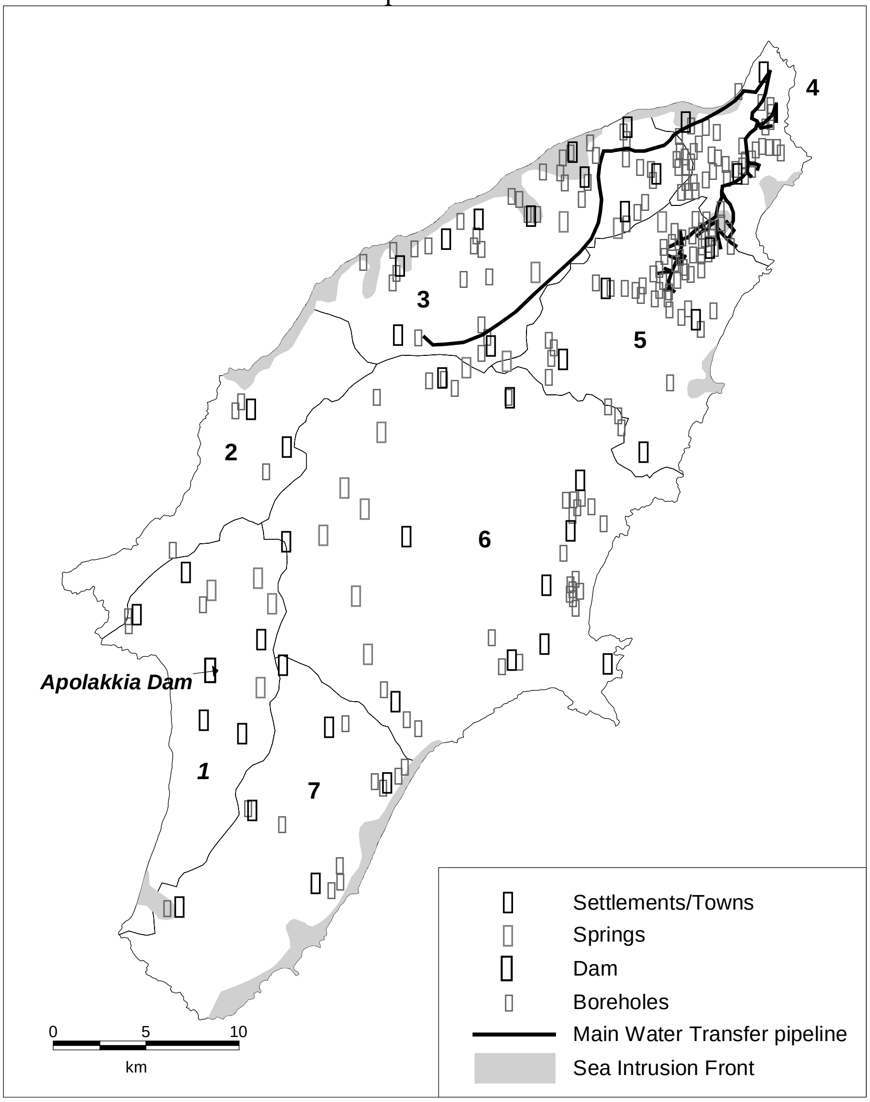


Figure 1. Water supply sources in the island of Rhodes

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 x 10^6 m^3 by the year 2020 and 28.1 x 10^6 m^3 by the year 2040, which accounts for almost 70% of the total water demand (41.9 x 10^6 m^3). Water demand growth 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.

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 socio-economic 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 the haphazard development; (b) a lack of adequate water supply (both in terms of quantity and quality), as a result of water intensive life styles 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) a 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 versus alternative (ideal) target characteristics for water infrastructure and management in the island of Rhodes.

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

Real	Ideal
A vulnerable to natural hazards and poorly maintained infrastructure	A 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

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

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 x 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.

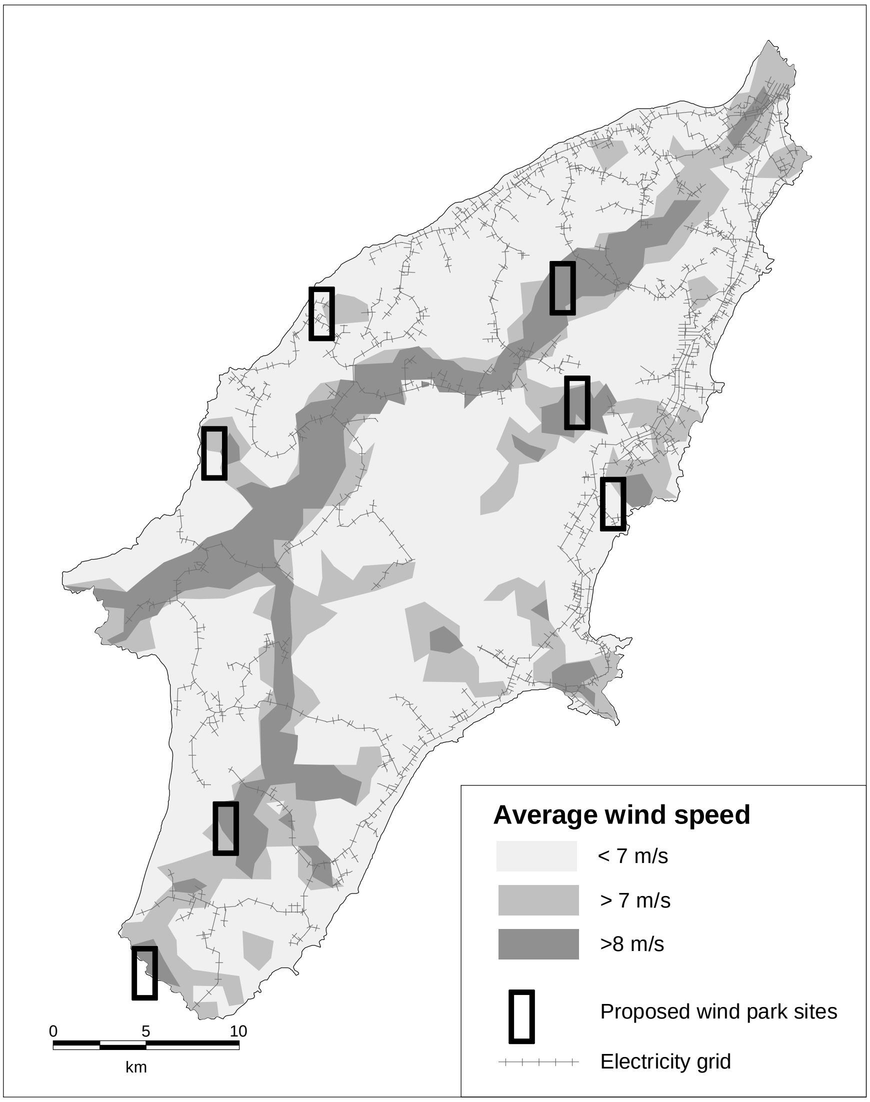


Figure 2. Potential wind park sites

In order to formulate viable water supply augmentation responses in the island of Rhodes, the presented policy options have to be examined through well articulated standards and criteria. Such criteria ideally incorporate: technical feasibility, economic efficiency, ecological sustainability, and social equity. However the present approach is strictly concentrating 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 Gadouras areas and the use of the existing Apolakkia reservoir for the service of urban water needs of the neighboring areas (Figure 3. 3).

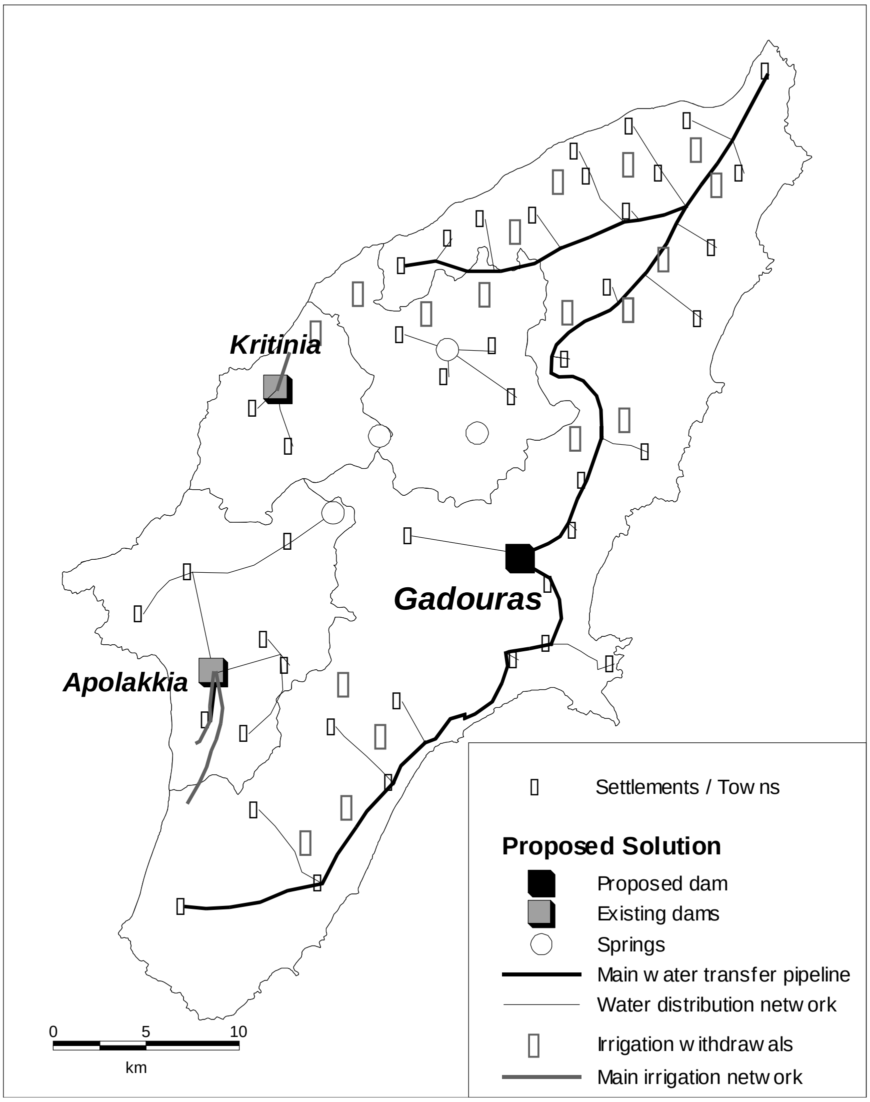


Figure 3. Construction of surface storage reservoirs

Gadouras dam with a total annual storage capacity of 30 x 10^6 m^3/yr should cover, when finished in year 2005, the urban water demand of the northern part of the island, the south and eastern tourist coastal zone up to 2040. The smaller dam of Kritinia, currently at the final stage of construction, with a capacity of 2.5 x 10^6 m^3/yr 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 8x 10^6 m^3/yr), 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 €/yr 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 (UNEP 1996)

	Cost (million €)
Dam, spillway, outlet work	47.666

Open channel	2.026
Tunnels	4.867
Pipeline (and related earth work)	37.967
Treatment plant	7.886
Pumping stations	1.488
Total installation cost	101.9

Environmental impacts 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 and namely desalination. In this cluster of supply augmentation responses two different options are discussed and evaluated: (a) conventional desalination and (b) desalination powered by Renewable Energy Sources. Additionally, two alternative schemes are examined. The first one concentrates on a single central unit supplying water the whole area that will be supplied from the Gadouras dam, while the second one is based on peripherally distributed small units.

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) is selected as the optimal desalination process. With respect to recent technology developments a conservative estimation 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. The estimation of energy flows to and from the wind park and the desalination unit is presented in Appendix II.

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 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, the Benefit to Cost Ratio and the Internal Rate of Return of the investment. The detailed economic analysis is outlined in Appendix III.

Figure 4resents the Net Present Value for all supply augmenting options that have been considered so far. Economic benefits (volume of 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.

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 (<5000)	1275	0.425
Medium (<15000)	1105	
Large (> 15000)	935	
Wind Park		
General costs (€)	Specific Costs (€/WT)	O & M Costs (€/WT/yr)
74,000	711,000	17,000

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

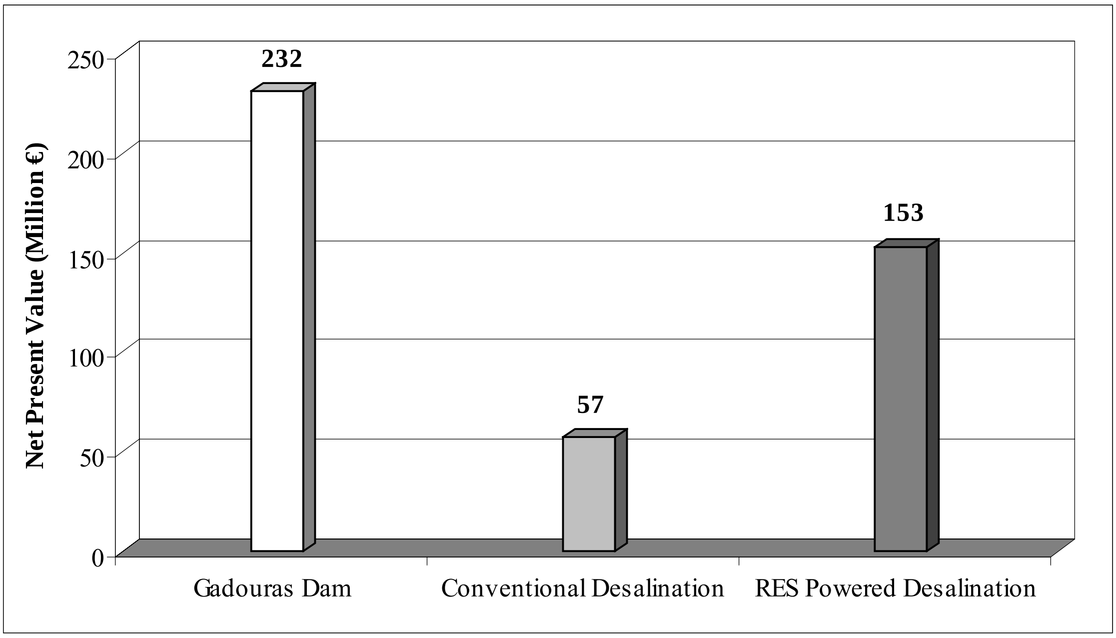


Figure 4. Net Present Value for Gadouras dam, conventional and RES – powered desalination units

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 (Figure 3) and induced environmental impacts 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.

A decentralized desalination supply scheme

In this scheme, the construction of smaller decentralized desalination units, located near the water demand sites, would present less operational problems and confront favorably the risk of failure. Therefore, the construction of six desalination units with the appropriate individual capacity, instead of one for the total may be proposed. he spatial distribution of the units is presented in Figure 5 and explicitly in the following:

- 1 unit for the Northwest coast (Paradeisi- Kremasti)
- 1 unit for the Southeast coast (Gennadi – Kattavia)
- 1 unit for the East coast (Lindos area)
- 3 units for the Northeast coast (Koskinou – Archangelos) and for the city of Rhodes.

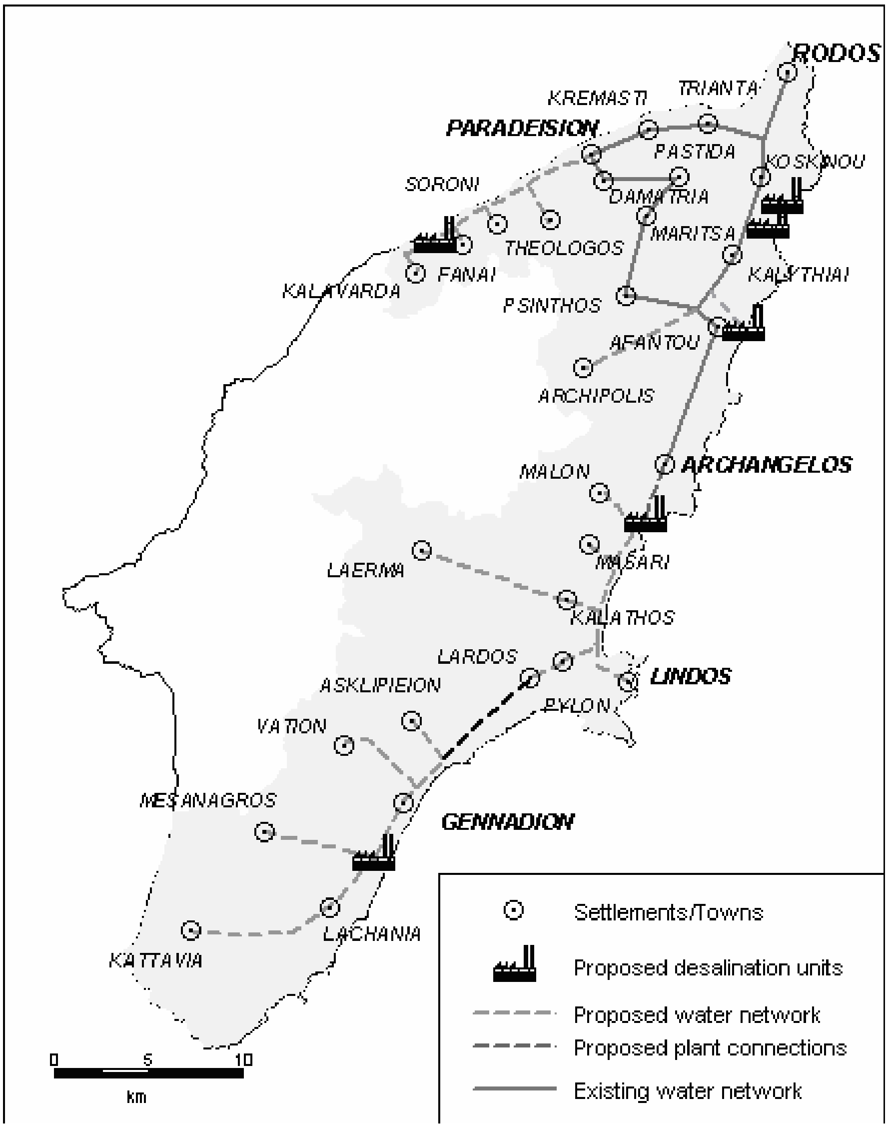


Figure 5. Spatial distribution of small scale desalination units

The total capacity of the six desalination units is presented in Figure 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).

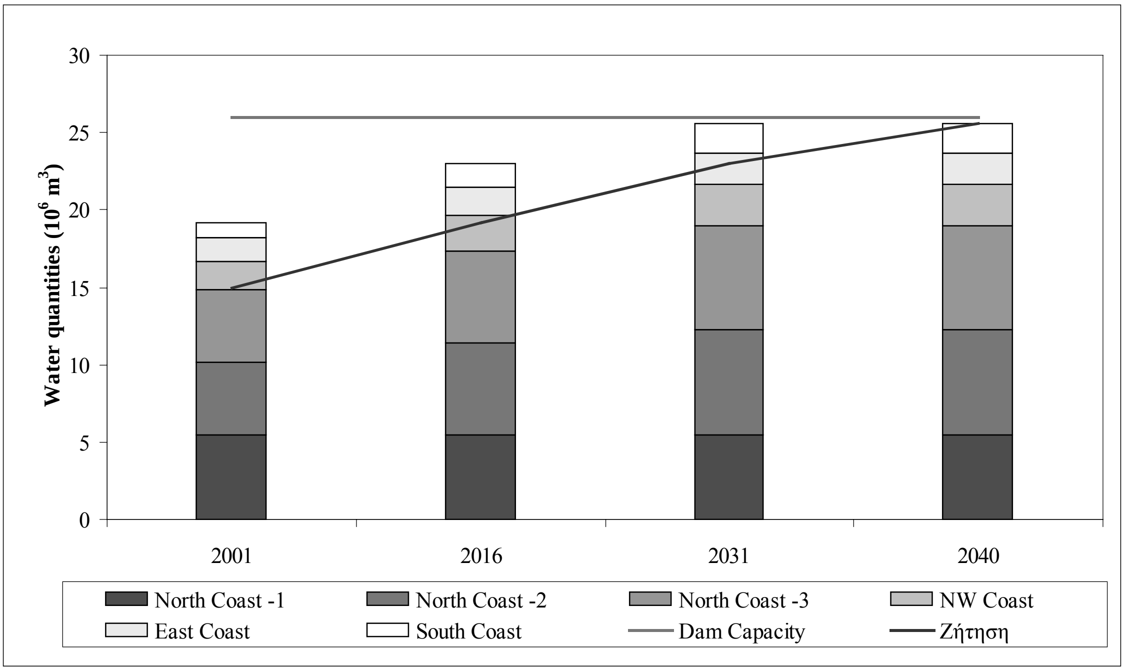


Figure 6. Capacity of small scale desalination units

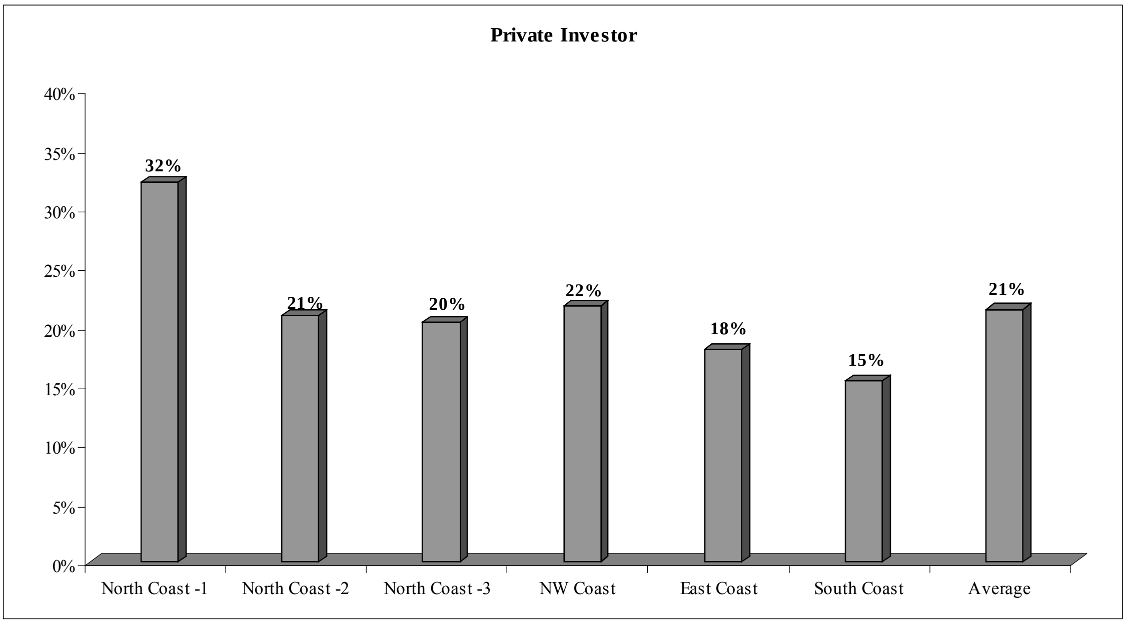
For the cost benefit analysis of the proposed scheme, two different alternatives are evaluated, differing on the degree of involvement of the public sector.
In the first alternative (Private Investor), the investment is a completely private one. Financing for capital costs is as follows:

- 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 Figure 7.

Table 6. Water Production Cost for small scale desalination units (€/m3)

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



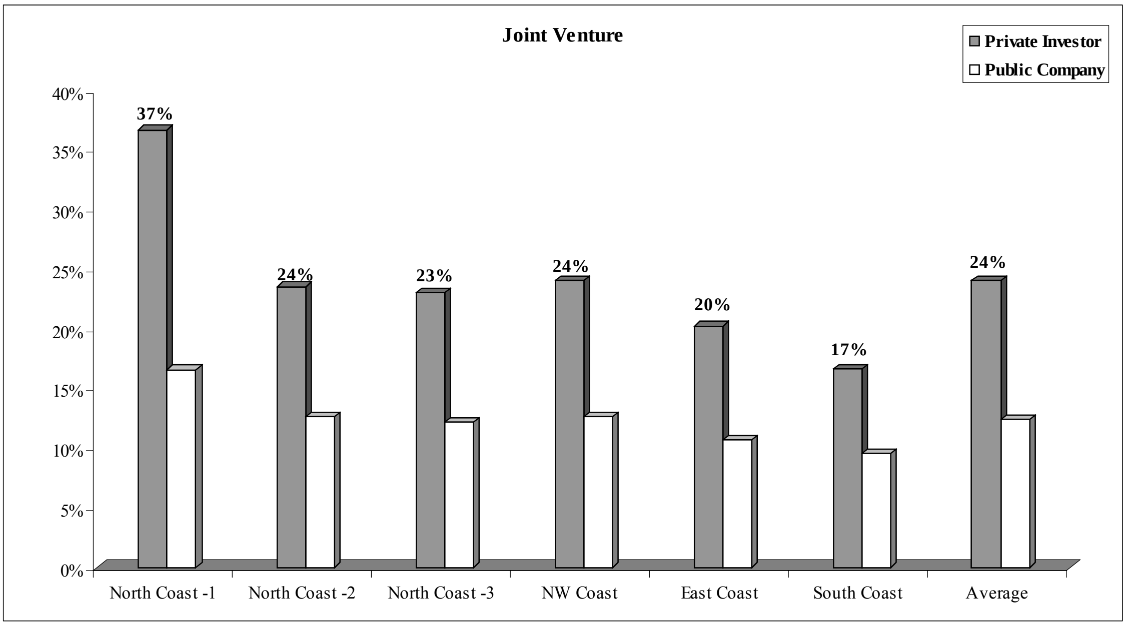


Figure 7. Internal Rate of Return (IRR) for small scale desalination units

Due to economies of scale, water production cost is higher in the case of small desalination units. 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.

5. Concluding Remarks

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 Renewable Energy Sources 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 enough water supply that may also adjust to water demand fluctuation and increases, while it offers few environmental impacts. The forecasted further reduction of the specific energy consumption of the Reverse Osmosis desalination process is also expected to lower significantly water production costs.
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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Appendix I. Notation

$p(U)$ = Probability of occurrence of wind speed U

U = Wind speed,

k = Shape coefficient of the k-Weibull distribution,

C = Scale coefficient

Γ = Γ-function

$\overline{U}$ = Mean annual wind speed

U_H = Wind speed at height H

U_{ref} = Wind speed at reference height H_{ref} (in most cases 10 m)

r = Index depending on the roughness of the terrain (for flat regions, 0.17)

E_{WT} = Annual energy production of the wind turbine

U_{CutOut} = Maximum operating wind speed

$P(U)$ = Power output at wind speed U

$E_{WT \rightarrow DES}$ = Wind energy absorbed by the desalination plant

N_{WT} = Number of wind turbines

U_{Pdes} = Wind speed which corresponds to power equal to P_W / N_{WT} at the power curve of the wind-turbine

WPC = Water Production Cost

A_j = Annual expenditure in year j

n = Water Management Alternative Lifetime

$\overline{WP}$ = Average yearly water production for the period n

$C_{INV-des,j}$ = Investment cost for desalination in year j

$C_{INV-RES,j}$ = Investment cost for the wind park in year j

$C_{O\&M-des,j}$ = Operation and Maintenance costs for the desalination unit in year j

$C_{O\&M-RES,j}$ = Operation and Maintenance costs for the wind park in year j

SP_E = Electricity selling price

$Q_{E,j}$ = Excess power sold to the grid in year j

BP_E = Electricity buying price

PE_j = Energy bought from the grid in year j

WSP = Water Selling Price

NPV = Net present value

B/C = Benefit to cost ratio

Appendix II. Wind Park and Desalination Unit Energy Balance Estimation

The produced energy from a wind turbine depends on the power curve of the wind-turbine and the instant wind velocity. The time variability of wind speed is usually modelled by the K-Weibull distribution. The probability of occurrence of a specific wind speed is estimated using equation 2-1.

$$p(U) = \frac{k}{C}\left(\frac{U}{C}\right)^{k-1} \exp\left(-\left(\frac{U}{C}\right)^{k}\right) \quad (2\text{-}1)$$

The scale parameter C of the Weibull distribution can be estimated using equation 2-2.

$$C = \frac{\overline{U}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (2\text{-}2)$$

Consequently, the only necessary inputs for modelling the wind speed in a specific region are the mean annual wind speed and the shape parameter.
The instantaneous power output of a wind turbine is a function of the wind speed at the rotor height and is given by the power curve $P(U)$. Usually the mean annual wind speed is measured at height 10 m. The wind speed at rotor height can be estimated from the wind speed at 10 m using equation 2-3. The annual energy production of the wind turbine is estimated using equation 2-4.

$$U_H = U_{ref}\left(\frac{H}{H_{ref}}\right)^{r} \quad (2\text{-}3)$$

$$E_{WT} = 8760 \cdot \int_{0}^{Ucutout} p(U) \cdot P(U)\,dU \quad (2\text{-}4)$$

The annual energy requirements of the desalination process, E_{DES}, are estimated by:

$$E_{DES} = 8760 \cdot P_W \quad (2\text{-}5)$$

where, P_w, is the power needed by the desalination process.

Assuming that the wind turbines can provide the desalination plant with power up to P_W, the maximum annual wind energy that the desalination plant can absorb is estimated by:

$$E_{WT \to DES} = 8760 \cdot N_{WT} \cdot \left[\int_{0}^{U_{Pdes}} P(U)p(U)dU + \int_{U_{Pdes}0}^{U_{cutout}} P_{Pdes}\, p(U)dU\right] \quad (2\text{-}6)$$

Figure 8 presents the interrelation of the power requirements by the desalination process and the power output of the wind turbine.

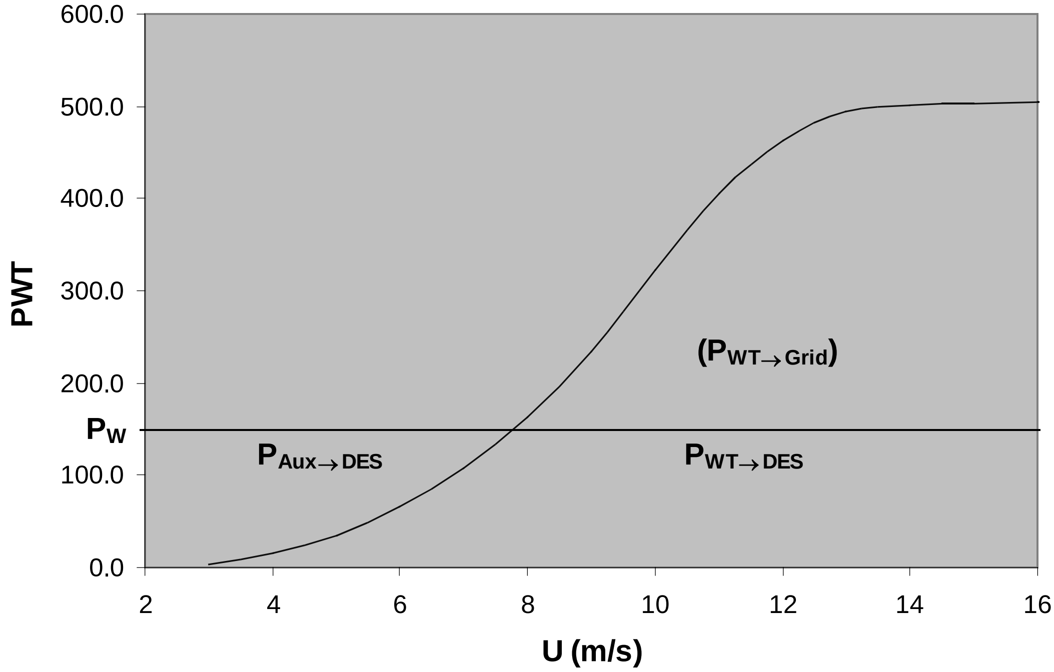

Figure 8. Power curve and power absorbed by the desalination unit

The auxiliary energy sources such as the grid or a diesel generator provide the desalination plant with the required energy in order to cover the energy demand during low wind speed. The annual energy flows from auxiliary energy sources is estimated by equation 2-7:

$E_{Aux \to DES} = E_{DES} - E_{WT \to DES}$ (2-7)

The excess power that is not used by the desalination unit is sold to the grid in the case of grid-connected plants or dumped in the case of stand-alone plants. The wind energy sold to the grid is given by equation 2-8.

$E_{WT \to Grid} = E_{WT} - E_{WT \to DES}$ (2-8)

Appendix III. Economic Indices Estimation

The economic evaluation of the proposed water management alternatives is conducted by the estimation of the average water production cost, the net present value and the internal rate of return for each of the projects and the investors involved.

Water Production Cost Estimation

The water production cost is a function of the initial investment and the operational and maintenance costs of the RES powered desalination plant. Both the desalination unit and the RES unit costs are taken into account in the estimation of water production cost. For the grid connected plants examined in the present work, potential revenues from power sales have to be excluded from water production cost estimation, since they cover a fraction of the plant annual costs and do not influence the final production cost. In general, water production cost for the proposed schemes is estimated by Eq. 3-1:

$$WPC = \frac{\sum_{j=0}^{n} A_j * \frac{i*(1+i)^j - 1}{i}}{\overline{WP}} \qquad (3\text{-}1)$$

The annual expenditure A_j is computed through the estimation of annual costs as follows:

$$A_j = C_{INV-des,j} + C_{INV-RES,j} + C_{O\&M-des,j} + C_{O\&M-res,j} - SP_E * Q_{E,j} + BP_E * PE_j \quad (3\text{-}2)$$

Net Present Value and Benefit to Cost Ratio

The Net Present Value of the investment for an average water selling price WSP is estimated by:

$$NPV = \sum_{j=0}^{n} \left(WSP * Q_{w,j} - A_j\right) * \frac{1}{(1+i)^j} \qquad (3\text{-}3)$$

Finally, the Benefit to Cost Ratio is defined as the Net Present Value of revenues divided by the Net Present Value of annual expenditures:

$$B/C = \frac{\sum_{j=0}^{n} WSP * Q_{W,j} * \frac{1}{(1+i)^j}}{\sum_{j=0}^{n} A_j * \frac{1}{(1+i)^j}} \qquad (3\text{-}4)$$

$B/C\ U\ k\ ^{C}\ \Gamma\ \overline{U}\ U_H\ r\ P(U)\ WPC\ n\ \overline{WP}\ SP_E\ BP_E\ WSP$